EFFECTS OF HIGH CARBON DIOXIDE CONCENTRATION ON OIL PALM GROWTH AND DEVELOPMENT

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DEDICATION

For my beloved parents, Hjh Norizan Abdul Samat and Hj Shahabuddin Md Noor,

my darling husband, Raja Shafiq Mukri Raja Hasnan,

my daughters, Raja Ayra Raja Shafiq Mukri and

Raja Adeena Raja Shafiq Mukri

and my youngest sister, Nur Athira Syafiqah Shahabuddin,

Million thanks for your unlimited prayers, encouragement, understanding and endless love.

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ABSTRACT

The current atmospheric CO_2 level is increasing annually and may affect plant growth, physiology and productivity. A CO_2 enrichment study on oil palm clone P164 using Open Top Chamber (OTC) technique was conducted to evaluate the effects on oil palm growth, physiology, bunch production and oil quality. The palms were grown in OTC with two types of CO_2 levels; 600 ppm (CO_2-enriched) and ambient CO_2 level (control) and planted in the field under normal conditions (absolute control). After six years of observation, CO_2-enriched palms showed a higher biomass percentage of 22.6% to 23.7% compared to control and absolute control palms. The increase in biomass was contributed by rachis length and trunk height with a reading of 689.63 ± 7.70 cm and 201.25 ± 10.18 cm respectively. This positive growth can be attributed to higher photosynthetic rate of 23.51 ± 0.57 $\mu molm^{-2}s^{-1}$ and affecting the water use efficiency of 5.33 ± 0.10 $\mu molmol^{-1}$ CO_2. Control palms showed the highest bunch weight (kg), meanwhile absolute control palms showed the highest fruit to bunch ratio (%) over five-year period. However, there was no significant difference in fatty acid compositions (FAC), iodine value and carotene content extracted from fruit bunches of all treatments. Under high CO_2 level, clonal palm leaves had reduced percentage of nitrogen (N), phosphorous (P) and potassium (K). Enhanced photosynthetic rate due to high CO_2 level markedly increased clonal palm growth and biomass. Valuable information of this study may be beneficial for the oil palm industry to develop suitable mitigation strategies in the future.

ABSTRAK

Paras gas CO_2 semasa semakin meningkat setiap tahun dan boleh mempengaruhi pertumbuhan, fisiologi dan produktiviti tumbuhan. Kajian pengayaan gas CO_2 yang menggunakan teknik 'Open Top Chamber' (OTC) telah dijalankan untuk menilai kesan terhadap pertumbuhan, fisiologi, hasil tandan dan kualiti minyak pokok sawit klon P164. Pokok sawit ditanam di dalam OTC dengan dua jenis paras CO_2; 600 ppm (diperkayakan) dan CO_2 persekitaran (kawalan) dan ditanam di ladang biasa (kawalan sepenuhnya). Selepas enam tahun pemerhatian, pokok sawit yang diperkayakan CO_2 menunjukkan peratusan biojisim yang lebih tinggi sebanyak 22.6% hingga 23.7% berbanding pokok kawalan dan kawalan sepenuhnya. Peningkatan biojisim disumbangkan oleh panjang rakis dan ketinggian batang dengan bacaan masing-masing 689.63 ± 7.70 cm dan 201.25 ± 10.18 cm. Pertumbuhan yang positif ini disebabkan oleh kadar fotosintesis yang lebih tinggi iaitu 23.51 ± 0.57 $\mu molm^{-2}s^{-1}$ dan mempengaruhi kecekapan penggunaan air iaitu sebanyak 5.33 ± 0.10 $\mu molmol^{-1}$ CO_2. Pokok kawalan menunjukkan jumlah berat tandan tertinggi (kg), sementara pokok kawalan sepenuhnya menunjukkan nisbah buah per tandan (%) yang lebih tinggi dalam tempoh lima tahun. Walau bagaimanapun, tidak ada perbezaan signifikan dalam komposisi asid lemak (FAC), nilai iodin dan kandungan karotena yang diekstrak daripada tandan buah bagi semua rawatan. Dalam paras CO_2 yang tinggi, daun klon sawit telah menunjukkan pengurangan kandungan nitrogen (N), fosforus (P) dan kalium (K). Kadar fotosintesis yang dipertingkatkan disebabkan oleh aras gas CO_2 yang tinggi meningkatkan pertumbuhan dan biojisim klon sawit. Maklumat daripada hasil kajian ini mungkin penting untuk strategi mitigasi bagi industri sawit negara pada masa akan datang.

