Journal of Agricultural Science; Vol. 16, No. 4; 2024
ISSN 1916-9752 E-ISSN 1916-9760
Published by Canadian Center of Science and Education

Agronomic Suitability for Oil Palm Growing in Uganda

Gabriel Ddamulira[1], Alex Asiimwe[1], Fred Masika[2], Moses Amugoli[1], Gerald Ddumba[1] & Mcebisi Maphosa[3]

[1] National Crops Resources Research Institute, Kampala, Uganda

[2] Muni University, Arua, Uganda

[3] Lupane State University, Bulawayo, Zimbabwe

Correspondence: Gabriel Ddamulira, Horticulture and Oil Palm Programme, National Crops Resources Research Institute, P.O. Box 7084, Kampala, Uganda. Tel: 256-774-229-749. E-mail: gdamuli@gmail.com

Received: November 1, 2023 Accepted: January 7, 2024 Online Published: March 15, 2024

doi:10.5539/jas.v16n4p14 URL: https://doi.org/10.5539/jas.v16n4p14

Abstract

The ever-increasing demand for vegetable oils with its products in Uganda, calls for new areas to be put under oil palm cultivation. A study was conducted to investigate the agronomic suitability of oil palm cultivation in six areas located within a 30 km radius off-shore, on the island and more than 30 km radius off-shore on the mainland. The experiment was superimposed on 45 × 45 m plots in oil palm adaptive trial plantations established in 2008 in Bugiri, Mayuge, Buvuma, Mukono, Kibaale and Masaka districts. The experiment was laid out in a randomized complete block design with three replications. Data on number of oil palm bunches, bunch weight and yield was collected while climatic data (rainfall, temperature, relative humidity and radiation) was acquired from meteorological stations near the experimental locations. Rainfall data analyzed and dry season duration suggested that Mayuge, Masaka, Mukono, Buvuma and Kibaale were moderately favorable for oil palm growing, while temperature and radiation data indicated that all study locations were suitable for oil palm growing. Furthermore, based on relative humidity, Buvuma, Mayuge and Bugiri were suitable for oil palm cultivation but Kibaale, Masaka and Mukono were moderately suitable. Oil palm yield varied significantly ($P < 0.05$) across locations. The yield was much greater in Mukono (17.7 t/ha/yr) followed by Buvuma (13.8 t/ha/yr) and Kibaale (12.9 t/ha/yr) then Mayuge (10.7 t/ha/yr), Bugiri (10.2 t/ha/yr), and Masaka (10.3 t/ha/yr). The significantly high yield of oil palm observed in Mukono was attributed to the high rainfall received in this location. Based on research findings, Mukono, Masaka, Bugiri, Buvuma, Kibaale and areas within the 30 km radius of Lake Victoria are agronomically suitable for oil palm cultivation.

Keywords: oil palm, growth, study areas, suitability

1. Introduction

Oil palm, *Elaeis guineensis* is widely cultivated in South-East Asia, Latin America and Africa (Euler et al., 2016). As of 2018, worldwide palm oil usage had surpassed 30% of global vegetable oil consumption making palm oil the most consumed vegetable oil (USDA, 2019). Palm oil like in other countries is a stable supply of much-needed vegetable oils in Uganda. This is because oil palm produces the most oil per unit area of any vegetable oil crop (Pegah & Wataru, 2020). Based on its importance in the vegetable oil sector, the Ugandan government introduced oil palm production in 2001 with the goal of increasing local vegetable oil production, improving access to affordable vegetable oil products for Ugandan consumers, and providing income sources for smallholder farmers (IFAD, 2012).

The first commercial oil palm growing in Uganda started in 2005 on Bugala Island in Kalangala district (MAAIF, 2016). This initiative was a government intervention (import substitution), as a remedy to reduce on foreign exchange spent on importing crude palm oil into Uganda (NOPP, 2020). Currently, 11,484 ha of oil palm cultivated on Bugala island yields about 40,000 metric tonnes of crude palm oil annually (Ddamulira et al., 2020). This is still far below the current country demand of 410,000 metric tonnes of crude palm oil. Oil palm expansion on Bugala Island is no longer possible because the island reached its biological capacity in terms of oil palm trees that could be sustainably planted without negatively impacting its ecosystem (NOPP, 2018). Hence the need for oil palms expansion to be relocated to other parts of the country.

