Indian Journal of Agricultural Sciences **87** (5): 571–9, May 2017/Review Article
https://doi.org/10.56093/ijas.v87i5.70087

Research Review Article

Oil palm *(Elaeis guineensis)* genetic resources for abiotic stress tolerance: A review

P MURUGESAN[1], G M ASWATHY[2], K SUNIL KUMAR[3], P MASILAMANI[4], VINOD KUMAR[5] and V RAVI[6]

ICAR-Indian Institute of Oil Palm Research, Research Centre, Palode, Thiruvananthapuram, Kerala 695 562

Received: 02 September 2016; Accepted: 26 October 2016

ABSTRACT

Oil palm (*Elaeis guineensis* Jacq.) once grown widely in forests and adjoining areas was subsequently domesticated as a plantation crops. Global oil palm area has quintupled from 1990 and it is grown in an area of 17 million ha with a palm oil production of 59.42 million tonnes. Oil yield is dependent not only on genotypes but also on environmental factors. The growth of common oil palm varieties is suppressed at temperatures below 15°C. Oil palm is a drought tolerant crop as it is surviving in locations with a dry season of several months. Nevertheless water deficit stress reduces the palm fresh fruit bunch yield to less than 5 tonnes/ ha along with significant reduction (up to 26.30%) in vegetative growth. Excess soil moisture and continuous water logging are detrimental to oil palm fresh fruit bunch production. The important parameters, viz. the root biomass, potential root extraction ratio (PRER), rate of stomatal conductance and photosynthesis can be used for screening oil palm genotypes for drought tolerance. The progenies of Bamenda × Ekona and Tanzania × Ekona hybrids had drought tolerance and produced 40-42 tonnes of fresh fruit bunch during initial three years. The progenies of crosses between Deli × Yangambi (NIFOR, Nigeria), Bamenda × Ekona (ASD Costa Rica), Tanzania × Ekona and IRHO7010 were reported to adapt to prolonged drought conditions in Nigeria, Costa Rica and Colombia, respectively. Cameroon and Tanzanian genetic sources had cold tolerance and hybrids of Dami Deli × Cameroon /Tanzania crosses and Amazon (variety) are available with Agricultural Services Development, Costa Rica. *Elaeis oleifera* has inherent characteristics to tolerate drought and water stagnation, pest and disease resistance and exhibits slow vertical growth. ASD Costa Rica had developed compact palm utilising the genetic resources of *E.oleifera.* Varieties with short leaves and slow vertical growth are most preferred traits in oil palm industry to increase the productivity per unit area as they can be planted at high density. Information on early maturing varieties, dwarfness, rapid and quality planting material production technologies in relation to abiotic stress tolerance for oil palm are scanty.

Key words: Adverse climate, Drought, Genetic resources, Growth, Oil palm, Yield

Oil palm (*Elaeis guineensis* Jacq.) once grown widely in forests was subsequently domesticated as a plantation crop first in South East Asia and latter in West Africa (Gerritsma and Wessel 1997). It is one of the fastest expanding commercial tree crops in the tropics (Clay 2013) within ±10° latitude of the equator including Africa, South East Asia and South and Central America. It is endemic to the tropical lowlands of West and Central Africa, spreading from 16°N in Senegal to 15°S in Angola. In west and central Africa, oil palm occupied mainly in areas parallel to the Atlantic Coast extending from Cape Verde to Angola. In central Africa, the oil palm belt extends inlands, covering Congo-K and parts of Congo-B and Angola. Oil palm has been distributed during early trade from west Africa to east Tanzania, and to the islands of Pemba, Zanzibar and Madagascar (Corley and Tinker 2003). The main oil palm growing countries in the world are Angola, Benin, Cameroon, Congo, Ghana, Cote d Ivoire, Ivory Coast, Nigeria, Sierra Leone, Brazil, Colombia, Costa Rica, Ecuador, Indonesia, Malaysia, Papua New Guinea, Sierra Leone and Thailand. Indonesia and Malaysia produces 81% of the world's total fruit production with fruit bunch yield averaging 17-21 tonnes/ ha (containing 3.4 – 4.2 mt/ha of mesocarp oil). The global palm oil production in the year 2015-16 was 59.42 million tonnes (http://www.globalpalmoilproduction.com/) and Indonesia contributes nearly half of global palm oil production followed by Malaysia (FAO 2014). Global oil palm cultivation area has

---

[1,3] Principal Scientists (e mail:gesan70@gmail.com, sunilk.icar@gmail.com), ICAR-Indian Institute of Oil Palm Research, Research Centre, Palode, Pacha, Thiruvananthapuram, Kerala 695 562. [2] Research Fellow (e mail: gmaswathysaju@gmail.com), ICAR- Indian Institute of Oil Palm Research, Research Centre, Palode, Pacha, Thiruvananthapuram, Kerala 695 562. [4] Professor (e mail: masil_mahesh@yahoo.com), Agricultural Engineering College and Research Institute, Kumulur, Tiruchirapalli, Tamil Nadu 621 712. [5] Head (e mail: vinodkapoor.cpri@gmail.com), Central Potato Research Station, Kufri, Shimla 171 012. [6] Head (e mail: velravi03@yahoo.co.in.), ICAR-Central Tuber Crops Research Institute, Sreekaryam, Thiruvananthapuram, Kerala 695 017.

quintupled from 1990 to 2013 and is currently grown in an area of 17 million ha (M ha) (FAO 2014). In India, oil palm is cultivated in an area of 2.3 lakh ha across 11 states (Ravichandran *et al*. 2014). Andhra Pradesh, Karnataka, Tamil Nadu, Mizoram and Kerala are the major oil palm growing states in the country, of which Andhra Pradesh alone has a share of more than 65% in area under the crop (Ravichandran *et al*. 2014). Oil yield is dependent not only on genetic resources but also on environmental factors such as relative humidity, water availability, soil texture, fertilizer application, cultural practices and sunshine availability (Henson and Harun 2005). Oil palms are also found on swampy river banks on alluvial plains and low lying river islands. Soil compaction does not affect fresh fruit bunch yield of oil palm (Haniff *et al*. 2005, Yahya *et al.* 2010). Oil palm nutrition and new production technologies are expected to become more prominent as new breeds are produced with true to type inbreeds and uniform genetic makeup (Soh 2012).

