Journal of Pharmacognosy and Phytochemistry

Available online at www.phytojournal.com

E-ISSN: 2278-4136
P-ISSN: 2349-8234
JPP 2019; 8(4): 2684-2689
Received: 19-05-2019
Accepted: 21-06-2019

M Chandra Surya Rao
Department of Horticulture, College of Horticulture, Dr. Y.S.R. Horticultural University, Venkataramannagudem, West Godavari District, Andhra Pradesh, India

BN Rao
ICAR-Indian Institute of Oil Palm Research, Pedavegi, West Godavari District, Andhra Pradesh, India

V Vijaya Bhaskar
Department of Horticulture, College of Horticulture, Dr. Y.S.R. Horticultural University, Anantharajupeta, Kadapa District, Andhra Pradesh, India

K Suresh
ICAR-Indian Institute of Oil Palm Research, Pedavegi, West Godavari District, Andhra Pradesh, India

DV Swamy
Department of Horticulture, College of Horticulture, Dr. Y.S.R. Horticultural University, Venkataramannagudem, West Godavari District, Andhra Pradesh, India

Correspondence
V Vijaya Bhaskar
Department of Horticulture, College of Horticulture, Dr. Y.S.R. Horticultural University, Anantharajupeta, Kadapa District, Andhra Pradesh, India

Influence of different levels and methods of irrigation on biochemical responses in oil palm (*Elaeis guineensis* Jacq.)

M Chandra Surya Rao, BN Rao, V Vijaya Bhaskar, K Suresh and DV Swamy

Abstract
Irrigation plays an important role in increasing the yield and quality of oil palm. The present investigation was carried out with an objective to investigate the relationship between methods of irrigation using crop factors on biochemical responses of oil palm in relation to yield of fresh fruit bunches. Significantly highest proline (2.37%), carbohydrates (9.77%) and nitrate reductase activity (66.60 moles of nitrate $min^{-1}g^{-1}$) were observed in palms irrigated with drip method of irrigation. Among the levels of irrigation, palms irrigated with 0.8 crop factor recorded significantly highest proline (2.56%), protein (5.58%), lipid peroxidation (8.73 n moles g^{-1}) and nitrate reductase (73.65 moles of nitrite min^{-1} g^{-1}) activities. Interaction effect of irrigation water applied through drip method at crop factor 0.8 recorded highest number of female inflorescences (7.16) thus increasing number of fresh fruit bunches (7.16), total weight of FFBs (148.44 kg/palm/year) thereby FFB yield (21.23 t/ha). Significantly highest proline (2.77%) accumulation and lipid peroxidation (9.03 nmoles g^{-1}) were observed in the palms irrigated through drip method at crop factor 0.6.

Keywords: Lipid peroxidation, lipoxigenase activity, nitrate reductase activity, oil palm, proline content, protein content

Introduction
Oil palm (*Elaeis guineensis* Jacq.) belonging to the family Arecaceae, is considered as a small holder’s irrigated crop in India. It is a monoecious and bisexual plant. Oil palm is considered as a typical tropical palm grown commonly in the regions of hot and humid tropical climate with optimal temperatures ranging between 80-90ºF. However, successful cultivation of oil palm has also been reported from areas experiencing daily average temperature below 75ºF (Ferwerda, 1977) [10]. Zhu *et al.* (2008) [36] reported that palms receiving direct sunlight of 5-7 hours a day were found very much beneficial for optimal growth and development. Traditionally oil palm is grown in areas where the annual rainfall exceeds 2000 mm with well distribution during most part of the year. Under such type of conditions, the fresh fruit bunch yields are high as observed in countries like Malaysia and Indonesia in comparison to countries like Nigeria and *Cote d' Ivorie* which experience a marked and prolonged dry spell. Irrigation trials conducted in these countries have shown some positive responses to irrigation in terms of growth and yield of fresh fruit bunches. Oil palm, in general, is cultivated as a rainfed crop in most parts of the world, whereas, supplemental irrigation water during moisture deficit period under hot and humid tropical climatic conditions has been identified as the most important factor in determining the fresh fruit bunch yield. However, information available on irrigation aspects for different regions in different parts of the world is meager. Availability of water in the soil has been considered as an important factor in attaining proper growth (Henson and Harun, 2005) [17] and functions as a signal for female sex expression (Jones, 1997) [20]. Under low moisture conditions, large numbers of male inflorescence production coupled with slow growth observed leading to poor productivity. The basic science relating to water stress responses in oil palm is a hot topic which should be investigated screening for water deficit tolerance. Water deficit is a major abiotic stress, which is widely distributed worldwide over 1.2 billion hectares, especially in the rain-fed areas (Chaves and Oliveira, 2004; Kijne, 2006 and Passioura, 2007) [7, 22, 27]. The water deficit environment has been considered as a key factor that limits plant growth and development prior to the loss of productivity in crop species (Reddy *et al.*, 2004; Blum, 2005 and Neumann, 2008) [31, 5, 25]. Basic knowledge on the biochemical responses of oil palm to methods of irrigation coupled with levels of irrigation based on environmental crop factors is still not understood properly and the literature available is also meager on this subject. Hence, the present investigation aimed to study the influence of

