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Adaptation and Mitigation Strategies for Climate-Resilient Oil Palm

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Abstract

The impacts of climate change on oil palm are being witnessed in Malaysia, Indonesia, Columbia, and other oil palm-growing nations of the world. Climate change might worsen existing regional disparities as it will reduce oil palm yields mostly in lands located at lower latitudes, where many developing countries are situated. Being grown as an irrigated crop in India, oil palm is likely to be more vulnerable due to excessive use of natural resources particularly water with poor adaptive mechanisms. The water requirement is estimated to increase by 10% for every 1°C rise in temperature. Under such situations, when oil palm yield decreases, small and marginal oil palm growers would be affected most. Hence, consequences of climate change could be severe on livelihood security of the poor in the absence of better adaptation strategies. Strategies to enhance local adaptation capacity are therefore required to reduce climatic impacts and maintain regional stability in oil production. At the same time, oil palm offers several opportunities to mitigate the portion of global greenhouse gas emissions that are directly dependent upon land use and land-management techniques. This chapter reviews issues relating to impacts of climate change with special emphasis on adaptation and mitigation strategies for climate-resilient oil palm production. Adaptation and mitigation strategies in oil palm could be carried out to alleviate the potential negative effects of climate change. However, important synergies need to be identified as mitigation strategies may compete with local agricultural practices aimed at maintaining production. The specific research priorities for oil palm under Indian conditions to combat climate change have also been highlighted.

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18.1 Introduction

Among the most important agricultural crops in the tropics is oil palm. Palm oil is used in a wide range of products and an important source of vegetable oil (Corley 2009) and is increasingly used as a feedstock for biofuel production (Henderson and Osborne 2000; Basiron 2007; Koh 2007). Oil palm is one of the highest edible oil yielding perennial crop that can yield 4–6 t ha^{-1} $year^{-1}$ (crude palm oil) and 0.4–0.6 t ha^{-1} $year^{-1}$ (palm kernel oil) from 3rd to 25th year of its productive life span. Globally, oil palm cultivation is centered in the tropics with highest levels of production in Indonesia and Malaysia (Basiron 2007). Both Indonesia and Malaysia are located in global biodiversity hotspots (Myers et al. 2000), so expansion in these areas is likely to have a large negative impact on biodiversity at the global scale (Sodhi et al. 2010). Various expert committees constituted by Ministry of Agriculture, Government of India, have identified 1.036 million ha in 14 states of the country as suitable for oil palm cultivation. About 80% of the area identified is located in the states of Andhra Pradesh, Karnataka, and Tamil Nadu grown under irrigated conditions. Till 2012, an area of 210 thousand ha could be covered in different states. The yields obtained by the progressive farmers of different oil palm-growing states in India range between 20 and 30 t FFB ha^{-1} $year^{-1}$. If concerted efforts are taken to bring 1 million ha under oil palm, in the identified potential areas, it would be possible to get 3–4 MT of palm oil and 0.3–0.4 MT of palm kernel oil within two decades.

According to the Third Assessment Report of Intergovernmental Panel on Climate Change (IPCC), it was found that average surface temperature of the earth has increased by 0.6°C over the twentieth century. The sea level rise has also been estimated at a rate of 1–2 mm annually during the last century. It further forecasts that globally averaged surface temperature would rise by 1.4–5.8°C and the global mean sea level may rise by 0.09–0.88 mm during 1990–2100 (UNIES 2007). IPCC has already forecasted that in the coming decades, agriculture worldwide will have to face negative aspects of this changing climate. It is anticipated that the effects on crop yields in the mid- and high-latitude regions would be less adverse than in low-latitude regions. Decrease of potential yields in warmer areas is likely to be due to shortening of crop growth period, decrease in water availability due to higher rates of evapotranspiration, and poor vernalization (Chattopadhyay 2005).

Due to climate change, the increase in temperature and variability in rainfall pattern could lead to development of abiotic stresses like heat, drought, and flooding. These stresses could occur in varying degrees coinciding with different growth and phenological phases of crops, in turn affecting their productivity and quality. Hence, timely and appropriate measures to overcome negative impacts of climate change on oil palm need to be initiated. In this chapter, the potential impacts of high temperature, water stress, and elevated CO_2 on oil palm and possible adaptation strategies to overcome these impacts are discussed.