Major abiotic stresses such as water deficit (drought), waterlogging and high temperature are the most serious constraints for global edible oil palm production and are predicted to worsen with anticipated climate change. Abundant variation exists in oil palm genetic resources for desirable traits which can be exploited for developing stress tolerant varieties (Rajanaidu *et al*. 1993). Collection and conservation of germplasm has been accelerated in the oil palm growing countries (Malaysia, Indonesia, Nigeria, Brazil, Costa Rica, Colombia, Thailand, Papua New Guinea and Ecuador) in the past 30-40 years to prevent the extinction of landraces and wild relatives. Germplasm of oil palm or its wild materials, just like a few other perennial crops, are found only in specific regions of the world such as in west Africa and central America. The major players involved in oil palm collections in the primary centres of origin are Malaysian Palm Oil Board (MPOB, Malaysia), Centre de Coopération Internationale en recherché agronomique pour le développement (CIRAD, France), Corporation Research Centre for Oil Palm (CENIPALMA, Colombia), Brazilian Agricultural Research Corporation (EMBRAPA, Brazil), Centre National De Recherche Agronomique (CNRA, Ivory Coast), Institut National des Recherches Agricoles du Bénin (INRAB, Bénin), The Institute of Agricultural Research for Development (IRAD, Cameroon) and Agricultural Services Development (ASD, Costa Rica). Oil palm responds to good management practices and there is scope for improving fresh fruit bunch (FFB) and oil yields further using diverse genetic materials. Oil palm clonal propagation has now become a technology with commercial output of clonal plantlets constituting 5-10% of the annual oil palm planting material requirement in Malaysia. Although oil palm survives in parts of west Africa under dry season of several months. Significant reduction in fruit bunch yield may occur due to prolonged water deficit stress conditions. As oil palm industry expands into regions with less favourable climate, breeding for drought tolerance is becoming more important. Oil palm improvement studies are important for identifying genetic resources with drought tolerant traits (Zlatev and Lidon 2012) and evolve climate smart varieties to combat the vagaries of climate change.

Growth and productivity of oil palm

The palm oil plant is grown in a nursery for 12-18 months before it is planted in the field where it bears fruit 30 months later and has an economic life of 20-30 years. A mature tree produces a new leaf primodium about every two weeks. This spear leaf takes about 24 months to develop and unfold in the centre of the palm crown and such leaves are produced at the rate of 20-25 per year and they are photosynthetically active for about 21 months. At a time, the upper canopy of the crown consist 40-50 opened leaves and 50-60 in various stages of development (Corley and Tinker 2016). A premature folding over of the intermediate and inferior leaves, while they are still green in colour is frequently observed in palms which are suffering with water deficiency. Henson *et al*. (2005) reported that the rate of spear leaf elongation can be used as an indicator of stress of the palms. Some palms exhibits curved young leaves and unexpanded accumulation of new leaves (spears). The folded mature leaves close their stomata during daytime, except for a few hours early in the morning, causing reduction in photosynthetic activity of these leaves. The mature leaf is pinnate which bears linear leaflets or pinnae on each side of the leaf stalk. The rachis length is about 8m, leaflet length is about 1.3m, leaflet breadth about 6cm, leaflet numbers varying between 250 and 300, tree height increment 40-50cm per year. Murugesan *et al.* (2015) recorded variation of rachis length (1.39 to 6.92 m), leaflet length (60.83 to 92.00 cm) and leaflet breadth (2.16 to 5.95 cm) in selected African oil palm germplasm. In adverse weather conditions palms will not show wilting symptoms due to its high proportion of lignified cells and epidermis with thick cuticle in the upper and adaxial surface in leaves. The stomata of the leaves are semi-xenomorphic with a structure adapted for the prevention of desiccation over long periods of drought. Oil palm has an adventious root system with primary, secondary and tertiary roots and roots can reach to the depth of 5-6m, but active primary roots are present in the shallow depth of 60 cm. In each leaf base there is one inflorescence primodium which latter develop into separate male and female inflorescences. After pollination the female inflorescence developed as a bunch of 10-15 numbers in a year. The early initiation and development of the inflorescence which are located deep inside the enclosed leaves takes on average 2.5 to 3 years. The first fruit normally ripens during the third year after planting. Varieties which can produce inflorescence earlier than 2.5 years are known and will be of great value for drought tolerance. A normal plantation yields four tonnes of palm oil per hectare per year. The best plantations have yields of 7-8 tonnes/ ha or even greater. Although there are peaks and troughs, harvesting of fruits occurs all the year-round, producing a continuous supply of oil. Three types of fruit forms, viz *dura* (thick shelled), *tenera* (thin shelled, with fibre ring in the mesocarp) and *pisifera* (shelless and sterile, used as male parent for hybrid seed production) are available in the oil palm. The *duras* are used as female parent and hybridised with *pisifera* to produce high yielding *tenera*. Oil palm is propagated by seed and seed has physical dormancy, hypogeal germination behaviour (Baskin and Baskin 2014) with intermediate storage (Ellis *et al*. 1991).