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LIST OF SYMBOLS AND ABBREVIATIONS

%	-	percent
$\mu mol\ m^{-2}s^{-1}$	-	micro mole per meter square per second
$\mu mol\ mol^{-1}$	-	micro mole carbon dioxide per mole air
B_2O_3	-	boron trioxide
C	-	carbon
C_3	-	C_3 photosynthesis
C_4	-	C_4 photosynthesis
cm	-	centimeter
CO_2	-	carbon dioxide gas
g	-	gram
g_s	-	stomatal conductance
h	-	height
H_2O	-	water
K_2O	-	potassium oxide
kg	-	kilogram
kg/m^3	-	kilogram per meter cubic
kPa	-	kilopascal
m	-	meter
MgO	-	magnesium oxide
mm	-	milimeter
$molm^{-2}s^{-1}$	-	mole per meter square per second
$mmolm^{-2}s^{-1}$	-	milimole per meter square per second
N_2	-	nitrogen gas
O_2	-	oxygen gas

^{o}C	-	degree Celcius
$P_2 O_5$	-	phosphorus pentoxide
ppm	-	parts per million
r	-	radius
SeO_2	-	selenium dioxide gas
vol	-	volume
Π	-	Pi (3.142)
2-OG	-	oxoglutarate

AcCoA	-	acetyl coenzyme A
ADB	-	Asian Development Bank
ATP	-	adenosine triphosphate
CAM	-	crassulacean acid metabolism
Cc	-	Calvin cycle
CHOs	-	carbohydrates
CPO	-	crude palm oil
EPA	-	Environmental Protection Agency
ETC	-	electron transfer chain
F/B	-	fruit to bunch
FACE	-	Free-air CO_2 enrichment
Fd	-	ferrodoxin
FNR	-	ferredoxin NADP+ oxireductase
IPCC	-	Intergovernmental Panel on Climate Change
L	-	liter
LAI	-	leaf area index
LEF	-	linear electron flux
LHCs	-	light harvesting complexes
MPOB	-	Malaysian Palm Oil Board
MPOC	-	Malaysian Palm Oil Council
N	-	nitrogen
NADPH	-	nicotinamide adenine dinucleotide phosphate
NEP	-	national economy policy
NIFOR	-	Nigerian Institute for Oil Palm Research

O/B	-	oil to bunch
OAA	-	oxaloacetate
OEC	-	oxygen evolving complex
OTC	-	open top chamber
P	-	phosphorus
PAR	-	photosynthetically active radiation
PC	-	plastocyanin
PEP	-	phosphoenolpyruvate
PMF	-	proton motive force
PORIM	-	Palm Oil Research Institute Malaysia
PPFD	-	photosynthetic photon flux density
PQ	-	plastoquinone
PS	-	photosystem
PSII	-	photosystem II
Pyr	-	pyruvate
RL	-	rachis length
RuBP	-	ribulose biphosphate
SLA	-	specific leaf area
SPAD	-	soil-plant analysis development
TD	-	trunk diameter
TH	-	trunk height
TLA	-	true leaf area
TP	-	triosephosphate
UV	-	ultraviolet
VPD	-	vapour pressure deficit
YAP	-	years after planting

LIST OF PUBLICATIONS

Proceedings / Scientific Journals:

i. Nur Amanina Shahabuddin, Mohd Haniff Harun, Mohd Roslan Md Noor, and Md Hasnudin Md Yunos. (2011). Vegetative growth of photosynthesis of oil palm under elevated carbon dioxide. *Proceeding of Agriculture, Biotechnology and Sustainability Conference, PIPOC 2011*, 15-17 November 2011, Kuala Lumpur.