18.2 Climate Change and Oil Palm

The ideal climatic requirements for oil palm are:

(a) Annual rainfall of 2,000 mm or greater, evenly distributed, without a marked dry season, and preferably at least 100 mm in each month
(b) Mean maximum temperature of 29–33°C
(c) Mean minimum temperature of 22–24°C
(d) Relative humidity above 45%
(e) Low vapor pressure deficit
(f) Sunshine of 5–7 h day^{-1} in all months
(g) Solar radiation of 15 MJ m^{-2} day^{-1}

A changing climate would affect oil palm plantations in many ways, with either benefits or negative consequences dominating in different agricultural agroclimatic regions. However, the factors that prevail regionally may change over time, as gradual and possibly abrupt climate changes develop in this century. Rising atmospheric CO_2 concentration, higher temperature, changing patterns of precipitation, and altered frequencies of extreme events will have significant effects on oil palm production, with associated consequences for water resources and pest/disease distributions.

18.2.1 Precipitation

The climatic models predict a change in precipitation by 5–25% over India by the end of the century with more reductions in winter rainfall than summer monsoon leading to droughts during summer months. The major effects of global climate change on crop water relations are likely to occur due to more erratic rainfall patterns and unpredictable high temperature spells. The effect of drought on oil palm growth can be divided into five stages (Lubis et al. 1993). During the first stage, i.e., when water deficit is less than 200 mm year^{-1}, palms do not show any serious problem. The second stage occurs when water deficit is 200–300 mm year^{-1} and symptoms like sticking of frond and immature leaves together and may not open. The old fronds become defective also. The third stage occurs when water deficit is 300–400 mm year^{-1} and common symptoms are number of stick and unopened leaves increases to 4–5 and number of defective old fronds will be seen in 1–1.5 spirals and fronds become dry. Subsequently when water deficit increases to 500 mm year^{-1}, young fronds will not open and leaf bud cracks, becomes defective, and breaks.

The Deli origin showed more tolerance when crossed with palms from Tanzania, Yangambi, and La Mé populations. Observations on root system of several oil palm families showed that tolerant crosses have a better-developed root system than susceptible crosses. Stomatal opening, leaf water potential, and membrane breakdown can be considered as possible selection criteria for drought tolerance in oil palm (Cornaire et al. 1989). In oil palm, leaf starch is hydrolyzed during dry season, and there is an increase in soluble sugar concentration (Adjahossou and Silva 1978). Accumulation of large amounts of proline contributes to osmotic adjustment and serves as cytoplasmic osmotic balance for potassium accumulation in the vacuole.

Moisture stress suppresses female inflorescence formation and increases abortion of female inflorescences. The inadequate water supply to meet such high evapotranspiration demand during dry period would severely affect sex differentiation and subsequent inflorescence development process which will eventually reduce the ultimate yield. An irrigation trial on a semicommercial scale in a dry area has achieved 38.8 t FFB ha^{-1} year^{-1} at the third year of irrigation as compared with only 14.1 t FFB ha^{-1} year^{-1} without irrigation. At 8–10 years old, the irrigated palms could sustain a yield of 30–35 t FFB ha^{-1} year^{-1} as compared with 16–18 t FFB ha^{-1} year^{-1} of nonirrigated palms (Foo 1998).

Screening of African dura germplasm for drought tolerance based on physiological markers has been done in India (Mathur et al. 2001; Suresh et al. 2004, 2008a, 2010). Based on these results, superior drought-tolerant duras have been identified. ZS-1 was the most drought-tolerant dura compared to that of other duras, while TS-9 was most susceptible one. Studies on membrane susceptibility indices (MSI) indicated that ZS-2 recorded highest value closely followed by TS-9 indicating their better tolerance to drought (Suresh 2010). Fourteen dura (Africa) × pisifera crosses were screened for drought tolerance in nursery by undertaking studies on membrane stability indices (MSI). Highest MSI was recorded in 34CD × 110P closed followed by 124CD × 17P and 66CD × 129P, indicating their better tolerance to drought. 254CD × 14P and 435CD × 14P recorded lower MSI indicating their poor tolerance to drought.

Suresh et al. (2012) studied genotypic variations in leaf water potential, gas exchange parameters, and chlorophyll fluorescence in five oil palm (*Elaeis guineensis* Jacq.) *tenera* hybrids at nursery, which indicated that at 24 days of imposition of water stress, highest leaf water potential was observed in 913 × 1988 which did not differ significantly with that of 1425 × 2277 and 7418 × 1988. Photosynthetic rate and stomatal conductance were significantly decreased in all hybrids due to water stress. There was a reduced apparent electron transport rate in 7418 × 1988 and 1425 × 2277 at 12 days of rehydration indicating its lesser tolerance to water stress. Highest non-photochemical quenching was observed in 7418 × 1988 after rehydration indicating its better adaptation to counter excess light energy produced due to low photosynthesis.