Effect of water deficit stress on oil palm

Oil palm yields are high in regions with an annual rain fall of 2000 mm distributed evenly during the year (Corley and Tinker 2003). However, crop is cultivated successfully in west Africa, south America, India and Thailand under less favourable environments with seasonal drought. The response of oil palm to water deficit stress (WDS) conditions is well known (Nouy *et al.*1999, Lee *et al*. 2005, Legros *et al*. 2009, Omorefe and Bonaventure 2010, Al Amin *et al*. 2011, Fahramand *et al*. 2014, Putra *et al*. 2015).Water deficit stress is the major limiting factor for oil palm survival, growth and productivity (Cornaire *et al*.1994, Lee *et al*. 2005). WDS reduces the palm fresh fruit bunch yield to less than 5 tonnes/ha along with significant reduction in vegetative growth or up to 26.30% (Al-Amin *et al*. 2011). However, the effect of WDS on fruit bunch yield varies depending on its timing of occurrence and severity relative to bunch developmental stage. WDS caused reduction in relative water content (Fahramand *et al*. 2014 and Zain *et al*. 2014), stomatal closure, decrease in stomatal conductance, chlorophyll a/b, nitrogen and phosphorus content in leaf tissue (Legros *et al*. 2009, Cha-um *et al*. 2010, Cao *et al*. 2011, Sun *et al*. 2011, Zlatev and Lindon 2012, Ashraf and Harris 2013) and the inhibition of photosynthesis (Henson and Harun 2007). The decline in photosynthetic capacity under WDS was due to the low intracellular concentration of CO_2, chlorophyll degradation, inhibition of electron transfer processes and photo phosphorylation, structural and functional damage of leaves and the accumulation of sucrose and hexoses in leaves (Hajiboland and Farhanghi 2010, Hajiboland *et al*. 2012, Gupta and Solanki 2013). The decline of assimilate production significantly inhibited the growth of plants and decreased plant dry biomass (Al-Amin *et al*. 2011 and Matius *et al.* 2004). Stomatal conductance and transpiration rate of the oil palm decreased after period of drought stress when compared to the normal conditions (Han *et al*. 2008, Hajiboland and Farhanghi 2010 and Hajiboland *et al*. 2012). Drought stress inhibited the rate of stomatal conductance so that the diffusion of CO_2 into the leaf mesophyll decreased (Ismail *et al*. 2004, Han *et al*. 2008, Hajiboland and Farhanghi 2010 and Hajiboland *et al*. 2012). The relative water content of osmotically stressed oil palm seedlings decreased, but the proline content and the electrolyte leakage of the seedlings increased with decreasing water potential (Nana Yamada *et al.* 2011 and Suriyan Cha-um *et al*. 2012). Increase in trunk and canopy height increases transpiration rate of larger (i.e. older) oil palms trees (Hollinger *et al*. 1994, Goldstein *et al.* 1998, Madurapperuma *et al*. 2009 and Vanclay 2009). Oil palm genotypes exhibit different response to WDS in terms of membrane integrity and protein loss (Asemota and Conaire 2011). A low yielding but drought tolerant oil palm genotype had fewer open stomata, greater leaf water potential and less membrane damage under drought than a high yielding but susceptible hybrid (Cornaire *et al*. 1994). Oil palm progenies exhibiting significant difference in root development can be exploited in selection programme (Conaire *et al*. 2005). Tolerant oil palm genotype had higher Total Root Length (TRL), Total Root Surface Area (TRSA) and Potential Root Water Extraction Ratio (PRER) than susceptible genotypes based on half- distances between roots and the distance of water migration from soil to root (Nodichao *et al.* 2011). Significant difference exists between tolerant and susceptible oil palm *tenera* progenies in root length density (m root m^2 ground area) and rate of water uptake during the dry season (Nodichao *et al.* 2011). PRER was determined in conjunction with soil moisture extraction efficiency (SMEE). PRER appears as helpful indicator for comparing or ranking oil palm genotypes and assessing genetic variability of drought tolerance (Nodichao *et al.* 2011 and Jazayeri *et al.* 2015). Total root biomass observed in the dry climates of West Africa (Ivory Coast and Benin) and compared with palms of same age groups in Indonesia and Malaysia. The values of root biomass recorded in Ivory Coast was 31.5 t/ha for 13 year old palms whereas, palms planted in Malaysia and Indonesia had lower biomass 7.5 t/ha and 9.7 t/ha to 14.1 t/ha respectively (Corley and Tinker 2016).

Some research findings suggest that the greater oil yield in South East Asian countries is attributed primarily due to a high fresh fruit bunch yield (FFB), i.e. production of more fruit bunches per palm rather than an increase in average fruit bunch weight (Henson and Harun 2005, Wahid *et al.* 2005 and Soh 2012). Although, several factors have largely contributed to the bunch and oil yield improvement in the oil palm, the greater rise to the tune of 5 to 6 tonnes of oil per ha per year achieved in Malaysia is the result of improved genotypes, advanced cultural practices and favourable agro-climatic conditions (Soh 2012). In recent years, oil palm growth and fruit bunch yield is affected by the climate anomaly 'El Nino' which causes drought in South East Asia (Legros *et al.* 2009). In South East Asian countries especially in Malaysia and Indonesia fruit bunch production remains uniform throughout the year, whereas in Nigeria and other African countries with seasonal drought, distinct peak and lean season is observed (Corley and Tinker 2003). The main growth period sensitive to drought stress was estimated to be 29 months before bunch maturity (Legros *et al.* 2009) which is associated with inflorescence sex determination. The sensitive stages of growth to stresses are reported to occur during the initial inflorescence and fruit development stages. The actual influence of any stress incidence on FFB production could only be seen after 1 to 3 years later (Haniff *et al*. 2016).

India has large area (about 0.23 million ha) of oil palm under irrigated conditions. The major oil palm growing states in India namely, Andhra Pradesh and Karnataka have an annual dry season of about six months between December and May. However, the ground water resources are rich in these regions and this can be used to provide irrigation during the dry spell (Kallarackal *et al*. 2004). Genetic differences in survival among oil palm progenies under drought have been reported. Under drought conditions, progenies from the cross *Deli* × *La Me* had greater mortality, lesser fruit bunch yield than those from the cross between Deli and Yangambi (Houssou *et al*. 1989).

Some natural oil palms are grown in the Northern Regions of Ghana under erratic rainfall pattern and very high temperatures (Sapey *et al.* 2012). The genotypes from this region may have drought tolerant traits and genes induced by the adverse conditions over a long period. CSIR-Oil Palm Research Institute (OPRI, Benin) undertook a joint prospection in Ghana to screen oil palm genotypes for tolerance to drought and further incorporation of such traits into elite lines. In *dura* palm, all the physiological parameters except intercellular CO_2 concentration and leaf temperature were greater under irrigated conditions when compared to WDS conditions (Mathur *et al.* 2001). Guinea Bissau oil palm germplasm tolerant to WDS had high stomatal conductance and photosynthetic rates (Suresh *et al.* 2004). Oil palm genotypes screened under West Godavari of Andhra Pradesh conditions in India revealed that Zambian accession of ZS1 had greater drought tolerance, whereas Tanzanian (TS-9) accessions were found to be susceptible (Suresh *et al.* 2008). Housson *et al.* (1989) found some progenies had high yields and low mortality under stress and Villalobos and Rodriquez (1998) reported that number of bunches produced during initial two years can be used to assess yield potential of *teneras* under extreme stress. Murugesan *et al*. (2015) reported greater number of small fruit bunches in Guinea Bissau accessions with short rachis, leaflets under rainfed conditions which are considered as phenotypic manifestation of drought tolerance. Oil palm accessions had significant difference in stomatal opening and photosynthetic rate during dry season in Congo and these parameters can be used for selection for drought tolerance (Smith 1993). Seventeen years old irrigated oil palm leaves had leaf water potential (LWP) varying between -1.7 MPa and -1.0 MPa in unirrigated palms due to stomatal closure and stomatal control of leaf water status is the main reason why oil palm can survive long dry periods. Young palms (10 months after planting) were unable to maintain LWP (– 1.95 MPa) a high leaf water potential under severe drought conditions. Rainfall and temperature affected fruit bunch yield and oil quality in *dura* type oil palm (Muhammad *et al.* 2011). Oil palm fruits harvested in dry season had reduced per cent of myristic (0.27) and palmitic acid (4.42) and increased per cent stearic (0.90) and linoleic acid (1.79) in mesocarp oil when compared to those harvested during wet season. The duration of bunch ripening during rainy season was 156 days, whereas it took 165 days during dry season (Murugesan and Rethinam 2000). Though water availability obviously plays a roll on the length of bunch ripening, other factors such as temperature and solar radiation also influence fruit development process (Murugesan and Rethinam 2000). Supplementary irrigation during dry spell significantly increased oil palm fruit bunch yield (Palat *et al.* 2008, Mathur *et al.* 2001, Suresh *et al.* 2008, 2010, 2012, Suresh and Mathur 2009). Fresh fruit bunches and bunch numbers in the oil palm plantations grown in Benin, Colombia, Ivory Coast, Malaysia and Thailand (Corley and Tinker 2016) (Table 1). Fruit bunch yield loss may vary between 10 and 20 % for each 100 mm increase in water deficit (Palat *et al*. 2008, Carr 2011). Irrigation to the tune of 1130 mm had increased the annual fruit bunch yield from 10.5 tonnes/ha to 23.5 tonnes/ha and similar yield increase was achieved with reduced quantity of water to the tune of 650mm by scheduling irrigation on the basis of stomatal opening (Carr 2011). When irrigation was delayed, the stomata took several weeks to respond to water application and then failed to reopen fully. According to Palat *et al.* (2009), among four different methods of irrigation, viz furrow, sprinkler, micro sprinklers and drip experimented in Thailand, drip irrigation was found to be the best method of irrigation for attaining maximum fruit bunch yield (Tittinutchanon *et al*. 2009), although the differences in fresh fruit yields were not significant.

