LAND SUITABILITY EVALUATION AND SOIL MANAGEMENT PRACTICES FOR OIL PALM YIELD IMPROVEMENT IN LAKE VICTORIA REGION UGANDA

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FACULTY OF SUSTAINABLE AGRICULTURE
UNIVERSITI MALAYSIA SABAH

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DECLARATION

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ABSTRACT

Topography, rainfall, and soil physicochemical properties influence the performance of oil palm progenies and the subsequent soil management practices in a plantation. This has a significant impact on the productivity of oil palm plantations. Therefore, this study conducted in a mature oil palm plantation in Uganda from 2016 to 2021 enabled an understanding of the effect of the mentioned factors on the oil palm yield. The initial approach was a semi-detailed soil survey followed by land evaluation using the matching technique and the subsequent creation of maps for the various soils and their management groups. The study was done using a factorial randomized complete block design. The two factors in this study were two oil palm progenies and six soil management groups. Each of these factor combinations was replicated three times. The replicates represented the blocks of the experiment. This resulted in 36 experimental plots. Site-specific agronomic practices involving the use of organic and inorganic fertilizers, soil erosion control, and soil moisture conservation were done starting in the year 2017 until 2021. Rainfall data was obtained for ten years (2012-2021). Fresh fruit bunch yield data was recorded for the six years (2016-2021). This yield data was subjected to analysis of variance using SPSS software. Furthermore, the benefit-cost ratio was used to evaluate the financial performance of the Uganda and Malaysia plantations. The results showed that slope classes ranged from level (0-2°) to somewhat steep (20-25°), and the rolling (6-12°) covered 69.7% of the plantation. For soil, the sandy clay loam texture dominated (40%), cation exchange capacity ranged from low (2.10 cmol kg^{-1}) to high (16.20 cmol kg^{-1}), soil pH was mostly acidic (3.5-4.4) and organic carbon content ranged from low (1.17%) to high (4.05%). The mean annual rainfall (1,604 mm) was moderate with more than four dry months. There was a significant interaction ($P<0.05$) between the two progenies and the soil management groups for mean fresh fruit bunch yields, for the years 2016 and 2021. In the year 2021, the highest mean yields were obtained from the two largest soil management groups B (20.21 t ha^{-1}), and A (19.46 t ha^{-1}). The lowest yields were obtained from soil management groups Ait (18.03 t ha^{-1}) and Bi (17.79 t ha^{-1}). There was a significant difference ($P<0.05$) in fresh fruit bunch yield between the two progenies. Deli x Ghana produced a yield of 19.98 t ha^{-1} which was 13% or 2.38 t ha^{-1} higher than Guthrie D x P which produced 17.60 t ha^{-1}. There was a significant difference ($P<0.05$) in yields between the years 2016 and 2021. The mean yield in 2021 was 21.46 t ha^{-1}, which was 33%, or 5.34 t ha^{-1} higher than that of 2016, which yielded only 16.12 t ha^{-1}. Benefit-cost ratio analysis results for the Uganda and Malaysia plantations were 3.20 and 2.19 respectively. Both investments are profitable but returns from the Uganda plantation were 32% more than that of the Malaysia plantation. Therefore, the site-specific agronomic practices that were implemented involving the use of both organic and inorganic fertilizers, soil erosion control, and soil moisture conservation increased the yields of the Uganda plantation. Besides cheap labour availability, the increase in yield of the Uganda plantation reduced the fresh fruit bunch and crude palm oil production costs per tonne. Therefore, implementation of standard site-specific agronomic practices to mitigate low soil fertility, soil erosion, and moisture deficit can lead to high and sustainable oil palm yields of the Uganda oil palm plantation. These practices should be maintained or improved for higher yields hence profitability of the plantation.