To understand plant stress responses in the form of sap flux and transpirational adjustments made by oil palm under Indian conditions, sap flow studies have been undertaken (Suresh et al. 2006; Suresh and Nagamani 2007), and results revealed that sap flux increased gradually from 9.00 AM reaching a peak during 1.00 to 2.00 AM and decreased as day progressed. Evapotranspiration and vapor pressure deficit also showed similar trend as that of sap flux. Seasonal variations in sap flux indicated higher sap flux during February and March and lower flux during May and June. The lower flux during dry months could be due to closure of stomata after midday as atmospheric vapor pressure deficit increased.

18.2.2 Temperature

Oil palm, being an equatorial crop, demands high temperature for its growth and yield. The climate projection studies indicate a general increase in temperatures in the order of 3–6°C over the base period average, depending on the scenario, with more warming in northern parts than southern parts. Phytotron studies indicated that best growth of oil palm was at 32/22 (mean 27°C). The next level with a mean temperature of 22°C gave only slightly slower growth. At a mean temperature of 17°C, it was only half of the best and very little growth occurred at a mean temperature of 12°C (17/7). It is however difficult to separate the effect of minimum and maximum temperature on growth and yield of oil palm. The best mean temperature range is 24–28°C, although palms at high elevation or at the geographical limit of about 15°N may be growing with mean minimum temperatures of less than 20°C for part of the year.

Higher temperatures can reduce or even halt photosynthesis, prevent pollination and anthesis, and decrease number of female inflorescences, abortion of bunches leading to bunch failure. As temperature rises, photosynthetic activity in oil palm increases until the temperature reaches 20°C. The rate of photosynthesis then plateaus until temperature reaches 35°C, where it begins to decline and at 40°C, photosynthesis ceases completely. High temperatures can also dehydrate oil palm. When oil palm folds its leaflets to reduce exposure to the sun, photosynthesis is reduced. When the stomata on abaxial side of leaflets close to reduce the transpiration load, CO_2 uptake is also reduced and thereby photosynthesis. Diurnal variations in oil palm under irrigated conditions also explain the sensitivity of stomata leading to decreased photosynthetic rates after 10.00 AM due to increase in ambient and leaf temperatures. Higher temperature (>38°C) might cause early ripening of bunches in the same whorl of palm (pseudo-ripening) during summer (1–2 weeks) leading to drastic reduction in oil extraction rates (<8%). The effect of any kind of stress (temperature/water deficits) on oil palm is revealed 1.5–2 years later on bunch yield. Oil palm being a perennial crop, there is limited scope for scheduling crop calendar.

18.2.3 Atmospheric Carbon Dioxide Concentration

Though increased CO_2 enhances the productivity of the C_3 plants in the arid regions of India, the increase in temperature may offset the beneficial effects of CO_2. Observations on oil palm CO_2-enriched seedlings indicated increased photosynthetic rate (12 folds) attributed to higher intercellular CO_2 level, decreased both stomatal conductance and transpiration (3 folds), and water use efficiency (4 folds) as compared to the control. Hence, CO_2 enrichment technique for the tropical lowlands under the greenhouse prototype controlled environment is technically feasible and has a great application potential in the seedling/nursery industry (seedlings and advanced planting materials), for production research and development study, and in the climate change impact analyses for possible enhanced bioproductivity and income generation (Hawa 2006).

However, CO_2 imposed a very marked effect on growth and leaf gas exchange parameters although all the variables measured did not differ significantly when palms were exposed to 800 and 1,200 μmol, mol^{-1} of CO_2. Exposing seedlings to higher (800 μmol mol^{-1}) CO_2 concentration resulted in higher total biomass, net assimilation rate, relative growth rate, plant height, frond number, basal diameter, and total leaf area compared to the controlled seedlings. Further increase in CO_2 concentration (1,200 μmol mol^{-1}) saturated the quantum efficiency of PSII. Total chlorophyll content and stomata density were found to be reduced. Upon enrichment, net photosynthesis and water use efficiency increased, but there was a reduction in stomata conductance and evapotranspiration rate. Increase in water use efficiency under increased CO_2 concentration implied that plant could use less water per unit carbohydrate produced especially when undergoing stress. Seedlings treated with high CO_2 increased their apparent quantum yield and maximum photosynthetic capacity, but light compensation point was reduced.