The progenies of Bamenda × Ekona and Tanzania × Ekona crosses had drought tolerance and produced 40-42 tonnes of fresh fruit bunch per ha during initial three years as compared to conventional varieties which produced 33-38 t/ha at Santo Dominigo de Los Colorodos (Alvarado and Sterling 2005). Combination of water and nutrient stress significantly increases the root/shoot ratio.

Application of B at the rate of 0.33-0.57 g/seedling and Si at the rate of 2.22 g/seedling in oil palm induced tolerance to drought stress (Al-Amin *et al*. 2011). Application of Si

Table 1 Effect of irrigation on fresh fruit bunch yield and bunch numbers in young and matured oil palms in main oil palm growing locations of countries

Location	Water deficit (cm)	Age (years)	FFB Yield (t/ha/year)			Bunch numbers/palm/year		
			Control	Irrigated	% Increase	Control	Irrigated	% Increase
Benin	582	8-11	16.1	23.4	47	7.2	9.5	33
Colombia	266	4-8	14.2	19.3	36	9.5	12.5	32
Ivory Coast	275	3-5	6.5	11.5	76	10.6	17.1	61
Malaysia	82	5-10	24.7	25.3	2	13.6	14.1	3
Thailand	214	8-14	18.7	24.5	31			

increases oil palm resistance to drought (Sacala 2009). Under WDS Si application helps the oil palm plants to maintain the water content in the tissue, and increase photosynthetic activity (Bharwana *et al*. 2013), to support the establishment of leaves, to maintain the structure of xylem vessels under conditions of rapid transpiration rate, to improve the balance of nutrients, to reduce minerals toxicity and to increase the mechanical strength of plant tissues (Hattori *et al*. 2005, Sacala 2009). Other benefits of application of Si are greater water use efficiency by reducing the rate of water loss, elimination of cuticular transpiration and increase in the CO_2 assimilation rate and stomatal conductance (Gong *et al*. 2005, Hou *et al*. 2006, Sacala 2009).

Effect of cold, salinity and flooding on oil palm

In general, oil palm grows at an altitude below 500 m, but in some instances oil palms have been found thriving on mountains in east and west Africa up to 1700 m. Oil palm yields are maximum in regions with an annual mean maximum and minimum air temperatures of 29-33 °C and 22-24 °C respectively (Corley and Tinker 2003). Oil palm grows poorly at temperatures below 20 °C (Blaak and Sterling 1996) and the growth of common oil palm varieties is suppressed at temperatures below15°C (Corley and Tinker 2003). In Ethiopia at 960 AMSL, *Dura* ×*Pisifera* progenies had precocious flowering at 12 months after transplanting. Low temperature and water deficiency inhibit the growth of oil palm seedlings (Cao *et al.* 2011). The membrane injury index, malondialdehyde (MDA) and proline content in the leaves increased at low temperature and drought stress (Cao *et al*. 2009, Yang and Lin 2008). The *Dura*×*Pisifera* progenies of Bemenda ×AVROS and Tanzania × AVROS crosses tested at Tanzania at 1000 AMSL and in Ethiopia at 960 AMSL were more precocious with 70 and 62% of palms flowering following 12 months after planting than progenies of Deli × AVROS cross (3%). Certain oil palms were able to produce satisfactory yield altitude between 1000 to 2000 MSL in Cameroon (Blaak and Sterling 1996) and such materials were originally collected from Bamenda highlands. Agricultural Services Development Costa Rica could successfully develop cold tolerant *tenera* hybrids by crossing DAMI deli with Cameroon and Tanzanian selections. Such materials are grown in Ethiopia at 1000 MSL, Malawi, Kenya, Zambia and in Cameroon at altitudes of up to 1500 MSL. According to Chapman (2003), cold tolerant genotypes have been planted in Kachin state in northern Myanmar at high altitude at approximately 25°N. The cold tolerant oil palm germplasm from Cameroon had an average fruit bunch yield with a range of 60 to 120 kg/palm/year under North Eastern climatic conditions of India (Pillai *et al.* 2000 and Goutam Mandal *et al*. 2012).

Oil palm is grown widely on waterlogged conditions over tropical peat swamp forest in Sarawak, Malaysia (Melling *et al*. 2005). Oil palm tolerates the highly acidic non-forest soils (Butler and Laurance 2009). The sodium and proline content and electrolyte leakage increased in the oil palm seedlings subjected to salt stress (Cha-um *et al.* 2010). Unlike that of coconut palm, oil palm is not tolerant to sea water (Munns 1993). Excess rainfall and flooding is detrimental to oil palm fresh fruit bunch yield (Greenall 2008) Lamade *et al.* (1998) showed that waterlogging caused root death in nursery seedlings, with stomatal closure resulting in reduced rates of photosynthesis and dry matter production. High rainfall during La Nina events could also be detrimental to the oil palm fruit bunch development. Five months before fruit ripening is the time of female flower pollination. Heavy rainfall may affect pollinating weevil (*Elaeidobius kamerunicus*) activities and results in low to poor fruit set (Donough *et al*. 1996, Sugih *et al*. 1996). Reduced production of viable pollen may also affect pollination and fruit set (Rao and Law 1998). According to Haniff and Roslan (2002) fruit set level less than 40% can cause reductions oil extraction ratio because of low mean fruit bunch weight and bunch oil content. The accumulation of EgRBP42 (designated gene encoding a member of the plant heterogeneous nuclear Ribo Nucleo Protein (hnRNP -like RNA Binding Protein RBP) family from oil palm) and its transcripts were induced by abiotic stresses including salinity, drought, submergence, cold and heat stresses in leaf discs of oil palm (Yeap *et al*. 2012). They suggested that EgRBP42 is a RNA binding protein, which responds to various abiotic stresses, could be advantageous for oil palm under stress conditions. Frequently flooded soil conditions make the palm prone to disease (Munever *et al.* 2001). Under prolonged waterlogged conditions water uptake is affected in the palms. In Latin American countries, productivity and area under matured oil palm are hampered by spear rot disease due to excess soil moisture and water stagnation.