different methods and levels of irrigation water on the biochemical responses in oil palm in relation to economic yield of fresh fruit bunches.

Materials and Methods

The present investigation was carried out on eighteen years old oil palm plantation at ICAR-Indian Institute of Oil Palm Research, Pedavegi, Andhra Pradesh and was laid out in split-plot design with four replications consisting of main plot treatments with two different methods of irrigation systems (micro-jet and drip) and three sub-plot treatments of irrigation levels at crop factors (C.F = 0.6, 0.7 and 0.8) based on the rate of evapotranspiration. In general, 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 the climatic conditions prevailing in the area 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 a 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 the crop factor suitable. The following simple method of calculation has been devised based on the evaporation rates prevailing in the areas especially during summer months (Rao *et al.,* 2016) [29].

Evaporation from open pan: 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 Lm^{-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 it 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 treatments adopted 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 biochemical parameters were estimated during the month of April, 2017 *i.e.,* when the weather parameters were non-congenial for the better growth and development of oil palm. The number of male and female inflorescences produced between the 9th to 17th leaves were recorded at quarterly interval and expressed as number of male and female inflorescences produced per palm per year. Number of Fresh Fruit Bunches (FFBs) per palm were recorded in every harvest and expressed on yearly basis as number of fresh fruit bunches per palm per year. Total fresh fruit bunch weight of the palm was recorded per palm in each harvest and average of all harvests of the palms in the treatment is expressed as kilograms per palm per year. Average yield of fresh fruit bunches per palm in each treatment was multiplied with number of palms per hectare and expressed in tonnes. Proline content of fresh leaves of each treatment was determined by using rapid colorimetric method suggested by Bates *et al.* (1973) [4] and expressed as μ moles g^{-1} FW. The lipid peroxidation activity in the leaf tissue of oil palm was measured in terms of malondialdehyde (MDA, a product of lipid peroxidation) content determined by the thiobarbituric acid (TBA) reaction with minor modifications as explained by Heath and Packer (1968) [15]. Nitrate reductase activity of oil palm leaf tissue was measured as per the procedure outlined by Jaworski (1971) [19]. Superoxide dismutase (SOD) activity of oil palm leaf tissue was estimated as per the procedure explained by Dhindsa *et al.* (1981) [8]. The protein content in the leaves of oil palm sample was calculated as per the procedure explained by Lowry *et al*. (1951) [24]. Carbohydrates content was estimated as per the procedure explained by Hegde and Hofreiter (1962) [16]. The data arrived was subjected to statistical analysis as per the procedure outlined by Panse and Sukhatme (1985) [26]. The least significant difference was used to differentiate the significance among the treatments.