Because of the land scarcity on Bugala Island for future oil palm growth and expansion, it is necessary to assess new sites outside the island (off-shore) where oil palm could favorably be grown. Other islands, such as Buvuma, and places within a 30-kilometer radius of Lake Victoria (Bugiri, Mayuge, Masaka, and Mukono) are also prospective areas with potential for oil palm cultivation due to the lake's effect on their climatic conditions. However, the potential for such probable oil palm growing sites had yet to be established (Ddamulira et al., 2020). Furthermore, distant off-shore places like Kibaale, whose climate is similarly impacted by Lake Albert, were recommended as potential oil palm-producing areas; however, no research had been conducted to validate their agronomic appropriateness.

However, a number of agronomic and climatic factors affect successful oil palm cultivation (Fleiss et al., 2017; Masika et al., 2020), and these variables vary depending on regions (Carr, 2011; Henson & Harun, 2005). The main aim of this study was to determine the effect of agronomic and climatic factors on oil palm yield performance in Bugiri, Mayuge, Buvuma, Masaka, Mukono, and Kibaale so that expansion decisions could be made by policy makers. It was further hypothesized that oil palm yield did not significantly differ in different study locations and the agronomical feasibility of these regions for future oil palm production in Uganda was confirmed through experimental assessments.

2. Materials and Methods

2.1 Study Sites

The experiment was carried out at six locations: Mayuge, Bugiri, Masaka, Buvuma, Mukono, and Kibaale. These locations represented three micro-ecologies: 1) Off-shore lakes within a 30 km radius of Lake Victoria (Mukono, Mayuge, Bugiri, Masaka); 2) Lake Victoria islands (Buvuma); and 3) Off-shore locations more than 30 km from the Lake (Kibaale). The climatic conditions for each location are shown in Table 1. However, briefly, all the areas receive a bi-modal rainfall pattern with the first rains between March to June, and the second rains between August and November. However, Buvuma, one of the island research locations receives moderate rainfall even during dry season.

2.2 Experimental Design

The oil palm plantations in Bugiri, Mayuge, Masaka, Mukono, Buvuma, and Kibaale where the experiment was superimposed were established in 2008 as research trials. The trials were planted with hybrids (TAN AVROS: a cross between the Dura and Pisifera lines) from Nigeria that are cold-resistant. The trials at six locations were planted in triangular manner at spacing of 9 × 9 m distance. For this study experimental plots measuring 45 × 45 m were superimposed on existing oil palm plantations in six locations in random complete block design with three replications.

2.3 Agro-meteorological Assessment

The assessment of the climatic parameters for the growth of oil palm was done using secondary weather data. From 2017 to 2021, the research team collected the required climatic and yield data for the study sites. The climatic data especially annual temperature, rainfall, relative humidity, and radiation for all the study sites were downloaded from the knowledge database (http://www.worldclimate.com) and these were validated with data collected from national meteorological stations that where within 50 km radius of the study sites. The data downloaded was compared with established climatic data regimes which have been established as optimum for oil palm growth and development.

2.4 Soil Nutrient Analysis

In each field of the six study sites, 10 soil samples were randomly taken at a depth of 0-60 cm and used to determine the nutrient quality of soil in the experiment sites. Five samples were created by combining the samples from the same field and then taken to the laboratory at the department of soil science, Makerere University for analysis. In order to prepare the composite soil samples for routine measurement of texture, pH, organic matter (OM), total nitrogen (N), exchangeable calcium (Ca), magnesium (Mg), and potassium (K), accessible phosphorus (P), and nitrates in triplicates, the soil samples were air-dried, crushed, and passed through a 2-mm sieve. The soil pH was tested using the glass electrode method with a soil to water ratio of 1:2.5, and the texture was evaluated using the hydrometer method. Using the micro-Kjeldahl technique, soil total nitrogen was calculated (Anderson & Ingram, 1993). Olsen's technique (Olsen & Sommers, 1982) was used to extract the soil's readily accessible Phosphorus. A flame photometer was used to measure potassium, while an atomic spectrophotometer was used to measure exchangeable calcium and magnesium (Okalebo, 2002).