Breeding for cold and salinity tolerance along with dwarfness and high yield are important for oil palm improvement in view of expansion of oil palm in less favourable climatic conditions. Genetic resources possessing early bunch ripening and harvestable maturity can be exploited in breeding programme to avoid contingent and seasonal droughts. The wild American oil palm species *Elaeis oleifera* (HBK) is a promising genetic resource for some of the desirable traits related to biotic and abiotic stress tolerances. In spite of desirable qualities, the cultivation of pure stand of E. *oleifera* is not viable economically, due to its low yields (< 1.0 tonne oil/ha/yr) as compared to the *E.guineensis* (4-5 tonnes oil/ha/yr). However, since the two species hybridize easily, interspecific hybrids could be obtained with yields around 90% of the *E. guineensis.* To introgress the traits of oil quality and low height increment (dwarfness) from *E. oleifera* into *E. guineensis,* two species were hybridised to produce *oleifera* × *guineensis* (O×G) hybrids. Subsequently, O× G hybrid was backcrossed to its *E. guineensis* parent to improve the yield (Moretzsohn *et al*. 2002). There are indications that an interspecific hybrid (*E. guineensis* × *E. oleifera*) presents tolerance to drought, waterlogged soils and nutrient deficiency (Barcelos *et al.* 2005). Moreover, some selected inter specific hybrids (Deli × Yangambi.Nifor) were found to have slow fruit detachment (Ochoa *et al*. 2013), lower lipase activity and slow development of free fatty acids in oil (Cadena 2013). A germplasm accession of *Elaeis oleifera* of Surinam source showed early fruit ripening and harvestable maturity (4.5 months) under tropical climate of south India (Murugesan *et al.* 2011). It is reported that O × G hybrids developed from Taisha (Ecuador) had the potential to produce high oil yields close to that of *dura* × *pisifera* seeds of *E. guineensis* (Kushairi *et al.* 2010, Araya and Alvarado 2012). ASD Costa Rica had released a variety Amazon (EO × EG) capable to tolerate water stress, low temperature and bud rots. The expected bunch yield during the first harvest after planting in commercial plantation of variety Amazon will be 9.8 to 12.3 t/ha which is superior than prevailing variety called Coari with a yield potential of 2.9 to 7.5 t/ha (Alvarado and Henry 2015). Promising four back crossed families (sourced from South American countries) developed from united plantation berhad, Malaysia were capable of yielding Fresh Fruit Bunch up to 35 t/ha/yr during second year of harvest with oil/bunch ratio of 32% and oil yield potential of 10 t/ha/yr. Selection of ortets from these back crossed progenies are under progress with an objective to develop compact clones and seed progenies with 6.25% *E. oleifera* traits. Such hybrids are suitable for high density planting of 200 palms/ha compared to conventional 136 - 160 palms/ha (Corley and Tinker 2016). A 30 year programme of repeated back crossing and inter crossing within back crosses underlies the development of the compact palm by ASD Costa Rica (Escobar and Alvarado 2003). The best clone from the compact palm development programme out yielded progenies of Deli×AVROS cross (popular hybrids of current planting material). Old plantations of *E.guineensis* which are senile and affected with bud rot/spear rot diseases can be replanted with high yielding *E. oleifera* × *E. guineensis* hybrids (Corredor *et al*. 2008). Recent development and extensive replanting programme with commercial planting of EG×EO hybrids attributed to outbreak of disease problems in some oil palm growing regions of South America (De Franqueville 2003).

ACKNOWLEDGEMENT

Senior author thanks Dr P Rethinam, Former Director and Dr R K Mathur, Director, ICAR-IIOPR, Pedavegi, Andhra Pradesh, India for providing facilities for conducting experiments.

REFERENCES

Al Amin, Leal W, Jaafar A H and Ghani A Z. 2011. Assessing the impacts of climate change in the Malaysian Agriculture sector and its influence in investment decision. *Middle East Journal of Scientific Research* **7:** 225–34.

Alvarado A and Sterling F. 2005. Stress tolerant oil palm varieties. *ASD Oil Palm Papers* **28:** 5–14.

Alvarado, A and Henry J. 2015. Agronomic behavior of the Amazon hybrid. *ASD Oil Palm Papers* **44:** 9–16

Araya E and Alvarado A. 2012. Huella genética de clones compactos de palma aceitera (*Elaeis guineensis*): identificación con marcadores microsatélite. *ASD Oil Palm Papers* **39:** 35–42.

Asemota O and Conaire B. 2011. Identification of moisture stress tolerant oil palm genotypes. *African Journal of Agricultural Research* **5 (22):** 3 116–21.

Ashraf M and Harris P J C. 2013. Photosynthesis under stressful environments: An overview. *Photosynthetica* **51:** 163–90.

Barcelos E, Cunha N R W and Nouy B. 2005. Genetic resources of oil palm (*Elaeis guineensis* Jacq and *Elaeis oleifera* (Kunth) Cortes) available at EMBRAPA and its use. *In: BORÉM, A and VIANA, GV Plant Breeding, Viçosa,* UFV. 525 p.

Baskin J M and Baskin C C. 2014. What kind of seed dormancy might palms have? *Seed Science Research* **1**; **24(01):** 17–22.

Bharwana S A, Ali S, Farooq M A, Iqbal N, Abbas F and Ahmad M S A. 2013. Alleviation of lead toxicity by silicon is related to elevated photosynthesis, antioxidant enzymes suppressed lead uptake and oxidative stress in cotton. *Journal of Bioremediation and Biodegradation* **4:** 187–98.

Blaak G and Sterling F. 1996. The prospects of expanding oil palm cultivation to higher elevations through using cold tolerant plant material. *Planter* **72** (849): 645–52.

Butler R A and Laurence W F. 2008. New strategies for conserving tropical forests. *Trends in Ecology and Evolution*. **9**: 469–72.

Donough C, Chew K and Law I. 1996. Effect of fruit set on OER and KER: Results from studies at Pamol Estates (Sabah) Sdn. Bhd. *Planter* **72:** 03– 219.

Cadena T, Prada F, Perea A and Romero H M. 2013. Lipase activity, mesocarp oil contentand iodine value in oil palm fruits of *Elaeis guineensis*, *Elaeis oleifera* and the interspecific hybrid O × G (*E. Oleifera* × *E. guineensis*). *Journal of the Food Science and Agriculture* **93:** 674–80.