Various studies have suggested that many C_3 plants respond to CO_2 enrichment to a greater extent than at ambient CO_2 as a result of increased quantum yields (Hanstein and Felle 2002). A small increase in quantum yield may increase daily carbon gain under low light conditions (Kiirats et al. 2002). In oil palm, elevated CO_2 increased apparent quantum yields in 800 and 1,200 μmol mol^{-1} CO_2 treatments. Light response curve analysis of oil palm seedling had shown that CO_2 enriched seedlings had reduced their dark respiration rate by 43% to 70% through enhancement of their saturated photosynthetic capacity and apparent quantum yield by 52% to 78% and 15% to 62%, respectively. The enhancement of light compensation point and quantum yield signifies direct inhibition of the activity of key respiratory enzymes under elevated CO_2 (Drake et al. 1997). This result has been supported by Henson and Haniff (2006) who reported productivity or dry matter production of plants would increase if respiration could be minimized without affecting gross assimilation or if gross assimilation could be increased without increasing respiration. Usually, compensation irradiance is reduced while quantum efficiency is increased in plant under elevated CO_2 (Vivin et al. 1995). The same result was also observed by Kubiske and Pregitzer (1996) with red oak seedlings grown at elevated CO_2 in shaded open top chamber.

In oil palm, it was found that enrichment with high levels of CO_2 has enhanced the leaf gas exchange of oil palm seedlings. The upregulation of photosynthetic rate may be due to increased leaf intercellular CO_2 concentration (Ci) that could also be related to increase in the thickness of leaves achieved under elevated CO_2 that contains high photosynthetic protein especially Rubisco (Ramachandra and Das 1986). The latter might also upregulate several enzymes related to carbon metabolism which simultaneously increase the Ci (Anderson 2000). In oil palm, high photosynthetic rate under elevated CO_2 could be due to more efficient net assimilation resulting from extra carbon fixation as exhibited by high Ci which is related to increased thickness of mesophyll layer, mainly due to increased palisade layer (Lawson et al. 2002).

In oil palm, the increase in photosynthesis might be justified by reduced light compensation point and dark respiration rate in the plant enriched with high CO_2 having enhanced apparent quantum yield and net assimilation rates (Kubiske and Pregitzer 1996). Despite increases in A and WUE, stomatal conductance of oil palm seedlings enriched with high levels of CO_2 decreased, as levels of CO_2. The decreased g_s simultaneously reduced the transpiration rate of plants under elevated CO_2 (Raschke 1986; Lodge et al. 2001; Lawson et al. 2002). Nitrogen content was influenced by the application of CO_2 levels to the seedlings. As the levels of CO_2 increased from 400 to 1,200 μmol mol^{-1}, nitrogen content was found to be reduced. The decrease in nitrogen content with increasing CO_2 levels has been reported by Porteaus et al. (2009). Several researchers attributed this phenomenon to decreasing uptake of nitrogen as transpiration rate was decreased due to reduction in stomata conductance under elevated CO_2 level (Conroy and Hawking 1993).

18.2.4 Pests and Diseases

Pests associated with specific crops may become more active under climate change (Coakley et al. 1999; IPCC 1996). Increased use of agricultural chemicals might become necessary, with consequent health, ecological, and economic costs (Rosenzweig et al. 2002a, b; Chen and McCarl

2001). Warmer temperatures may increase the development rates of some insect species, resulting in shortened times between generations and improved capacity for overwintering at northern latitudes. Further some insect populations may become established early in the growing season, during more vulnerable stages of the crop.

Warmer winter temperatures favor the increase in insect pest populations of oil palm. Overall temperature increases may also influence crop pathogen interactions by speeding up the pathogen growth rates, which increases reproductive generations per cycle, decreasing pathogen mortality rate due to warmer temperatures and by making the crop more vulnerable. Incidence of slug caterpillar in oil palm occurs during the summer months (April–May) in Andhra Pradesh, causing severe defoliation and reduction in yields. Incidence of bunch end rot is noticed during summer, wherein a group of distal fruits abort and are delineated from the basal portion of the bunch and 25–50% of the bunch gets affected. Correlation studies of weather parameters with the manifestation of spear rot disease in oil palm indicated a positive correlation of the disease with rainfall and number of rainy days and a negative relationship with average maximum temperature. Higher incidences of spear rot and bud rot diseases were noticed during rainy seasons. Elevated CO_2 indirectly modify insect–crop relations, via an increase in the C–N ratio in crop leaves, which renders them less nutritious per unit mass and would stimulate increased feeding by insects, leading to more plant damage (Lincoln et al. 1984; Salt et al. 1995).

18.3 Climate Change Impacts: Case Studies

Research on the *El Niño*–Southern Oscillation (ENSO) phenomenon has found that this ocean–atmosphere interaction especially in tropical Pacific Ocean dramatically affects weather and climate in the nations bordering Pacific Ocean and even beyond the subtropics. *El Niño* and *La Niña* phases do occur in these regions due to this phenomenon. The Southern Oscillation Index (SOI) is calculated from monthly or seasonal fluctuations in the air pressure difference between Tahiti and Darwin, and this numerical index is a good approximation of the occurrences of *El Niño* and *La Niña*. SOI values exceeding (−10) for several months generally indicate *El Niño* episodes, while SOI of more than (+10) show *La Niña* events (Samah and Sootyanarayana 2000).