Results and Discussion

The data pertaining to biochemical parameters (Table 1) was found significant at different methods and levels of irrigation using crop factors. Proline content in the leaves of oil palm was found non-significant with different methods of irrigation, whereas, it was found significant with palms irrigated at different levels of crop factors. Palms irrigated at crop factor 0.6 have recorded significantly highest proline content (2.56%) when compared with palms irrigated at other crop factors. Interaction effect between the palms irrigated at different methods and levels of irrigation using different crop factors was found non-significant. The overall proline content ranged between 1.73-2.77% in leaves of oil palm irrigated at different levels of irrigation using crop factors through different methods. Accumulation of proline content in oil palm has been demonstrated as one of the most evident biochemical indices under severe water stress conditions (Cha-um *et al.,* 2010) [6]. Accumulation of large quantities of proline in the leaves has contributed to the osmotic adjustment and served as a cytoplasmic osmotic balance for potassium accumulation which is the main osmoticum in the vacuole. Harun (1997) [14] has observed an increase in the proline content of moisture stressed oil palm leaves which might be due to a rise in the stomatal resistance. Further, a decrease was observed in the proline content of oil palm leaves to the normal level after re-watering. In general, degradation of proteins found inhibited under severe moisture stress condition, thus leading to stimulated synthesis of proline observed in the vacuole. Heuer (1999) [18] also reported similar kind of observation which is in agreement with the present result.

Significant differences were observed in the total carbohydrate content of oil palm leaves irrigated at different methods and levels of irrigation based on crop factors. Among the methods of irrigation, palms irrigated through drip recorded significantly highest total carbohydrate (9.77%) content. Among the levels of irrigation, significantly highest total carbohydrate content in the leaves of oil palm (9.93%) was observed at crop factor 0.8. The interaction effect between palms irrigated at different methods and levels of irrigation was found non-significant with regard to total carbohydrate content. However, palms irrigated at crop factor 0.8 through drip method recorded highest carbohydrate (10.36%), whereas, lowest total carbohydrate (7.97%) content was observed in palms irrigated at crop factor 0.6 through micro-jet method. Carbohydrate reserves in the plant plays a vital role as a source of carbon. Starch content of leaves was found hydrolyzed during dry periods which can increase the soluble sugar concentration in the cell. Suresh *et al*, (2010) [35] explained that soluble sugar concentration generally falls in the stem during stress period as sugars are used for palm's metabolism and subsequently rise again in the second phase probably due to starch hydrolysis.

Protein content of leaves was found non-significant in the palms irrigated at different methods, whereas, significant differences were observed in the palms irrigated at different levels. Significantly highest mean protein content (5.58%) was observed in the leaves of oil palm irrigated at crop factor 0.8. Interaction effect between palms irrigated at different methods and levels of irrigation indicated a strong significance with mean protein content. Among the interactions, significantly highest protein content in the leaves (6.17%) was observed in palms irrigated through micro-jet method using crop factor 0.8, whereas, significantly lowest protein content in the leaves (3.51%) was observed in palms irrigated through micro-jet method using crop factor 0.6. A decline in the protein content of leaves of wheat was observed under severe water stress conditions (Singh and Usha, 2003) [33]. In contrary, El-Tayeb (2005) [9] noticed an increase in the total soluble protein content in the shoots and roots of barley seedlings with an increase in the salt (NaCl) induced stress. Ashraf *et al., (*2003) [3] reported accumulation of proteins in the leaves of pearl millet under severe water stress conditions which might be considered an adaptation mechanism. Katam *et al.*, (2007) [21] reported that investigations to determine the water stress induced changes in proteins content of plant leaves would establish functional relevance of proteins for developing water stress tolerant cultivars in crops. The present result is also in accordance with the earlier findings.

Lipoxigenase activity was found non-significant in palms irrigated at different methods of irrigation, whereas, it was found significant in palms irrigated at different levels of irrigation using crop factors. Lipoxigenase activity ranged between 5.81 to 9.03 n moles g^{-1} FW in the leaves of oil palm. Highest LOX activity (7.45 n moles g^{-1} FW) was observed in the leaves of oil palm irrigated through drip method of irrigation compared to that of palms irrigated through micro-jet (7.20 n moles g^{-1} FW) method. Among the levels of irrigation, palms irrigated at crop factor 0.6 recorded significantly highest LOX activity (8.73 n moles g^{-1} FW), whereas, significantly lowest activity of LOX (6.51 and 6.74 n moles g^{-1} FW respectively) was observed in palms irrigated at crop factor 0.7 and 0.8 respectively and were found at par with each other. Interaction effect between palms irrigated at different methods and levels of irrigation using crop factors was found non-significant. Highest LOX activity was observed in the palms irrigated through drip method at crop factor 0.6 (9.03 n moles g^{-1} FW) followed by palms irrigated through micro-jet method at crop factor 0.6. Lowest LOX activity was observed in palms irrigated through micro-jet method at crop factor 0.7. At cellular level, the impact of water stress is observed based on the integrity of cell membrane and the extent of solutes leakage, which is regulated by cell membrane stability. Normal cell functions are affected due to changes in the peroxidation of cell wall lipids during the period of water stress thereby leading to increased cell membrane permeability and solute leakage (Rajagopal *et al*., 2005) [28]. The present result is also in close agreement with the opinion expressed by Rajagopal *et al*. (2005) [28].