Cao H X, Sun C X, Shao H B and Lei X T. 2011. Effects of low temperature and drought on the physiological and growth changes in oil palm seedlings. *African Journal of Biotechnology* **10(14):** 2 630–7.

Cao J H, Li X P, Lin W F, Xie G S and Chen J M. 2009. Survey on resistance of 12 species oil palm cultivated in the field. *Chinese Journal of Tropical Agriculture* **29:** 1–6.

Carr M K. 2011. The water relations and irrigation requirements of oil palm (*Elaeis guineensis*) a review. *Experimental Agriculture* **47**(4): 629–52.

Chapman K R, Escobar R and Griffee P. 2003. Cold tolerant or altitude adapted oil palm hybrid development initiatives in the Asia/Pacific region. *Assumption University of Journal and Technology* **6**(3): 134–8

Cha-um S, Takabe T and Kirdmanee C. 2010. Ion contents, relative electrolyte leakage, proline accumulation, photosynthetic abilities and growth characters of oil palm seedlings in response to salt stress. *Pakistan Journal of Botany* **42**(3): 2191–2220.

Cha-um S, Takabe T and Kirdmanee C. 2010. Osmotic potential, photosynthetic abilities and growth characters of oil palm (*Elaeis guineensis* Jacq.) seedlings in responses to polyethylene glycol-induced water deficit. *African Journal of Biotechnology* ***9*****(39):** 6 509–16.

Cha-um S, Yamada N T, Takabe T and Chalermpol K. 2011. Mannitol induced water deficit stress in oil palm (*Elaeis guineensis* Jacq.) seedlings. *Journal of Oil Palm Research* **23:** 1193–1201.

Clay J. 2013. *World Agriculture and the Environment: A Commodity-By-Commodity Guide to Impacts and Practices*. Island Press, Washington DC, USA.

Conaire B, Asemoto O and Isemila A E. 2005. Pattern of seedling root development among some oil palm genotypes. *Journal of Agriculture and Environment International development* 2(1): 55–64.

Corley R H V and Tinker P B. 2003. *The Oil Palm,* p 562. Blackwell Science Ltd, Oxford.

Corley R H V and Tinker P B. 2016. *The Oil Palm*, p 639. Blackwell Science Ltd, Oxford.

Cornaire B, Daniel C, Zuily-Fodil Y and Lamade E. 1994. Oil palm performance under water stress. Background to the problem, first results and research approaches. *Oléagineux* (Paris) **49(1):** 1–12.

Corredor A, Martinez G and Silvia A. 2008. Problems of bud rot in Tumaco and tools for management and renewal of the crop. *Magazine Palmas* **29 (3):** 11–16.

De Franqueville H. 2003. Review paper: oil palm bud rot in Latin America. *Experimental Agriculture* 39**:** 225–40.

Ellis R H, Hong T D, Roberts E H and Soetisna U. 1991.Seed storage behaviour in *Elaeis guineensis*. *Seed Science Research* **1(02)**:99–104.

Escobar R and Alvardo A. 2003. Strategies in production of oil palm compact clones and seeds. (*In) Proceedings of Agricultural Conference Palm oil. The power house for the global oils and fats economy,* 24-28 August. Malaysian Palm Oil Board, Kuala lampur, pp 75–90

Fahramand M, Mahmoody M, Keykha A, Noori M and Rigi K. 2014. Influence of abiotic stress on proline, photosynthetic enzymes and growth. *International Research Journal of Applied and Basic Sciences* **8:** 257–65.

FAO: FAOSTAT online statistical service. 2014. Food and Agriculture Organization of the United Nations, Rome, Italy, available at: http://faostat3.fao.org/

Gerritsma W and Wessel M. 1997. Oil palm: Domestication achieved? *Netherlands Journal of Agricultural Sciences* **54:** 463–75.

Goldstein G, Andrade J L, Meinzer F C, Holbrook N M, Cavelier J, Jackson P and Celis A. 1998. Stem water storage and diurnal patterns of water use in tropical forest canopy trees. *Plant Cell & Environment* **21:** 397–406.

Gong H, Zhu X, Chen K, Wang S and Zhang C. 2005. Silicon alleviates oxidative damage of wheat plants in pots under drought. *Plant Science* **169:** 313–21.

Goutam Mandal, Mathur R K, Shit A K, Sunil Kumar K, Pillai R S N, Nagaraju A and Balakrishna P. 2012. Evaluation of African germplasm. *Global conference on Horticulture for food and livelihood option,* 28-31 May 2012. Bhubaneswar, p 51

Greenall M. 2008. La Nina is good for oil palm bad for soybeans. *Asia Plantation:* 6-7.

Gupta U and Solanki H. 2013. Impact of boron deficiency on plant growth. *International Journal of Bioassays* **2:** 1 048–50.

Hajiboland R and Farhanghi F. 2010. Effect of low boron supply in turnip plants under drought stress. *Biologia Plantarum* **55:** 775–8.

Hajiboland R, Farhanghi F and Aliasgharpour M. 2012. Morphological and anatomical modifications in leaf, stem and roots of four plant species under boron deficiency conditions. *Annals of Biology* **34:** 15–29.

Han S, Chen L S, Jiang H X, Smith B R, Yang L T and Xie C Y. 2008. Boron deficiency decreases growth and photosynthesis and increases starch and hexoses in leaves of citrus seedlings. *Journal of Plant Physiology* **165:** 1 331–4.

Haniff M H and Roslan M N. 2002. Fruit set and oil palm bunch components. *Journal of Oil Palm Research* **14(2):** 24–33.

Haniff M H, Rahim A S, Wahid O, Tarmizi T M and Faiz M M. 2005. Effects of soil compaction on oil palm productivity. *Proceedings of the PIPOC 2005, International Palm Oil Congress,* pp 469–75.

Haniff M H, Zuraidah Yahya, Afifah Abdul Razak, Jusoh Latif, Ayatollah Khomeini A Rahman M and Norman Kamarudin. 2016. Impact of El Nino and La Nino on oil palm FFB yield production in Malaysia. *International Journal of Agriculture and Environmental Research* **2(5):** 1 084–1 100.

Hattori T, Sonobe K, Inanaga S, An P and Morita S. 2005. Effects of silicon on photosynthesis of young cucumber seedlings under osmotic stress. *Journal of Plant Nutrition.***31:** 1 046–58.

Henson I E and Harun M H. 2007. Short term responses of oil palm to an interrupted dry season in north Kedah, Malaysia. *Journal of Oil Palm Research* **19:** 364–72.

Henson I E and Harun M H. 2005. 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 17***:** 73–91.