18.3.1 Malaysia

Oil palm is a tree crop, and the roots extend deep into the soil and cover a wide area laterally. In addition, it is well documented that the effect of soil moisture deficit is only revealed 1.5–2 years later on oil palm bunch yield by increasing the production of male inflorescences compared to that of female flowers and by inducing abortion of female inflorescences during their period of maximum growth. FFB residuals plotted against average derived Southern Oscillation Index (SOI) showed a random scatter indicating no relationship between oil palm FFB yield and the assumed climate water availability parameter SOI. The derived SOI indicator was imperfect as it did not match the particular yield sensitive development phase of oil palm (Samah and Sootyanarayana 2000).

The 1981 and 1982 episodes of *El Niño* in Malaysia have resulted in 21% loss, the following year, while the 1990 episode had resulted in a more than 10% yield loss in 1991. The most severe *El Niño* episode of 1997 resulted in yield losses of 16.8%. The resultant water stress, especially during 1997, resulted in a significant reduction in productivity (CGPRT Monograph 2002). Oil extraction rates have experienced varied fortunes due to climate change. In both Indonesia and Malaysia, the worst effects of the *El Niño* reduced the OER in the late 1990s (Carter and Jackson 2007).

La Niña causes increased rainfall in northern Australia, Kalimantan, Indonesia, Papua New Guinea, and Malaysia. Increased rainfall is good for oil palm, which requires at least 2,000 mm of rain a year or more. This would help oil palm trees to recover from the after effects of *El Niño*. In fact, palm oil yields across Indonesia and

Malaysia started to recover, and production started to equal pre-*El Niño* levels. However, excessive rainfall is detrimental as yield is significantly affected. It was reported that flood-related problems in southern Malaysia had decreased the production of crude palm oil to 1.1 million metric ton or 26.3% during December 2006 (Greenall 2008).

18.3.2 Columbia

Due to its perennial nature, oil palm reacts negatively to unfavorable climatic conditions, viz., evapotranspiration is reduced, leaf opening is delayed (first stage), and sexual differentiation is affected (reducing the proportion of female productive vs. male nonproductive inflorescences). Water is fundamental in sexual differentiation, development of central arrows, flowering, and fruit production. More female inflorescences are found when the level of solar radiation is good. If any of these requirements are not met, the final production will be reduced during the first and consecutive harvests. Higher (lower) production was observed during and 6 months after periods of enhanced (reduced) precipitation in oil palm due to the fruit's accelerated (slowed) maturity (final stages). The same pattern was also observed in the period that corresponds to the initial stages of bunch formation (27 months) and central arrow development (17 months), when the water supply in the soil became the most important factor for future production (Cadena et al. 2006).

In general, the region of Tumaco had a suitable HAI since rainfall exceeded evapotranspiration. However, for the years with higher drought probabilities (*La Niña* events), reduced precipitation in the second semester is accentuated. This deficit could be reflected in the next 3 year's production, which corresponds to bunch development. High (low) HAI values become important to the plant 17–27 months later, owing to a preservation (consumption) of rainwater in soils. This is the period in which the central arrow develops, which means that inadequate water supply during this stage will be reflected in low production two years later. Climatic variations had important effects on oil palm production during different stages of the plant's life cycle. The 1997/1998 *El Niño* was highly favorable to oil palm production in all its development stages, having a maximum cross-correlation with production 2.6 years later (2000). The 1999/2000 *La Niña* had the highest negative impact since it occurred during the second semester of the year, causing droughts and reduced oil palm production during 2002 (Cadena et al. 2006).

18.3.3 India

Most of the oil palm-growing areas lie on the eastern and western coast of India. The mean temperature in coastal Andhra Pradesh (East Coast) and Kerala (West Coast) from 1901 to 2006 reveals an increase of 0.8°C and 1.2°C, respectively. The rainfall pattern from 1901 to 2006 shows an increase of 3.47% in the coastal Andhra Pradesh and 2.58% in Kerala. A perusal of the mean temperature in Andhra Pradesh indicates that there has been an increase of 1.6°C and 1.59°C in East and West Godavari districts, respectively, during 1971–2002 (Suresh and Kochu Babu 2010).

As crop models for oil palm are lacking under Indian conditions, correlations between FFB yields, and mean temperatures were worked out in the major oil palm-growing areas—East and West Godavari districts of Andhra Pradesh and OPIL plantations of Kerala. The mean temperatures and FFB yields of oil palm plantations in East Godavari district of Andhra Pradesh from 1998 to 2007 indicate that there has been an increase of 0.3°C in temperature during the above period. FFB yields did not vary among the different years, which indicate that mean air temperature had little effect on it. As oil palm plantations in Andhra Pradesh are mostly grown under irrigated conditions, management of nutrients and water would be the key factors in determining FFB yields (Suresh and Arulraj 2010).