2.5 Oil Palm Field Management

When the field was established in 2008, NPK fertilizer in the ratios 13-8-27+0.5 Boron 250 g was administered to each hole where the trees were planted. Fertilizer was not used during the research period (2017-2021) to determine the minimal yield potential that may be produced from a farmer's low input cropping system (a system characterized by little or no fertilizer use). Weed management was mostly accomplished by ring weeding around the tree at three-month intervals, and pruning was performed concurrently with fruit harvesting.

2.6 Bunch Quantity and Weight Determination and Analyses

Data on yield parameters such as fruit bunch quantity and bunch weight were collected throughout a five-year period from 2017 to 2021. These parameters were collected by harvesting bunches every 10 days, and the number of fresh fruit bunches were tallied and weighted individually using a weighing scale. The cumulative yield of each month was used to calculate the yield per year. A homogeneity test was done according to Cochran's test to analyze the difference in data obtained across years and the variations between years. The yield parameters were then subjected to an analysis of variance (ANOVA) using Genstat version 11 (Payne, 2011). Significant means were distinguished using Least Significant Difference (LSD) at $\alpha < 0.05$.

3. Results

3.1 Climatic Factors Affecting Oil Palm Suitability

Based on the rainfall figures observed in the six sites (Table 1) only Mukono was moderately suitable for oil palm growth. However in terms of duration of dry season all the study sites (Mayuge, Masaka, Mukono, Buvuma, and Kibaale) were moderately suitable for oil palm growing (Table 2). Over the period the study was conducted temperatures at all sites were suitable for oil palm growing except Kibaale which was highly suitable (Table 1). Based on relative humidity, Buvuma, Mayuge, Bugiri and Mukono were suitable for oil palm growing whereas, Kibaale, and Masaka were moderately suitable (Tables 1 and 2). On the other hand, results on daily sun radiation showed that all the six sites were ideal for oil palm growing.

Table 1. Mean meteorological data for six study sites collected during the experimentation period

Study sites	Average rainfall (mm/year)	Temperature		Relative humidity (%)	Duration of dry season (month)	Solar radiation (MJ/M^3)
		T_{max} °C	T_{min} °C			
Mukono	1528	26	19	76	3	14.3
Buvuma	1363	26	19	78	2	14.9
Masaka	1383	25	17	72	3	15.7
Mayuge	1200	26	19	78	3	14.4
Bugiri	1200	26	17	81	3	14.7
Kibaale	1250	29	17	70	3	15.9

Source: Worldclimate.com (2023).

Table 2. Classification of climatic properties in relation to suitability for oil palm cultivation

Climate element	Highly suitable	Suitable	Moderately suitable	Currently unsuitable	Permanently unsuitable
Annual (mm/year)	2000-2500	1700-2000	1400-1700	1100-1400	< 1100
Duration of dry season (months)	0	1	2-4	5-6	> 6
Mean annual temperature (°C)	25-29	23-26	20-23	17-20	> 20
Relative humidity (%)	80-100	75-80	70-75	60-70	> 60
Daily solar radiation (MJ/M^3)	16-17	14-16	11-14	8-11	< 8

Source: Goh (2000).

3.2 Soil Nutrient Status in the Study Areas

Analysis of soil parameters, *i.e.*, pH and exchangeable bases (calcium and magnesium) indicated acceptable levels which were above the critical values (Table 3). Results in six sites indicated that organic matter values were below the critical values except for Mukono whose organic matter was above the critical value (Table 3). The essentials nutrients (nitrogen, phosphorus, and potassium) for oil palm growth varied depending on site. The nitrogen content in Kibaale and Mukono were above the critical level while for the rest of sites nitrogen was deficient (Table 3). In all the six sites under evaluation phosphorus was deficient and for potassium only Kibaale, Buvuma and Mukono had it in sufficient levels. In terms soil texture most sites had sandy loam or sandy clay, except Masaka, which had clay loam (Table 3).