ABSTRAK

PENILAIAN KESESUAIAN TANAH DAN AMALAN PENGURUSAN TANAH BAGI MEMPERBAIK HASIL KELAPA SAWIT DI TASIK VICTORIA WILAYAH UGANDA

Topografi, taburan hujan dan sifat fizikokimia tanah mempengaruhi prestasi progeni kelapa sawit selain amalan pengurusan tanah di ladang. Ini memberi impak yang besar kepada produktiviti ladang kelapa sawit. Oleh itu, kajian yang dijalankan di ladang kelapa sawit matang di Uganda dari 2016 hingga 2021 membolehkan pemahaman tentang kesan faktor-faktor yang disebutkan ke atas hasil kelapa sawit. Pendekatan awal adalah tinjauan tanah separa terperinci diikuti dengan penilaian tanah menggunakan teknik padanan dan penciptaan peta untuk pelbagai tanah dan kumpulan pengurusannya. Kajian dilakukan dengan menggunakan reka bentuk faktorial blok rawak lengkap. Dua faktor dalam kajian ini ialah dua progeni kelapa sawit dan enam kumpulan pengurusan tanah. Setiap kombinasi faktor ini telah direplikasi tiga kali. Replika mewakili blok eksperimen. Ini menghasilkan 36 plot eksperimen. Amalan agronomik khusus tapak melibatkan penggunaan baja organik dan bukan organik, kawalan hakisan tanah dan pemuliharaan lembapan tanah telah dilakukan bermula pada tahun 2017 hingga 2021. Data taburan hujan diperoleh untuk tempoh sepuluh tahun (2012-2021). Data hasil tandan buah segar direkodkan untuk enam tahun (2016-2021). Data hasil ini tertakluk kepada analisis varians menggunakan perisian SPSS. Tambahan pula, nisbah kos faedah digunakan untuk menilai prestasi kewangan ladang Uganda dan Malaysia. Keputusan menunjukkan bahawa kelas cerun berjulat dari landai (0-2°) hingga agak curam (20-25°), dan beralun (6-12°) meliputi 69.7% daripada ladang.Bagi tanah, lom lempung didominasi tanah lempung berpasir (40%), kapasiti pertukaran kation berjulat dari rendah (2.10 cmol kg^{-1}) hingga tinggi (16.20 cmol kg^{-1}), pH tanah kebanyakannya adalah berasid (3.5-4.4) dan kandungan karbon organik berjulat daripada rendah (1.17%) kepada tinggi (4.05%). Purata hujan tahunan (1,604 mm) adalah sederhana dengan lebih daripada empat bulan kering. Terdapat interaksi yang signifikan ($P<0.05$) antara kedua-dua progeni dan kumpulan pengurusan tanah bagi min hasil tandan buah segar, bagi tahun 2016 dan 2021. Pada tahun 2021, purata hasil tertinggi diperolehi daripada kumpulan pengurusan tanah B (20.21 t ha^{-1}), dan A (19.46 t ha^{-1}). Hasil yang paling rendah diperolehi daripada kumpulan pengurusan tanah Ait (18.03 t ha^{-1}) dan Bi (17.79 t ha^{-1}). Terdapat perbezaan yang signifikan ($P<0.05$) dalam hasil tandan buah segar antara kedua-dua progeni. Deli x Ghana menghasilkan hasil sebanyak 19.98 t ha^{-1} iaitu 13% atau 2.38 t ha^{-1} lebih tinggi daripada Guthrie D x P yang menghasilkan 17.60 t ha^{-1}. Terdapat perbezaan yang signifikan ($P<0.05$) dalam hasil antara tahun 2016 dan 2021. Purata hasil pada tahun 2021 ialah 21.46 t ha^{-1}, iaitu 33%, atau 5.34 t ha^{-1} lebih tinggi daripada 2016, yang menghasilkan hanya 16.12 t ha^{-1}. Keputusan analisis nisbah faedah-kos untuk ladang Uganda dan Malaysia ialah masing-masing 3.20 dan 2.19. Kedua-dua pelaburan itu menguntungkan tetapi pulangan daripada ladang Uganda adalah 32% lebih tinggi daripada ladang Malaysia. Oleh itu, amalan agronomi yang dilaksanakan melibatkan penggunaan kedua-dua baja organik dan bukan organik, kawalan hakisan tanah dan pemuliharaan kelembapan tanah meningkatkan hasil ladang Uganda. Di samping ketersediaan buruh yang murah, peningkatan hasil ladang Uganda mengurangkan kos tandan buah segar dan kos pengeluaran minyak sawit mentah bagi setiap tan. Oleh itu, pelaksanaan amalan agronomik khusus tapak untuk memperbaiki kesuburan tanah yang rendah, hakisan tanah dan defisit lembapan boleh membawa kepada hasil kelapa sawit yang tinggi dan mampan bagi ladang kelapa sawit Uganda. Amalan-amalan ini harus dikekalkan atau ditambah baik untuk hasil yang lebih tinggi seterusnya keuntungan ladang.