A perusal of the mean temperatures and FFB yields of oil palm plantations in West Godavari district of Andhra Pradesh from 1999 to 2007 indicates that there has been an increase of

0.61 °C during the period. There has been a weak correlation between mean temperature and FFB yields. The increase in FFB yields over the years is mainly due to better management of water and nutrients. Correlation studies between FFB yields of East and West Godavari districts of Andhra Pradesh and their mean temperature (1998–2007) also indicate a weak relationship between them. The effect of mean temperature on the average FFB yields (1988–2005) of oil palm plantations (OPIL) of Kerala under rainfed conditions indicates that the relationship between them is very weak and a probable dependence on rainfall (Suresh and Kochu Babu 2010; Suresh and Arulraj 2010).

18.4 Adaptation Strategies

Cumulative past emissions have already committed the planet to a certain degree of climate change and associated impacts over the coming decades regardless of what local, regional, and global actions are taken and which policy recommendations are adopted to slow anthropogenic emissions of greenhouse gases and thus to reduce the magnitude of climate change. Climate actions taken today will determine how such changes will further evolve in the second half of this century. Recent observations of increased frequency of climate extremes worldwide, as well as shifts in eco-zones, might be an indication of global warming-related changes already under way (IPCC 2001a, b, c; Milly et al. 2002; Root et al. 2003). Sectoral adaptation is thus very likely in the future and integral to the study of climate change impacts on agriculture (IPCC 2001a, b, c; Smit and Skinner 2002; Smith et al. 2003).

Adaptation in agriculture is the norm rather than the exception. In addition to changes driven by several socioeconomic factors like policy frameworks and market conditions, farmers always had to adapt to the vagaries of weather on weekly, seasonal, annual, and longer timescales. The real issue in the coming decades will be the degree and nature of climate change compared to the adaptation capacity of farmers. If future changes are relatively smooth, farmers may successfully adapt to changing climates in the coming decades by applying a variety of agronomic techniques that already work well under current climates, such as adjusting the timing of planting and harvesting operations, substituting cultivars, and modifying or changing their cropping systems. Adaptation strategies will vary with agricultural systems, location, and scenarios of climate change considered.

18.4.1 Development/Shifting to Heat/Drought-Tolerant Hybrids

The selection of crops and cultivars with tolerance to abiotic stresses like drought, flooding, high salt content in soil, high temperature, pest, and disease resistance allows utilizing genetic variability in new crop varieties if national programs have the required capacity and long-term support to use them. To strengthen capacity of developing countries to implement plant breeding programs and develop locally adapted crops, FAO and other like-minded institutions have started Global Initiative on Plant Breeding Capacity Build initiative during June 2007 to implementation of Article 6 of the Treaty for supporting the development of capacities in plant breeding. It emphasizes conserving diversity, adapting varieties to diverse and marginal conditions, broadening the genetic base of crops, promoting locally adapted crops and underutilized species, and reviewing breeding strategies and regulations concerning variety release and seed distribution. FAO's work on adapted crops includes decision-support tools such as Ecocrop to identify alternative crops for specific ecologies.

18.4.2 Soil and Land Management

Adaptation to climate change for oil palm cropping systems requires a higher resilience against both excess of water (due to high-intensity rainfall) and lack of water (due to extended drought periods). A key element to respond to both problems is soil organic matter, which improves and stabilizes the soil structure so that the soils can absorb higher amounts of water without much surface runoff, which could result in soil erosion and flooding. Soil organic matter also improves the water absorption capacity of the soil during extended drought.

Low tillage and maintenance of permanent soil cover are to be promoted that can increase soil organic matter and reduce impacts from flooding, erosion, drought, heavy rain, and winds. Among areas which can be explored are conservation agriculture, organic agriculture, and risk-coping production systems. Intensive soil tillage reduces soil organic matter through aerobic mineralization and low tillage, and the maintenance of a permanent soil cover through crop residues or cover crops increases soil organic matter. Conservation agriculture and organic agriculture are promising adaptation options in oil palm for their ability to increase soil organic carbon, reduce inorganic fertilizers use, and reduce on-farm energy costs.