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CHAPTER 1

INTRODUCTION

1.1 Background

Carbon dioxide (CO_2) is the main greenhouse gas that has been increasing in the atmosphere due to anthropogenic activities since the industrial revolution (Australian Department of the Environment, 2007). The contributors are burning of fossil fuel (coal, oil and natural gas) for energy in transportation and machinery, open burning as well as deforestation. These activities release more CO_2 to the atmosphere and influence the forest as a natural sink, consequently modifying the natural carbon cycle process (Pidwirny, 2006). Future climate scenario predicts rising CO_2 level for the next coming decades, contributing to a warmer climate, influencing rainfall patterns, reducing ice and snow cover, raising sea level and increasing sea acidity. Since 1970 to 2004, its annual emission increased by about 80% and it is projected to continue to increase as much as 500 – 1000 ppm by 2100 (IPCC, 2007). Over half of the global carbon uptake is by plants as CO_2 serves as substrates for photosynthesis (Bowes, 1991).

Rising CO_2 level markedly affects plant growth, physiology and chemistry (Ziska, 2008). In plant metabolism, CO_2 is broken down into smaller carbon molecules chemically. Glucose is used for respiration process, releasing energy to power up metabolic activities. Photosynthesis process which assimilates carbon, hydrogen and oxygen into organic molecules produces about 96% of the total dry mass of a plant (Marschner, 1995). Since the main components of photosynthesis process are CO_2, water and light energy, increasing CO_2 availability may affect plant growth and photosynthesis. The direct physiological effects of enriched CO_2 atmospheres for plant species are becoming increasingly well-documented (Curtis and Wang, 1998). The fertilising effect of elevated CO_2 may give impact to crop productivity and agro-ecosystems (Goudriaan and Unsworth, 1990). Under higher CO_2 concentration, the photosynthetic pathway plays an important role in influencing plant growth and yield. Different plant species respond differently to elevated CO_2 levels, including the C_3 plants. Some examples of C_3 plants are root and tuber crops (cassava, sweet potato, potato, sugar beet and yam), nuts, vegetables, fibre crops, evergreen trees and shrubs of the tropics, subtropics and the Mediterranean, temperate evergreen conifers, deciduous trees and shrubs and weedy plants (Prasad and Allen, 2004; Bareja, 2013).

Oil palm (*Elaeis guineensis* Jacq.) is a perennial crop and classified as a C_3 plant (Corley and Tinker, 2003). It is grown expansively in the tropical regions such as Indonesia, Malaysia, Thailand, West Africa and South America. As a perennial crop, it starts yielding fresh fruit bunches at three years after planting to produce oil palm products mainly involved in the food, oleochemical, and biofuel industries (Barcelos *et al*., 2015). This most efficient oil-bearing crop was introduced to Malaysia in the early 1870s and the cultivation increased rapidly in 1960s under the government's agricultural diversification program. It is currently the fourth largest contributor to Malaysia's economy and one of the main driving forces for the nation's agro-industry (Ferdous Alam *et al*., 2015).

The oil palm industry is the most important commodity in Malaysia as the second largest producer and exporter in the world (Choo, 2012). Malaysia produced 11% of the world's oils and fats (MPOC, 2012). Being a C_3 plant, oil palm can use high CO_2 level better than C_4 plants. A study has proven that oil palm seedlings can increase photosynthetic rate and water use efficiency by one and five-fold under high CO_2 condition (Ibrahim *et al*., 2010). In Asian and Pacific counties, the agriculture sector is important since 2.2 billion people rely on it for their living (ADB, 2009). However, CO_2 enrichment studies on tropical plants particularly the technology and techniques are less characterised (Hawa, 2004). Hence, it is important to recognise how increasing CO_2 will impact on crop productivity and food supply in tropical regions especially in Asia. Rising atmospheric CO_2 concentration could have far-reaching implications on oil palm growth, bunch production and oil quality in the future. Information on the effects of elevated CO_2 to oil palm performance and yield is still insufficient and worth exploring.