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LIST OF ABBREVIATIONS

ABW	-	Average Bunch Weight
ACET	-	African Center for Economic Transformations
AFP	-	Average Fertilizer Productivity
BN	-	Bunch Number
BRD	-	Bunch Rot Disease
BCR	-	Benefit Cost Ratio
CEC	-	Cation Exchange Capacity
CPO	-	Crude Palm Oil
DWFI	-	Daugherty Water for Food Institute
EFB	-	Empty Fruit Bunch
FAO	-	Food and Agriculture Organization
FFB	-	Fresh Fruit Bunch
GML	-	Ground Magnesium Limestone
GIS	-	Geographical Information System
GPS	-	Geographical Positioning System
GYP	-	Genetic Yield Potential
IFAD	-	International Fund for Agriculture
IPNI	-	International Plant Nutrition Institute
KDLG	-	Kalangala District Local Government
LCC	-	Leguminous Cover Crop
LSD	-	Least Significant Difference
LSI	-	Land Suitability Index
MAAIF	-	Ministry of Agriculture Animal Industry and Fisheries
NEMA	-	National Environmental Management Authority
NIFOR	-	International Institute for Oil Palm Research
NOPP	-	National Oil Palm Project
OC	-	Organic Carbon
OM	-	Organic Matter
OER	-	Oil Extraction Rate
OPF	-	Oil Palm Frond
OPUL	-	Oil Palm Uganda Limited
PAR	-	Photosynthetically Active Radiation
PIND	-	Partnership Initiatives in Niger Delta
RCBD	-	Random Complete Block Design
RSPO	-	Round Table on Sustainable Palm Oil

RUE	-	Radiation Use Efficiency
SMG	-	Soil Management Group
SPSS	-	Statistical Package for the Social Sciences
SSA	-	Sub-Saharan Africa
SYP	-	Site Yield Potential
TEP	-	Total Economic Potential
USD	-	United States Dollar
VODP	-	Vegetable Oil Development Project

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CHAPTER 1

INTRODUCTION

1.1 Background of the Study

Palm oil is increasingly needed around the world for home cooking, biofuel, and as a raw material for many manufacturing industries (Qaim *et al.*, 2020). In 2018, there were over 7 billion people worldwide; by 2050, that figure is expected to reach over 9.8 billion (Thatcher *et al.*, 2018). However, the production of palm oil in 2018 was estimated at 72 million tonnes (USDA, 2021). Projections indicate that by 2050, 313 to 679 million tonnes of palm oil will be needed (Xin *et al*., 2022). The oil palm industry is a backbone to the economy of several tropical countries, including Malaysia and Indonesia (Ashton-Butt *et al*., 2018; Liew *et al*., 2015; Potter, 2015; Qaim *et al*., 2020).