Nitrate reductase activity of oil palm leaves was found significant at different methods and levels of irrigation. Nitrate reductase activity of oil palm leaves ranged between 33.39-96.77 n moles of nitrate $min.^{-1}$ g^{-1} irrespective of the method and level of irrigation. Significantly highest nitrate reductase activity (66.60 n moles of nitrate $min.^{-1}$ g^{-1}) was recorded in the leaves of palms irrigated through drip method compared to that of palms irrigated through micro-jet (43.68 n moles of nitrate $min.^{-1}$ g^{-1}) method. Among the levels of irrigation using crop factors, significantly highest nitrate reductase activity (73.65 n moles of nitrate $min.^{-1}$ g^{-1}) was observed in palms irrigated at crop factor 0.8, while, significantly lowest nitrate reductase activity (39.48 n moles of nitrate $min.^{-1}$ g^{-1}) was observed in the leaves of oil palm irrigated at crop factor 0.6. The nitrate reductase activity in the leaves of oil palm was found to gradually increase with an increase in the crop factor. Interaction effect between palms irrigated at different methods and levels of irrigation was also found significant. Palms irrigated through drip method at crop factor 0.8 recorded significantly highest nitrate reductase activity (96.77 n moles of nitrate $min.^{-1}$ g^{-1}), whereas, palms irrigated through drip method at crop factor 0.6 recorded significantly lowest nitrate reductase activity (33.39 n moles of nitrate $min.^{-1}$ g^{-1}). Uptake of nitrate and subsequent reduction by nitrate reductase will be more in palms irrigated through drip method of irrigation compared to micro-jet as drip system has the advantage of keeping root zone in moist condition thereby reducing the conveyance, percolation and evaporation losses. Micro-jet method, on the other hand reduces the conveyance losses, but evaporation losses could be high enough. As water is a precious and scarce input, effective use of water through drip method enhances physiological activities in oil palm. Nitrate reductase is regulated in a complex manner by both short term modulation of activity and long term regulation of gene expression in response to light and nitrogen supply. In addition to this, mechanism which is responsible for regulation of nitrate reductase activity in short term has been known for many years that nitrate reductase also control the protein level by regulating protein synthesis (Somers *et al*., 1983) [34].

Superoxide dismutase (SOD) activity was found significant in palms irrigated at different levels of irrigation. The SOD activity in the leaves of oil palm ranged between 0.02-0.04 units mg^{-1} protein FW irrespective of method and level of irrigation. The SOD activity was found non-significant in the leaves of oil palm irrigated through different methods of irrigation. Among the levels of irrigation using crop factors, significantly highest SOD activity was observed in the leaves of oil palm irrigated at crop factor 0.7 and 0.8. Interaction effect between palms irrigated at different methods and levels of irrigation using crop factors was found non-significant.

Highest SOD activity was observed in the leaves of oil palm irrigated through drip at crop factor 0.8 (0.04 units of mg protein g^{-1} FW), whereas, lowest SOD activity was observed in palms irrigated through micro-jet method at crop factor 0.6 (0.02 units of mg protein g^{-1} FW). An increase in the photosynthetic electron flux to oxygen leads to a decrease in the photosynthetic rate thereby resulting an increase in the production of reactive oxygen species which include superoxide radicals, hydrogen peroxide and hydroxyl radicals which were found damaging the cell wall, lipids, proteins and pigments unless they are scavenged rapidly within the chloroplast by the activities of anti-oxidative enzymes (Asada, 2006) [2]. However, plants have well developed defense mechanisms against reactive oxygen species by the involvement of limiting the formation of reactive oxygen species as well as instituting its removal. Under the normal conditions, the formation and removal of reactive oxygen species were observed in balance. When the defense mechanism gets weakened with the formation of increased reactive oxygen species under water stress conditions, plants generally respond to a rise in the formation of reactive oxygen species with the defense mechanism that is unable to remove the increased enzymatic or non-enzymatic antioxidant processes (Alscher and Hess, 1993) [1], but the mechanisms underlying with these processes is not well understood.