18.5 Mitigation Strategies

While oil palm production stands to be affected by projected climate change, it has been a source of greenhouse gases to the atmosphere, thus itself contributing to climate change. Clearing and management of land for food and livestock production over the past century was responsible for cumulative carbon emissions of about 150 gt C, compared to 300 gt C from fossil fuels (LULUCF 2000). At present, agriculture and associated land use changes emit about a quarter of the carbon dioxide (through deforestation and soil organic carbon depletion, machine and fertilizer use), half of the methane (via livestock and rice cultivation), and three-fourths of the nitrous oxide (through fertilizer applications and manure management) annually released into the atmosphere by human activities. Modifying current management of agricultural systems could therefore greatly help to mitigate global anthropogenic emissions. Many see such activities in the coming decades as new forms of environmental services to be provided to society by farmers, who in turn could additionally increase their income by selling carbon-emission credits to other carbon-emitting sectors.

18.5.1 Carbon Sequestration

Absorbing CO_2 from air and injecting it into the biomass is the only practical way of removing large volumes of greenhouse gases from the atmosphere. The processes that remove carbon from the biosphere are termed as carbon sequestration. Standing crops like oil palm serve as net accumulators of carbon, thereby offsetting carbon emissions, arising mainly from fossil fuel consumption. With respect to the net fixation or sequestration of carbon, there are possibilities of financial gains by developing countries like India through carbon trading under the terms of Kyoto Protocol. With more than 2.0 lakh hectares of oil palm plantations in India, oil palm seems to be a prime candidate for storing carbon and is also eligible for Clean Development Mechanism (CDM). To qualify as a CDM project, projects must be large and are expected to save millions of tons of greenhouse gases per year. Landmass of about 1,000 ha would need to be assembled for a project. In India, where land holdings are small, a number of plantations would need to be assembled to make it large.

Global carbon storage by oil palm is estimated at 74 Mt C year^{-1} for 12 m ha due to its high annual biomass productivity (50 t DM ha^{-1} year^{-1}) compared to that of coconut (28 t DM ha^{-1} year^{-1}). The amount of carbon sequestered by eleven-year-old oil palm hybrids under irrigated conditions ranged between 17.98 and 35.44 t C ha^{-1} with Papua New Guinea and Ivory Coast hybrids sequestering the highest and lowest carbon contents, respectively. Among the Palode hybrids, the carbon sequestered ranged from 20.26 (P12×313) to 26.05 t C ha^{-1} (P12×266). The carbon sequestered by the ASD Costa Rican hybrids was between 20.54 (ASD Deli×Ghana) and 35.44 t C ha^{-1} (ASD Deli×Ekona). The two Ivory Coast hybrids sequestered carbon between 17.98 and 28.73 t C ha^{-1} (Suresh and Kochu Babu 2008). Another study under irrigated conditions indicated that the carbon contents in the different fronds of a mature palm ranged from 0.413 to 1.314 kg. The carbon contents were low in the younger leaves and did not show any pattern among the middle and lower whorls (Suresh et al. 2008).

18.5.2 Zero Burning

Zero burning involves chipping or stacking the material cleared from a site being prepared for oil palm cultivation between the palm rows and leaving it to decay. This technique mitigates carbon dioxide emissions released from burning vegetation to clear land; however, it should be mentioned that unless a significant portion of the biomass from land clearing is used to manufacture wood products with a long useful life (instead of simply decaying), mechanical land clearing methods will only have a short-term effect on carbon emissions. Zero burning is now a well-established policy adopted by the majority of reputable estate companies to clear their land in Indonesia. Nevertheless, there remains a clear gap between stated company policies of zero burning and the interpretation of middle management on the ground and contractors engaged to clear land on behalf of oil palm companies (Sargeant 2001). Satellite imagery continues to prove that large-scale estates use fire to clear land. Estate companies still continue to use fire to clear land because it is easier to flick a match than to undertake manual land clearing. Many companies also continue to use fire rather than zero burning because it is thought to be a cheaper method of clearing land at the onset. This was confirmed by Guyon and Simorangkir (2002) who undertook extensive economic analysis on the costs and benefits of zero burning versus burning in commercial oil palm plantations.

18.5.3 Improve Water Management in Existing Oil Palm Plantations

Appropriate drainage system must be designed to remove excessive water in heavy soils but maintain the water table at a depth of 0.5–0.7 m from the soil surface to prevent excessively rapid depletion of the soil layer in existing oil palm plantations. A good drainage system will not only retard oxidation but also improve the yields and performance of the palms. If the drainage system is not good, palms tend to fall over and stem becomes bent. This results in an uneven canopy and reduced yield. It also makes harvesting and other field operations difficult (Kee et al. 2003).