Governments in Sub-Saharan Africa are increasingly becoming more interested in commercial oil palm investment as a result of the rising demand for palm oil globally and the successful economic growth in the key participating countries (Ayompe *et al*., 2021; Bakoumé *et al*., 2017; Ofosu-Budu & Sarpong, 2011; Ordway *et al*., 2019). In Uganda, oil palm development started recently in 2005, to promote domestic vegetable oil production for import substitution and poverty alleviation in rural areas (Ssemmanda & Opige, 2018; Taylor *et al*., 2019).

Except for Uganda, where increased climatic suitability is predicted to increase until 2100, other African countries would be less favorable for oil palm cultivation (Murphy et al., 2021). Therefore, Uganda has a potential to develop 69% of its arable land for oil palm cultivation to reach 5.1 million hectares (Pirker et al., 2016).

Despite oil palm being the top oil crop in the world (Rieger, 2006), soil fertility limits its productivity (Obi & Udoh, 2012). This justifies the importance of pedological information to guide soil fertility management because without it the oil palm yield performance is constrained (Kome *et al.*, 2020; Obi & Udoh, 2012). Soil fertility relates to the ability of soil to sustain plant growth by providing essential plant nutrients and favorable chemical, physical, and biological characteristics as a habitat for plant growth and the maintenance of ecosystem services (FAO, 2019).Managing soil fertility employs techniques that maximize and sustain the efficiency of the agronomic use of nutrients and improving crop productivity (Grant, 2017). Consequently, the goal of oil palm plantations is to sustain good soil fertility, particularly by using site-specific management techniques (Arshad, 2014; Paramananthan, 2000 a, b).

This process begins with land suitability evaluation, an economically effective agricultural tool used in land development planning to gather site-specific land resource data and assess the crop and suitability for various land use types (Malik *et al.*, 2021). Land suitability evaluation studies the physical characteristics of soil, topography and climate upon which site-specific soil management practices are decided for sustainable crop land productivity and site yield potential (FAO, 2006; Paramananthan, 2015). From several land evaluation studies, 95% of the soils in Southeast are acidic with low fertility, and extremely weathered alike to those in tropical Africa but achieved high FFB yields (Corley & Tinker, 2016 ; Imogie, *et al.*, 2008; Mutert, 1999; Shamshuddin *et al.*, 2015; Shamshuddin & Wan, 2011).

High sustainable oil palm fresh fruit bunch (FFB) yields of more than 25 t ha-1 are achievable in Southeast Asia because of the widely implemented site-specific soil management practices and favorable agro-climatic conditions (Pirker *et al.*, 2016; Pupathy & Sundian, 2020; Shevade & Loboda, 2019) . Furthermore, besides the above, planting of improved genotypes increases oil palm productivity (Soh, 2012). Site-specificity in oil palm plantation management also respects the fact that the productivity of various oil palm progenies significantly differ in response to changes in climate, topography and agronomic practices (Behera *et al.*, 2022; Dassou *et al.*, 2021; Rafii *et al.*, 2012).

Therefore, developing plantations in the tropics requires slightly a higher capital investment to overcome constraints of low intrinsic soil fertility thereby also necessitating a thorough assessment of the economy and labor factors (Paramananthan, 2013; Paramananthan *et al.*, 2000).

1.2 Problem Statement

The estimated population of Uganda in 2050 is 86.5 million, up from 40 million in 2018 (UBOS, 2016). However, domestic plantations in Uganda generated only about 40,000 metric tonnes of palm oil in 2018, less the country's yearly requirement of 120,000 metric tonnes (Manishimwe, 2018; Muwanga, 2019). With Uganda's intentions to make biodiesel from palm oil, this is particularly concerning (Bakoumé *et al.*, 2017). There are 6,500 ha reported to belong to the large scale plantation (MAAIF, 2018). The fresh fruit bunches (FFB) and crude palm oil (CPO) outputs from this plantation increased from 23,423 and 4,692 tonnes in 2010 to 150, 543 and 37,363 tonnes respectively in 2018 (MAAIF/VODP, 2019).