The data with regard to number of male and female inflorescences produced per palm per year (Table 2) was found non-significant with different methods of irrigation. However, significant differences were observed in the production of number of male and female inflorescences in palms irrigated at different levels of irrigation. Significantly highest number of female and lowest number of male inflorescences (7.03 and 5.75 respectively) was observed in palms irrigated at crop factors 0.7 and 0.8 respectively. Interaction effect between methods of irrigation and levels of irrigation using crop factors was found non-significant with regard to production of number of male and female inflorescences. Application of irrigation water to palms has shown profound influence on the production of male and female inflorescences. Occurrence of male and female inflorescences is a result of differentiation that is known to occur 27 to 35 months before anthesis and is concurrent with the process of leaf production (Hartley, 1988) [13]. Leaves and stem have a concurrence with reproductive growth. A small reduction in these two attributes due to shortage of irrigation water supply showed an amplification of inhibitory effect on the number of female inflorescences produced per palm per year which ultimately showed the effect on the number of fresh fruit bunches produced per palm per year. Further, the tendency of male inflorescence production is generally higher with a decrease in the availability of water particularly during the periods of differentiation of vegetative primordia to floral primordia which lead to temporal dioecism *i.e.,* production of male inflorescences to reduce the energy cost on the reproduction. In the present study, it was observed that application of higher amounts of irrigation water at crop factor 0.8 has recorded lower number of male inflorescences production at the same time increased the production of number of female inflorescences. Gawankar *et al.* (2003) [12], Gajbhiye *et al.* (2011) [11] and Sanjeevraddi *et al.* (2014) [32] also reported similar kind of observation in their earlier studies which were found in accordance with the present results.

The data pertaining to production of number of fresh fruit bunches per palm per year (Table 2) has recorded non-significant differences between the methods of irrigation. However, application of different levels of irrigation water based on crop factor has recorded a significant difference in the number of fresh fruit bunches per palm per year. Significantly highest number of fresh fruit bunches per palm per year (7.03) was observed in palms irrigated at crop factor 0.7 and was found at par with the application of irrigation water at crop factor 0.8, whereas, significantly lowest number of fresh fruit bunches per palm per year (5.49) was recorded in palms irrigated at crop factor 0.6. Interaction effect between methods of irrigation and levels of irrigation using crop factors was found non-significant. However, palms irrigated through drip method at crop factor 0.8 has recorded production of highest number of fresh fruit bunches per palm per year (7.16), whereas, crop factor 0.6 has recorded lowest number of fresh fruit bunches produced per palm per year (5.22) through drip method. Production of male and female inflorescences in oil palm has been considered due to the process of differentiation of vegetative primordia to floral primordia which is known to occur between 27 to 35 months before anthesis and was found concurrent with the process of leaf production (Hartley, 1988) [13]. Among the reproductive attributes, production of female inflorescences appeared to be highly sensitive to water stress showing a reduction. The number of fresh fruit bunches production per palm per year depends mainly on the number of productive female inflorescences produced on the palm. In the present investigation, it is clear that quantity of irrigation water applied to palm at each level is the same through different methods of irrigation. Hence, it may be concluded that method of irrigation has no significant impact on the vegetative growth of the plant as well as on the development of reproductive parts mainly formation of female inflorescences which ultimately influence the number of fresh fruit bunches formed on the palm. However, palms irrigated at crop factor 0.7 have recorded significantly highest number of female inflorescences per palm per year (7.03) thereby recorded significantly highest number of fresh fruit bunches (7.03) per palm per year. Gawankar *et al.* (2003) [12], Rao (2009) [30], Gajbhiye *et al.* (2011) [11] and Sanjeevraddi *et al.* (2014) [32] reported similar kind of observation in their earlier investigations while working on oil palm and were found in accordance with the present results.