Hollinger D Y, Kelliher F M, Schulze E D and Köstner B M.1994. Coupling of tree transpiration to atmospheric turbulence. *Nature* **371:** 60–2.

Hou L, Szwonek E and Shangjun X. 2006. Advances in Silicon research of horticultural crops. *Vegetable Crops Research Bulletin* **64:** 5–17.

Houssou M, Omore A and Meunier J. 1989. Breeding for drought resistance in the oil palm 1. Variability of some crosses for their productivity and their mortality. *Paper presented at Conference Palms and palm products,* 21-25 November, Nigerian Institute of Oil Palm Research, Benin City. http://www.globalpalmoilproduction.com

Ismail M R, Yusoff M K and Mahmood M. 2004. Growth, water relations, stomatal conductance and proline concentration in water stressed banana (*Musa* sp.) plants. *Asian Journal of Plant Science* **3:** 709–13.

Jazayeri S M, Rivera Y D, Reyes J E C and Romero H M. 2015. Physiological effects of water deficit on two oil palm (*Elaeis guineensis*. Jacq.) genotypes. *Agronomia Colombiana* **33(2):** 164-173.

Kallarackal J, Jeyakumar P and George S J. 2004.Water use of irrigated oil palm at three different arid locations in Peninsular India. *Journal of Oil Palm Research* **16:**45-53.

Kushairi A, Tarmizi A H, Zamzuri I, Ong Abdullah M, Samsul Kamal R, Ooi S E and Rajanaidu N. 2010. Production, Performance and Advances in Oil Palm Tissue Culture. *(In) International seminar on Advances in Oil Palm Tissue Culture* 29 May 2010. pp 1-23. Yogyakarta, Indonesia.

Lamade E, Setiyo E and Purba A. 1998c. Gas exchange and carbon allocation of oil palm seedlings submitted to water logging in interaction with N fertiliser application. *(In Proceedings of International Oil Palm Conference. Commodity of the Past, Today and the Future.* pp 573-584. Indonesian Oil palm Research Institute, Medan.

Lee C, Niga, Romzi I and Ismail H. 2005. Early growth and yield performance of irrigated and no-irrigated oil palms planted on undulating and terraced areas in land peninsular Malaysia. *(In) Proceedings of Agriculture Biotechnology and Sustainability Conference .PIPOC 2005. MPOB.* pp 267-284. International Palm Oil Conference Selangor. Malaysia.

Legros S, Serra I M, Caliman J P, Siregar F A, Clement-Vidal A and Dingkuhn M. 2009. Phenology and growth adjustments of oil palm (*Elaeis guineensis*) to photoperiod and climate variability. *Annals of Botany* **104:** 1171-1182.

Legros S, Serra I M, Caliman J P, Siregar F A, Clement-Vidal A, Fabre D and Dingkuhn M. 2009. Phenology, growth and physiological adjustments of oil palm (*Elaeis guineensis* Jacq) to sink limitation induced by fruit pruning. *Annals of Botany* **104:** 1183-94.

Madurapperuma W S, de Costa W, Sangakkara U R and Jayasekara C. 2009. Estimation of water use of mature coconut (*Cocos nucifera* L.) cultivars (CRIC 60 and CRIC 65) grown in the low country intermediate zone using the compensation heat pulse method (CHPM). *Journal of the National Science Foundation Sri Lanka* **37:** 175–86.

Mathur R K, Suresh K, Nair S, Parimala K and Shivaramakrishna V N P. 2001. Evaluation of exotic *dura* germplasm for water use efficiency in oil palm (*Elaeis guineensis* Jacq.). *Indian Journal of Plant Genetic Resources* **14(2):** 257-9.

Matius N T, Liwang T, Danuwikarsa M I, Suryatmana G, Djajasukanta H, Saodah D and Astika I G P W. 2004. Biochemical responses of several oil palm (*Elaeis guineensis* Jacq.) progenies to drought stress in field condition. *Indonesian Journal of Biotechnology Research on Estate Crops* **72:** 38-56.

Melling L, Hatano R and Goh K J. 2005. Soil CO_2 flux from three ecosystems in tropical peat land of Sarawak, Malaysia. *Tellus* **57B:** 1-11.

Moretzsohn M C, Ferreira M A, Amaral Z P S, Coelho P J O, Grattapaglia D, Ferreira M E. 2002. Genetic diversity of Brazilian oil palm (*Elaeis oleifera* H.B.K.) germplasm collected in the Amazon forest. *Euphytica* **124:** 35-45.

Muhammad S, Leewanich P, Punsuvon V, Chanprames S and Srinives P. 2011. Seasonal effects on bunch components *Elaeis guineensis* and fatty acid composition in *dura* oil palm. *African Journal of Agricultural Research* **6(7):** 1835-43.

Munever F, Acosta A and Gomez P. 2001. Edaphic factors associated with bud rot in the oil palm of Colombia. *Palmas* **22(2):** 9-19.

Munns R. 1993. Physiological processes limiting plant growth in saline soils some dogmas and hypotheses. *Plant Cell and Environment* **16:** 15-24.

Murugesan P and Rethinam P. 2000. Duration of oil palm bunch ripening under coastal climate of Andhra Pradesh India. *International Journal of Oil Palm* **1(1&2):** 65-6.

Murugesan P, Haseela H, Gopakumar S, Shareef MV.2011. Fruit and seed development in *Elaeis oleifera* (HBK) Cortes of Surinam origin. *Indian Journal of Horticulture*. **68(1)**:28-30.

Murugesan P, Rani K L M, Ramajayam D, Sunilkumar K, Mathur R K, Ravichandran G, Kumar P N and Arunachalam V. 2015. Genetic diversity of vegetative and bunch traits of African oil palm (*Elaeis guineensis*) germplasm in India. *Indian Journal of Agricultural Sciences* **85(7)**:892-5.

Nana Yamada, Suriyam Cha-Um, Hakutokageyama, Worrawat Proden, Yoshito Tanaka, Chalermpol Kirdmanee and Teruhiro Takabe. 2011. Isolation and characterisation of proline/betaine transporter gene from oil palm. *Tree Physiology* **31:** 462-8.

Nodichao L, Chopart J L, Roupsard O, Vauclin M, Ake S and Jourdan C. 2011. Genotypic variability of oil palm root system distribution in the field. Consequences for water uptake. *Plant and Soil* **341 (1-2):** 505-20.

Nouy B, Baudouin, Diegui N and Omore A.1999. Oil palm under limiting water supply conditions. *Plantations Research Development* **6:** 31-45.

Ochoa I E , Suarez C A and Cayon D G. 2013. Desarrollo y maduracion de frutos en Palma de aceite (*Elaeis guineensis* Jacq.) e hibridos O×G (*E.oleifera* × *E.guineensis*) de palma Unipalma S.A. Palmas, **34**: 326-36.