A quick analysis from the recent data, the Uganda nucleus plantation average FFB yield from 2017 to 2021 was 17.39 t ha^{-1} (IFAD/NOPP, 2021). Studies from some commercial oil palm plantations of Sub-Saharan Africa report that inadequate soil management and poor plantation establishment results into low fresh fruit bunch yields ranging between 15.4 t ha^{-1} to 16 t ha^{-1} (Bakoumé *et al.*, 2017; Rhebergen *et al.*, 2018). In contrast, the agricultural investment in Sub-Saharan Africa was reported unprofitable due to limited research on the impact of soil variability on crop yields (Rushemuka *et al.*, 2014). Thus several plantations of Africa solely rely on fertilizer usage as a solution to poor soil fertility (Dea & Scoones, 2003). In Uganda, there is scarcity of detailed published information about land suitability evaluation (National Land Use Policy, 2007). In other words, the basic soil studies conducted in Uganda in the years 1958–1960 generalized the properties of distinct soils, meaning that they are inaccurate to serve as a guide for modern farming.

This implies that the reality of the diversity in soil fertility was not fully captured. Semi-detailed soil surveys were encouraged in Uganda to map and classify the soil according to the current internationally recognized classification systems and also guide site specific soil fertility management (National Land Use Policy, 2007).

It is also important to update the rainfall data of oil palm growing regions to provide information about drought periods so that soil moisture conservation and fertility management are effectively implemented (Nda *et al.*, 2018). This is because climate change has affected tropical regions signaled by the more frequent and prolonged drought (Tamara, 2021). Oil palm productivity studies based on large commercial scale plantations are considered reliable because site specific parameters are determined in commercial blocks (Kee *et al.*, 1994). However, extensive research works on oil palm in Uganda targeted smallholder fields to establish fertilizer requirements, cropping systems, cultivar selection, weeding, and harvesting methods (Ddamulira *et al.*, 2020; Ysselmuiden, 1993).

Therefore, the limited research and documentation about the variability of soils utilized for oil palm growing in Uganda could probably be responsible for failure of the large-scale commercial plantation to produce satisfactory fresh fruit bunches (FFB) yields per unit land area. This is because there are no studied relationships between soil management & FFB yields in Uganda. Furthermore, there is so far no conducted studies about the cost implication of soil management in Uganda oil palm large-scale plantations. In this research oil palm fields within the commercial oil palm plantation, where soils are spatially related within each cluster but independent between clusters were clustered.

Thus, each cluster of soils is unique and is implemented with site-specific soil management practices, which is technically known as soil management Grouping. As a result, the impact of the soil management practices and rainfall on the FFB productivity with the associated financial consequences can be thoroughly investigated, comprehended, and recorded. Therefore, from this study the Uganda oil palm industry can benefit the National food security and economy through increased domestic crude palm oil (CPO) production hereafter reducing the country's vegetable oil deficit.

1.3 Objectives of the Study

This study was conducted to; -

i. Evaluate the land of an oil palm plantation in Uganda for soil management grouping.
ii. Evaluate the yield response of two oil palm progenies grown on six site-specifically managed soil groups.
iii. Evaluate the costs and returns of two oil palm plantations located on Bugala Island Uganda and Sabah State Malaysia.

1.4 Hypothesis of the Study

H0: The soil properties of Uganda oil palm plantation are similar thus classifiable under only one soil management group (SMG)

H1: There is a dissimilarity in the soil properties of Uganda oil palm plantation thus classifiable under various soil management groups (SMGs)

H0: The annual fresh fruit bunch (FFB) yield across various soil management groups planted with different progenies in Uganda plantation is the same.

H1: The annual fresh fruit bunch (FFB) yield across various soil management groups planted with different oil palm progenies in Uganda plantation is different.