Data with regard to total weight of fresh fruit bunches per palm per year was found non-significant (Table 2) with different methods of irrigation, levels of irrigation using crop factors and their interaction effect. Data with regard to total weight of fresh fruit bunches per palm per year ranged between 115.47-148.44 kg irrespective of the method and level of irrigation using crop factor. Highest total weight of fresh fruit bunches per palm per year was observed in palms irrigated through drip method at crop factor 0.8 (148.44 kg), whereas, lowest total weight of fresh fruit bunches per palm per year was observed in palms irrigated through drip at crop factor 0.6 (115.47 kg). Under the conditions of lack of assured rainfall, supplemental irrigation is considered the most potential factor of crop inputs in increasing the growth and development of palms. Larsen (1981) [23] has opined that unavailability of sufficient moisture to the palms during their growth and development led to alterations in the physiological and biochemical mechanisms thereby pre-disposing the plants to insect pests and diseases which ultimately reduced the quantity and quality of economically important products. Assured supply of irrigation water through drip method of irrigation at crop factor 0.8 recorded an increase in the number of leaves produced per palm per year (data not shown) which led to an increase in the photosynthetic rate, thus increased the production of photo assimilates which led to an increase in the total weight of fresh fruit bunches by irrigating through drip method of irrigation at crop factor 0.8. Rao (2009) [30] in his earlier study has reported similar kind of observation in oil palm which was found in agreement with the present result.

The data pertaining to yield of fresh fruit bunches per palm per year (Table 2) has recorded non-significant differences between the methods of irrigation. However, application of irrigation water at different levels based on crop factors recorded significant differences with regard to yield of fresh fruit bunches per palm per year. Significantly highest annual yield of fresh fruit bunches (19.83 t/ha) was observed in palms irrigated at crop factor 0.7 and was found at par with the application of irrigation water at crop factor 0.8. Significantly lowest annual yield of fresh fruit bunches per palm per year was observed in palms irrigated at crop factor 0.6 (17.57 t/ha). Interaction effect between methods of irrigation and levels of irrigation using crop factor 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 in palms irrigated through drip method at crop factor 0.8 followed by micro-jet method at crop factor 0.8 (19.68 t/ha). Lowest annual yield of fresh fruit bunches (16.51 t/ha) was observed in palms irrigated through drip at 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. Gawankar *et al.* (2003) [12] and Rao (2009) [30] also reported similar kind of observation in their earlier studies on oil palm which supported the present investigation.

Based on the results obtained it may be concluded that supply of sufficient moisture to the palms through drip method of irrigation at crop factor 0.8 during the critical stages of plant growth and development influenced many of the biochemical activities *viz.,* enhanced production of carbohydrates, proteins, lipoxigenase activity and free radical scavenging superoxide dismutase activity which showed an influence on the production of increased female inflorescences in the palms thereby an increase was observed in the production of fresh fruit bunch yield in oil palm.

Table 1: Effect of different irrigation methods and levels of irrigation (based on crop factor) on biochemical responses in oil palm

Treatments	Proline content (%)	Total carbohydrate content (%)	Protein content (%)	Lipoxigenase activity (n moles g^{-1} FW)	Nitrate reductase activity (n moles of nitrate $min.^{-1}$ g^{-1})	Superoxide dismutase (units mg^{-1} protein FW)
Irrigation methods (M)						
M_1 (Micro-jet)	2.01	8.94	4.87	7.20	43.68	0.03
M_2 (Drip)	2.37	9.77	4.76	7.45	66.60	0.03
LSD (p = 0.05)	NS	0.626	NS	NS	3.175	NS
Irrigation levels (L)						
(L_1) Crop factor 0.6	2.56	8.76	3.61	8.73	39.48	0.02
(L_2) Crop factor 0.7	1.93	9.38	5.27	6.51	52.29	0.03
(L_3) Crop factor 0.8	2.07	9.93	5.58	6.74	73.65	0.03
LSD (p = 0.05)	0.514	0.648	0.330	1.262	3.584	0.0.5
Interaction of M x L						
M_1L_1	2.36	7.97	3.51	8.43	33.39	0.02
M_1L_2	1.73	9.34	4.93	5.81	47.14	0.03
M_1L_3	1.94	9.51	6.17	7.36	50.53	0.03
M_2L_1	2.77	9.55	3.70	9.03	45.58	0.03
M_2L_2	2.12	9.41	5.61	7.21	57.45	0.03
M_2L_3	2.21	10.36	4.98	6.11	96.77	0.04
LSD (p = 0.05)	NS	NS	0.523	NS	5.592	NS