1.2 Research objectives

This study was conducted with the following objectives:

(i) to identify the effects of high CO_2 level on oil palm growth and physiology.
(ii) to evaluate oil palm bunch production and oil quality in rising CO_2 condition.
(iii) to determine nutrient concentration in oil palm leaves under high CO_2 environment.

1.3 Scope of study and limitations

This study was focused on the effects of elevated CO_2 on oil palm growth, development and yield. The palms were grown in an Open Top Chamber (OTC) structure with elevated CO_2 level condition. The duration of this study was from year 1 to 6 after the nursery planting. Morphological attributes (leaflet number, length and width, petiole width and thickness, and rachis length) and physiological activities (photosynthetic rate, stomatal conductance, transpiration rate and instantaneous water use efficiency) measurements were recorded at six-month intervals.

Flower census was conducted every two months in order to obtain the oil palm sex ratio and to forecast yield. When male and female inflorescences reach the maturity stage, they are ready for anthesis and within five months, the oil palm bunch will reach ripeness stage (Corley *et al.*, 1995). Yield record and bunch quality components (bunch weight, fruit to bunch ratio, and oil to bunch ratio) in response to CO_2-enriched conditions were conducted after each fresh fruit bunch was harvested at two rounds per month. Harvesting interval might be between ten to 16 days using minimum ripeness standard (Gan *et al*., 1994). It is important to investigate nutrient uptake by oil palm when grown in high CO_2 concentration. Annual average values of all parameters mentioned were reported based on oil palm years after planting (YAP).

Although this study has reached its aims, there were some unavoidable limitations. First, because of the budget constraint and the high cost of OTC structure, this study had a small number of sample size: four OTCs each had a palm. Each OTC was designed for an oil palm until it reached the eight years of age and it had the maximum canopy coverage. The OTC dimension was 10 m high and 9 m diameter, indicating the average palm height and a standard planting distance in a normal field condition. Second, there was lack of oil palm pollinating weevils, *Elaeidobius kamerunicus* populations in the OTC. The OTC structure had restricted the entrance of weevils from the outside as shown during the lowest total bunch weight from four to six YAP. Assisted pollination was carried out to introduce more weevil populations in the OTC. Efficient weevil pollination increased yield as a result of increasing bunch weight and fruit to bunch ratio (Haniff and Roslan, 2002).

1.4 Significance of study

Having discussed the problem statement, the research questions that led this research were as follows: (1) Did elevated atmospheric CO_2 positively affect oil palm growth, development and yield? (2) What was the suitable technique to study oil palm response to rising CO_2?

It was hypothesised that oil palms grown in elevated CO_2 level had enhanced growth and biomass due to increased photosynthesis and water use efficiency. Oil palm that responded markedly upon CO_2 enrichment had improved yield and might have the potential to decrease CO_2 emissions in the next decade. There have been few studies on the effects of CO_2 on oil palm growth and photosynthesis (Henson and Haniff, 2005). Henson (1991a) investigated carboxylation efficiency and oil palm leaflets compensation points under ambient CO_2 and below ambient CO_2 concentrations. The leaflet photosynthetic rate increased linearly when exposed to increased CO_2 concentrations from 100 to 500 µmol mol^{-1} at high (>1100 µmol m^{-2}s^{-1}) photosynthetically active radiation (PAR) (Dufrene and Saugier, 1993). Young oil palm seedling growth and photosynthetic rates were enhanced when exposed to 550 and 700 µmol mol^{-1} CO_2 in OTCs (Awang and Furukawa, 1994).

However, information on CO_2 enrichment technique and plant response in tropical regions is still insufficient. Studies on the CO_2 enrichment technique in the tropics are also scarce (Hawa, 2004). Therefore, it is important to establish CO_2 enrichment technology for oil palm especially for large oil palm producers. Valuable information on the responses of oil palm to increasing CO_2 will be provided and beneficial for the oil palm industry to develop suitable mitigation strategies.

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