H0: The costs and returns of two oil palm plantations located in Uganda and Malaysia under the same management are similar.

H1: The costs and returns of two oil palm plantations located in Uganda and Malaysia-Sabah respectively under the same management are not the same.

CHAPTER 2

LITERATURE REVIEW

2.1 The Oil Palm

The African oil palm *(Elaeis guineensis Jacq.*) is an outstanding oil palm species grown for large scale commercial vegetable oil production (Barcelos *et al.*, 2015; Corley & Tinker, 2016). It belongs to *Arecoideae* sub-family and the tribe *Cocoseae* (Dransfield *et al.*, 2005). Its native range extends from Guinea to Angola (Corley & Tinker, 2016). *Elaeis guineensis Jacq* is the highest oil-producing crop and the most important source of vegetable oil among the 17 major-oil and fat producing crops traded internationally (Swaray *et al.*, 2020). Most commercial plantations are grown with intraspecific *dura* x *pisifera* (DXP) hybrid seeds owing to their high oil productivity (Almeida *et al.*, 2020; Corley & Tinker, 2003). Both parents of the resultant *Tenera* hybrid possess visible differences in the hard shell (Low *et al.,* 2008; Singh *et al.*, 2020). Because of the good combining ability from the bred *Tenera* seeds, this contributed to increase of palm oil yields by 30% (Kushairi *et al.*, 2010; Ooi *et al.*, 2016) . Their high productivity is further attributed to their adaptability and stability characteristics (Shukla *et al.*, 2015).

2.2 The Global Fresh Fruit Bunch and Palm Oil Production

Palm oil is consumed in over 150 of the world's 195 countries (ACET, 2014) . It is grown in 43 tropical countries across Asia, Africa, and Latin America (Dislich *et al.*, 2017; Qaim et al., 2020; Sheil, 2009). However, Malaysia and Indonesia generate more than 80% of the world's palm oil (Bazmi *et al.*, 2011; Ritchie & Roser, 2021).

As shown in Figure 2.1 below, the two major producing countries accounted for 83% of the global palm oil production in 2021. Indonesia and Malaysia accounted for 58% and 25% respectively of the produced palm oil. Thailand, Colombia, and Nigeria are also among the top five producers of palm oil in the world.