Table 2: Effect of different irrigation methods and levels of irrigation (based on crop factor) on the yield of fresh fruit bunches in oil palm

Treatments	Number of male inflorescences	Number of female inflorescences	Number of fresh fruit bunches per palm	Weight of fresh fruit bunches (kg/palm/year)	Yield of fresh fruit bunch (t/ha)
Irrigation methods (M)					
M_1 (Micro-jet)	6.16	7.08	6.43	141.00	19.84
M_2 (Drip)	5.87	7.29	6.45	127.05	18.17
LSD (p = 0.05)	NS	NS	NS	NS	NS
Irrigation levels (L)					
(L_1) Crop factor 0.6	5.75	5.49	5.49	126.22	17.57
(L_2) Crop factor 0.7	7.87	7.03	7.03	138.72	19.83
(L_3) Crop factor 0.8	7.93	6.80	6.80	137.15	19.61
LSD (p = 0.05)	0.464	1.100	1.010	NS	1.944
Interaction of M x L					
M_1L_1	7.75	5.77	5.77	136.96	18.62
M_1L_2	5.75	7.09	7.09	137.22	19.55
M_1L_3	5.00	6.43	6.43	139.69	19.68
M_2L_1	7.50	5.22	5.22	115.47	16.51
M_2L_2	5.00	6.97	6.97	129.00	18.44
M_2L_3	5.12	7.16	7.16	148.44	21.23
LSD (p = 0.05)	NS	NS	NS	NS	NS