18.5.4 Reduce Chemical Inputs to Reduce Other Greenhouse Gas Emissions

Chemical inputs, such as fertilizers, pesticides, and herbicides, release a host of greenhouse gases (carbon dioxide, nitrous oxide, and methane) into the atmosphere. It is important to consider the emissions of other greenhouse gases resulting from chemical inputs applied to oil palm plantations as the global community ultimately aims to identify strategies that can mitigate global warming. Oil palm is one of the largest consumers of inorganic fertilizer nutrients in Southeast Asia (Hardter and Fairhurst 2003). A typical oil palm plantation planted on mineral soils requires around 1,114 kg/ha of nutrient inputs over the first 5 years of planting. The most relevant nutrient input from a climate point of view is nitrogen. A typical oil palm plantation planted on both mineral and peat soils requires around 354 kg/ha of nitrogen over the first five years. This is usually applied with the use of a number of nitrogen-based fertilizers—NPK (ammonium nitrate), ammonium sulfate, and urea. In addition to this, pesticides and insecticides are also used liberally in oil palm plantations to control fungal diseases, weeds, and other pests commonly found in oil palm plantations (rhinoceros beetle). All these pests and diseases are more prevalent in oil palm plantations that use zero burning rather than fire to clear land. In the short term, zero burning can also require higher fertilizer requirements during the early years (0–2) because fire is an efficient means to convert nutrients contained in the standing biomass into minerals. However, mechanical land clearing may result in lower fertilizer application because the nutrients from decaying wood debris left after zero burning are released very slowly into the soil (Guyon and Simorangkir 2002).

Integrated pest management may be practiced, which involves the intelligent use of cultural, biological, and physical methods as needed to help minimize the requirement for pesticides. For instance, the rhinoceros beetle can be contained using a combination of cropping practices (pulverization, shredding the vegetation debris, and covering it with leguminous cover crops) or with biological controls, such as pheromone traps.

Integrated Pest Management practices are improving all the time but are currently considered to be more expensive than traditional pest management methods that utilize pesticides. Nevertheless, managing pests and diseases solely through heavy use of pesticides can potentially have significant environmental costs, including the runoff of pesticides into watercourses and the incidental killing of nontarget species.

Composting of Empty Fruit Bunches (EFB) and Palm Oil Mill Effluent (POME) enables the mills to achieve zero waste management while at the same time producing organic compost could successfully substitute chemical fertilizer (partially) in the plantations, enabling substantial savings and a sustainable business model. Biomass usage for energy production would displace fossil fuel-based energy in mills. Palm oil can be used either as palm biodiesel or burning palm oil directly as biofuel to replace fossil fuel so as to reduce carbon dioxide generation. The oil palm biomass is normally used as fuels for boilers to generate power.

18.6 Future Research Strategies

As oil palm has been introduced into India in the late eighties and the establishment of Directorate of Oil Palm Research only during 1995, research on oil palm on these aspects is very scanty, and hence, there is urgent need to focus more on the impact of climate change on the basic physiological aspects of the crop. The specific research priorities for this crop are as follows:

- To phenotype drought, salinity, and high temperature tolerance traits in oil palm tenera hybrids (indigenous and exotic) along with interspecific hybrids, dura and pisifera parents using phenomics platform.
- To quantify CO_2 flux, energy budget, and water transfer within an oil palm plantation using eddy covariance studies. There is an urgent need to collect available data on soil and carbon content in oil palm plantations and for possible precursor situations before establishment and understand the sequestration of carbon in soil and plants with careful attention to the Kyoto protocol for getting carbon permits. Studies on carbon sequestration and quantification of carbon flow and budget in oil palm agroecosystem will definitely help in this regard.
- To understand seasonal and annual variations in vegetative and reproductive growth, phenology, and yield components in response to climatic variables. Oil palm is highly sensitive to drought and is strongly affected by climatic anomalies such as *El Niño* in Southeast Asia. Intra- and interannual yield variations are very high and are difficult to interpret as physiological causes for general seasonal variation are largely unknown. Annual FFB production is continuous but generally shows marked seasonal peaks which cannot be explained either by carbon assimilation or by phenology. Very little information is known about endogenous or environmental control of periodic events in oil palm. The effect of climatic variability on yield components is complex due to longer developmental duration of female inflorescences and larger number of inflorescences having different developmental stage on the plant at a given point of time. The effect of drought on yield components occurs with long time lags as drought-sensitive processes like sex determination and abortion take place months or years before maturity of a given bunch. Relationship between environmental variables and vegetative and reproductive growth parameters can be worked out along with time lags. The results generated can be used to predict them with models.
- To assess and quantify impact of CO_2 and temperature in oil palm using CO_2 enrichment studies. A better understanding of the effects of elevated CO_2 and changes in soil water content on gas exchange processes and plant water relations could help in knowing its capacity to withstand drought. Experiments can be planned to understand the effect of elevated CO_2 on growth and various physiological processes in oil palm. Experiments can be undertaken to investigate effect of different CO_2 concentrations on seedling growth, leaf gas exchange characteristics, and nutrient status in oil palm hybrids belonging to different sources.

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