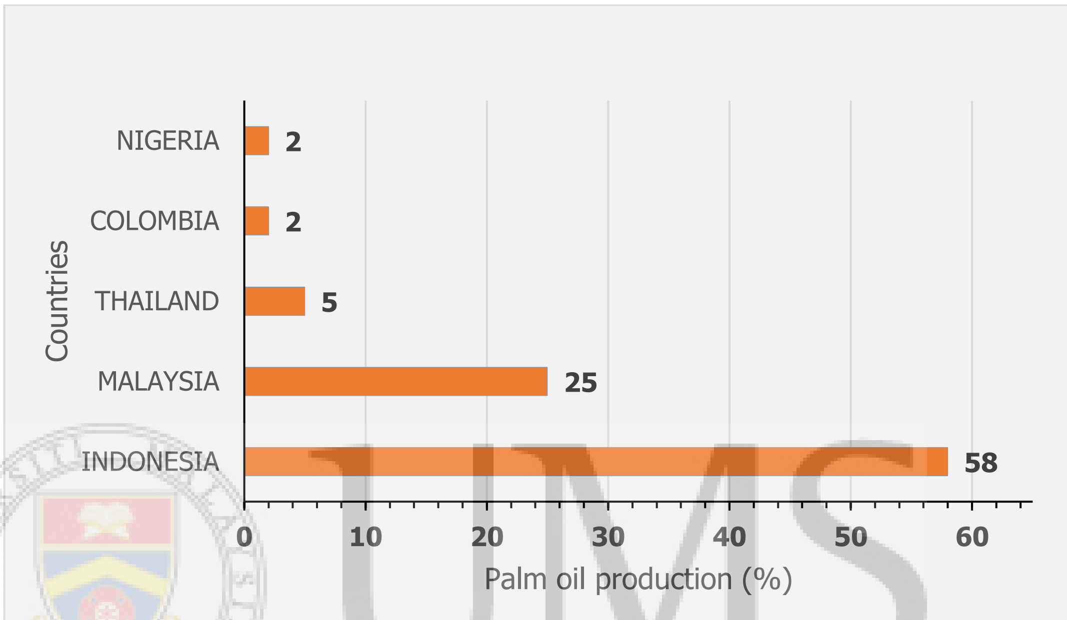

Figure 2.1 : Graph Showing Top Five Palm Oil Producing Countries in the world.
Source : Palm Oil 2021 World Production (USDA, 2021)

The fresh fruit bunch (FFB) productivity of mature commercial oil palm plantations in Malaysia and Indonesia is reported to be above 27 t ha^{-1} and 6 t ha^{-1} palm oil (Donough *et al.*, 2009). Reports from Indonesian plantations show that potential commercial FFB yields are in a range of 27-38 t ha^{-1} (Afriyanti *et al.*, 2016). Furthermore, evaluations of the production performance of the Dura x Pisifera progenies grown on coastal and inland estates of Malaysia produced FFB yields ranging between 28-30 and 22-28 tha^{-1} respectively (Noh *et al.*, 2012).

Also, yields of 17 t ha^{-1} were deemed low in research on mature oil palm plantations in Southeast Asia compared to harvested high yields of 20.5 t ha^{-1} per year (Butler *et al.*, 2009). This justified the intrinsic capability of the oil palm to yield highly when grown in a suitable monoculture environment without drought.

Besides the climatic factors , management practices in Southeast Asia plantations significantly contribute to good oil palm yield production (Mutsaers, 2019; Woittiez *et al*., 2017) . Latin America is the second largest palm oil producing continent represented by five countries in the 10 global giants (Castellanos-Navarrete *et al*., 2021; Tras, 2022). It accounts for 6% of the global palm oil production (Gromko, 2015). Guatemala has the highest palm oil productivity of 5 t ha^{-1} whereas Mexico, Peru and Ecuador have the lowest between 2.6 to 2.5 t ha^{-1} far lower than the 3.6 t ha^{-1} oil yields from the Southeast Asian plantations in the year 2021 (Kuepper *et al*., 2021). Bud rot disease (BRD) is among the major problems faced by oil palm plantations in South America where it affects the fruit bunch yield and oil quality (European Commission. Directorate General for the Environment. *et al*., 2018; Tupaz-Vera *et al*., 2021).

The Sub-Saharan Africa (SSA) is ranked third and is globally recognized as the least palm oil producer (Uckert *et al*., 2015). In 2013, the entire African continent relied on imported edible oil from Southeast Asia (Bakoumé *et al*., 2017). Nevertheless, Nigeria is globally ranked the fifth (Murphy *et al*., 2021) and the largest palm oil producer in Sub-Saharan Africa having contributed to 1.2 million tonnes of palm oil out of the 2.8 million tonnes produced on the continent in the year 2019 (Iskahar, 2022). Also, except for Côte d'Ivoire that was recognized as the net palm oil exporter in the year 2019, low palm oil production is observed from other large producing African countries such as Cameroon and Ghana (Iskahar, 2022).

Basing on the continent's annual demand for palm oil of 7.3 million tonnes reveals a 4.5 million tonnes deficit to feed the projected population of more than one billion people (Iskahar, 2021). Furthermore, as a remedy to bridge the existing deficit Sub-Saharan Africa is importing palm oil from Southeast Asian countries. Nucleus plantations have been established but palm oil yields rarely exceed 2.5 t ha^{-1} which is far below the 4 and 4.5 t ha^{-1} achievable in Malaysia and Indonesia respectively (Mutsaers, 2019).