Omorefe A and Bonaventure C. 2010. Identification of moisture stress tolerant oil palm genotypes .*African Journal of Agricultural Research* **5:** 3116-21.

Palat T, Chayawat N, Clendon J H and Corley R H V. 2009. A review of 15 years of oil palm irrigation research in Southern Thailand. *International Journal of Oil Palm Research* **6:** 146-54.

Palat T, Chayawat Nakharin, Clendon J H and Corley R H V. 2008. A review of 15 years of oil palm irrigation research in Southern Thailand. *Planter* **84 (989):** 537-46.

Pillai R S N, Blaak G and Paul Closen H. 2000. Collection of Oil Palm (*Elaeis guineenisis*, Jacq.) germplasm from Africa. *International Journal of Oil Palm* **1(1&2):** 23-37.

Putra E T S, Issukindarsyah, Taryono and Purwanto B H. 2015. Physiological response of oil palm seedlings to the drought stress using boron and silicon applications. *Journal of Agronomy* 1-13.

Rajanaidu N, Jalani S, Rao V, Kushairi A. 1993. Genotype – environment interaction (GE) studies in oil palm (*Elaeis guineensis*) progenies. (*In) Proceedings of 1991 ISOPB International. Workshop on genotype interaction studies in perennial tree crops*, Palm Oil Research Institute of Malaysia, Kuala Lumpur, pp 12-32

Rao V and Law I. 1998. The problem of poor fruit set in parts of East Malaysia. *Planter* **74(870):** 463-83.

Ravichandran G, Naveen Kumar P, Sunil Kumar K, Ramajayam D, Mathur R K, Murugesan P and Arulraj S. 2014. *Proceedings of National Oil Palm Seed Meet-2014*. Directorate of Oil Palm Research, Pedavegi, p 24

Sacala E. 2009. Role of silicon in plant resistance to water stress. *Journal of Elementology*. **14:** 619-630.

Sapey E, Adusei-Fosu K D, Agyei-Dwarko D and Okyere-Boateng G. 2012. Collection of oil palm (*Elaeis guineensis* Jacq.) germplasm in the Northern Regions of Ghana. *Asian Journal of Agricultural Sciences* **4(5)**: 325-8.

Smith B .1993. Correlations between vegetative and yield characteristics and photosynthetic rate and stomatal conductance in the oil palm (*Elaeis guineensis* Jacq). *Elaeis* **5:**12-26.

Soh A C. 2012. The future of oil palm clones in Malaysia. *Journal of Oil Palm & the Environment* **3**:93-7.

Sugih W, Heru S, Achmad F and Thiagarajan. 1996. Influence of rainfall, palm age and assisted pollination on oil palm fruit set in Riau, Indonesia. *(In) International Palm Oil Congress: Competitiveness for the 21st Century. Agriculture Conference*, *Kuala Lumpur*. 23-28 September 1996. Palm Oil Research Institute of Malaysia (PORIM), pp 207-20.

Sun C X, Cao H X, Shao H B, Lei X T, Xiao Y. 2011. Growth and physiological responses to water and nutrient stress in oil palm. *African Journal of Biotechnology* **10(51):**10465-71.

Suresh K and Mathur R K. 2009. Drought tolerance in Oil Palm (*Elaeis guineensis* Jacq.). *International Journal of Oil Palm* **6(2):** 1-6.

Suresh K, Mathur R K and Kochu Babu M. 2008. Screening of oil palm *duras* for drought tolerance stomatal response gas exchange and water relations. *Journal of Plantation Crops* **36(3):** 270-5.

Suresh K, Nagamani C, Sivakumar K M and Vinod Kumar. 2004. Variations in photosynthetic rate and associated parameters in the different *dura* oil palm germplasm. *Journal of Plantation Crops* **32:**67-9.

Suresh K, Nagamani G, Kantha D L and Kumar M K. 2012. Changes in photosynthetic activity in five common hybrids of oil palm (*Elaeis* guineenisis Jacq.) seedlings under water deficit. *Photosynthetica* **50(4):** 549-56.

Suresh K, Nagamani G, Ramachandrudu K and Mathur R K. 2010. Gas-exchange characteristics, leaf water potential and chlorophyll a fluorescence in oil palm (*Elaeis guineensis* Jacq.) seedlings under water stress and recovery. *Photosynthetica* **48(3):** 430-6.

Suriyan Cha-um, Takabe T, Kirdmanee C. 2012. Physio-biochemical responses of oil palm (*Elaeis guineensis* Jacq.) seedlings to mannitol- and polyethylene glycol-induced iso-osmotic stresses. *Plant Production Science* **15 (2):** 65-72.

Tittinutchanon P, Nakharin C, Clendon J H and Corley R H V. 2009. A review of 15 years of oil palm irrigation research in Southern Thailand. (*In) proceedings of National Conference on Oil Palm (Oil palm for farmers prosperity and edible oil security),* pp 46-154.

Vanclay J K. 2009. Managing water use from forest plantations. *Forest Ecology and Management* **257:** 385–9.

Villalobos E and Rodriguez W .1998. Evaluation of carbon assimilation capacity, efficiency in water use and drought resistance in progeny oil palms (*Elaeis guineensis* Jacq.) In Costa Rica. *University of Costa Rica, Project Report* **VI-734-97-16**, p 32.

Wahid M B, Abdullah S N and Henson I E. 2005. Oil palm—achievements and potential. *Plant Production Science* **8(3):**288-97.

Yahya Z, Husin A, Talip J, Othman J, Ahmed O H and Jalloh M B. 2010. Soil compaction and oil palm (*Elaeis guineensis*) yield in a clay textured soil. *American Journal of Agricultural and Biological Sciences* **5(1):** 15-9.

Yang H G and Lin W F. 2008. Effect of low temperature stress on some physiological characteristics of oil palm (*Elaeis guineensis* Jacq.) seedlings. *Chinese Agricultural Science Bulletin* **3:** 2009-24.

Yeap W C, Ooi T E K, Nmasivayam P, Kulaveerasingam H and Ho C L. 2012. EgRBP42 encoding an hnRNP-like RNA binding protein from *Elaeis guineenisis* Jacq. is responsive to abiotic stresses. *Plant Cell Reports* **31:** 1829-43.

Zain N A M, Ismail M R, Mahmood M, Puteh A and Ibrahim M H. 2014. Alleviation of water stress effects on MR220 rice by application of periodical water stress and potassium fertilization. *Molecules* **19:** 1795-1819.

Zlatev Z and Lidon F C. 2012. An overview on drought induced changes in plant growth, water relations and photosynthesis. *Emirates Journal of Food and Agriculture* **24:** 57-72.