References

1. Alscher RG, Hess JL. Antioxidants in higher plants. Boca Raton, CRC press, 1993.
2. Asada K. Production and scavenging of reactive oxygen species in chloroplasts and their functions. Plant Physioology. 2006; 141:391-396.
3. Ashraf M, Kausar A, Ashraf MV. Alluviation of salt stress in pearl millet (*Pennisetum glaucum* L.) through seed treatment. Agronomie. 2003; 23:227-234.
4. Bates LS, Waldeen RP, Teare ID. Rapid determination of free proline for water stress studies. Plant and Soil. 1973; 39:205-207.
5. Blum A. Drought resistance, water use efficiency and yield potential - are they compatible, dissonant or mutually exclusive. Australian Journal of Agricultural Research. 2005; 56:1159-1168.
6. Cha-um S, Takabe T, Kirdmanee C. Osmotic potential, photosynthetic abilities and growth characters of oil palm (*Elaeis guineensis* Jacq.) seedlings in responses to poly ethylene glycol induced water deficit. African Journal of Biotechnology. 2010; 9(39):6509-6516.
7. Chaves MM, Oliveira MM. Mechanisms underlying plant resilience to water deficits: prospects for water saving agriculture. Journal of Experimental Botany. 2004; 55:2365-2384.
8. Dhindsa RH, Dhindsa P, Thorpe TA. Leaf senescence: Correlated with increased levels of membrane permeability and lipid peroxidation and decreased level of SOD and CAT. Journal of Experimental Botany. 1981; 32:93-101.
9. El-Tayeb MA. Response of barley grains to the interactive effect of salinity and salicylic acid. Plant Growth Regulation. 2005; 45:215-224.
10. Ferwerda JD. Oil palm in ecophysiology of tropical crops. Academic Press, London. 1977; 351-388.
11. Gajbhiye RC, Gawankar MS, Arulraj S, Patil SL. Evaluation of drought tolerant oil palm genotypes for their performance in Konkan Region of Maharashtra. Journal of Plantation Crops. 2011; 39(1):161-163.
12. Gawankar MS, Devmore JP, Jamadagni BM, Sagvekar VV, Hameedkhan H. Effect of water stress on growth and yield of tenera oil palm. Journal of Applied Horticulture. 2003; 5(1):39-40.
13. Hartley CWS. The nutrition of oil palm. In: The oil palm-Tropical Agriculture Series, 3rd edition, Longman Scientific Intl, 1988, pp. 761.
14. Harun MH. Proline accumulation in the leaves of water stressed oil palm (*Elaeis guineensis* Jacq.) seedlings. Elaeis. 1997; 9:93-99.
15. Heath RL, Packer L. Photoperoxidation in isolated chloroplasts. I. Kinetics and stoichiometry of fatty acid peroxidation. Archives of Biochemistry and Biophysics. 1968; 125:189-198.
16. Hegde JE, Hofreiter BT. Carbohydrate chemistry 17. (*Eds.* Whistler, R.L. and Be Miller, J.N.). Academic Press, New York, 1962.
17. Henson IE, Harun MH. The influence of climatic conditions on gas and energy exchanges above a young oil palm stand in north Kedah, Malaysia. Journal of Oil Palm Research. 2005; 17:73-91.
18. Heuer B. Osmoregulatory role of proline in plants exposed to environmental stresses. In: Pessarakli, M. (Ed.), Handbook of Plant and Crop Stress. Marcel Dekker, New York, 1999, pp. 675-695.
19. Jaworski EG. Nitrate reductase assay in intact plant tissue. Biochemistry and Biophysics Research Communication. 1971; 43:1274-1279.
20. Jones LH. The effect of leaf pruning and other stresses on sex determination in the oil palm and their representation by a computer simulation. Journal of Theoretical Biology. 1997; 187:241-260.
21. Katam RSM, Basha HK, Vasanthaiah N, Naik KSS. Identification of drought tolerant groundnut genotypes employing proteomics approach. Journal of Satistical Agriculture Ressearch. 2007; 5(1):1-4.
22. Kijne JW. Abiotic stress and water scarcity: Identifying and resolving conflicts from plant level to global level. Field Crops Research. 2006; 97:3-18.
23. Larsen BJ. Drought resistance and water relations in conifers in relation to the nutrient. Pot Rev., 11, subj. 22, 28th Suite. 1-5, 1981.
24. Lowry OH, Rosebrough NJ, Farr AL, Randall RJ. Protein measurement with the Folin-Phenol reagent. Journal of Biological Chemistry. 1951; 193:265.
25. Neumann PM. Cropping mechanisms for crop plants in drought prone environments. Annals of Botany. 2008; 101: 901-907.
26. Panse VG, Sukhtame PV. Statistical methods for agricultural workers. Indian Council of Agricultural Research, New Delhi, 1985, pp. 176.
27. Passioura J. The drought environment: physical, biological and agricultural perspectives. Journal of Experimental Botany. 2007; 58:113-117.
28. Rajagopal V, Kasturibai KV, Kumar NS. Strategies for evolving drought tolerance in palms. National seminar on Research and Development of Oil Palm in India held during February 19-20, 2005 at Pedavegi, Andhra Pradesh, 2005, pp. 16-20.
29. Rao BN, Suresh K, Behera SK, Ramachandrudu K, Manorama K. Irrigation management in oil palm (Technical Bulletin). ICAR-IIOPR, Pedavegi, Andhra Pradesh, 2016.
30. Rao KK. Effect of different methods of irrigation and nutrient requirement on yield of oil palm. International Journal of Oil Palm Research. 2009; 6(1):31-34.
31. Reddy AR, Chaitanya KV, Vivekanandan M. Drought-induced responses of photosynthesis and antioxidant metabolism in higher plants. Journal of Plant Physiology. 2004; 161:1189-1202.
32. Sanjeevraddi G, Patil DR, Maheshwarappa HP, Arulraj S, Reddy BGM, Chandravathi B. Evaluation of African oil palm germplasm for drought tolerance. Journal of Plantation Crops. 2014; 42(2):170-174.
33. Singh B, Usha K. Salicylic acid induced physiological and biochemical changes in wheat seedlings under water stress. Plant Growth Regulation. 2003; 39:137-141.
34. Somers DA, Kuo T, Kleinhofs A, Warner RL, Oaks A. Plant Physiology. 1983; 72:949-952.
35. Suresh K, Kumar MK, Lalitha SVL, Manoja K, Rao BN. Relation between photosynthetic pigments and chl value readings in oil palm (*Elaeis guineensis* Jacq.) leaves. International Journal of Oil Palm. 2010; 7(1&2):1-3.
36. Zhu XC, Sun ZM, Tao YQ, Gao WH, Huang QA, Cang ZW *et al*. Introduction of prior variety of Elaeis guineensis from Malaysia. Guangdong Forest Science Technology. 2008; 24:84-86.