Table 3. Physical-chemical properties of soil sampled from six sites where the oil palm trials were conducted in 2019

Sites	pH	OM	N	P	K	Ca	Mg	Texture
		---------- % ---------		---------------------- mg/kg ----------------------				
Bugiri	6.4	1.50	0.16	8.7	9.2	3367.8	1543.4	Sandy clay
Buvuma	5.6	2.10	0.20	11.4	88.6	1583.7	243.2	Sandy clay
Kibaale	5.9	2.50	0.24	3.4	79.9	1638.9	585.5	Sandy clay
Masaka	6.0	2.80	0.18	6.4	39.9	1593.6	189.3	Clay loam
Mukono	5.9	3.10	0.25	10.3	79.6	1498.6	206.7	Sandy loam
Mayuge	6.2	1.80	0.19	9.1	9.8	2984.8	1734.3	Sandy clay
Critical value	**5.2***	**3.00***	**0.20***	**25***	**78.2***	**150***	**18***	Sandy loam

Note. *The values below the critical value means the soil parameter is deficient for oil palm growth (Foster, 1971).

3.2 Total Number of Fresh Fruit Bunches, Average Bunch Weight, and Yield for Five Years

During the research period, the total quantity of fresh fruit bunches, average weight, and yield per hectare per year increased in all of the study sites combined. From 2017 to 2019, the number of fruit bunches per acre increased but subsequently declined from 2020 to 2021 (Table 4). While the average bunch weight increased from 2017 to 2021. Similarly, the average yield increased from 9.8 t ha^{-1} yr^{-1} in 2017 to 15.1 t ha^{-1} yr^{-1} in 2021. These differences were statistically significant ($P > 0.05$) during the course of the five-years of experimentation (Table 4).

Table 4. Mean yield components of oil palm for five years in all the study areas

Years	Yield components		Average Yield (t/ha/yr)
	No. Fruit bunch/ha	Av. bunch weight (kg)	
2017	700a	14a	9.8a
2018	737a	16a	11.5b
2019	789a	16a	13.0c
2020	651b	21b	13.6c
2021	633b	24b	15.1d
CV (%)	15.6	19.2	11.9

Note. Yield component means followed by different letters in a column are significantly different and means followed by similar letters are not significantly different; CV: Coefficient of variation.

3.3 Number of Fresh Fruit Bunches, Average Bunch Weight, and Yield across Study Areas

The quantity of oil palm fruit bunches per hectare varied considerably ($P = 0.05$) among the research locations, with Buvuma having the fewest bunches per and Bugiri with most bunches. Although the quantity of oil palm fruit bunches did not change substantially between Mukono, Kibaale, and Buvuma, the fruit bunches acquired from the three locations differed significantly ($P = 0.05$) from those observed in Masaka, Bugiri, and Mayuge (Table 5).

Table 5. Mean yield components of oil palm acrossthe six study sites

Sites	Yield component		Average Yield (t/ha/yr)
	No. bunches/ha	Av. bunch weight (kg)	
Mayuge	673a	16a	10.7a
Bugiri	680a	15a	10.2a
Buvuma	508b	26b	13.8b
Kibaale	549b	24b	12.9b
Masaka	644a	16a	10.3a
Mukono	567b	30c	17.7c
CV (%)	17.4	20.3	13.6

The average bunch weight substantially (P = 0.05) varied across sites. Mukono had palms with the heaviest bunches, whereas oil palm trees in Bugiri and Mayuge had the lowest-weighted bunches (Table 5). Oil palm yield also varied significantly (P = 0.05) across sites with Bugiri having the lowest yield and Mukono had the highest yield (Table 5). Also palms in Buvuma and Kibaale equally yielded significantly higher than oil palm in Mayuge, Masaka, and Bugiri.

4. Discussion

Agro-climate is a fundamental resource for growing oil palm because its components such as temperature, radiation, relative humidity and rainfall determine whether an area is suitable or not suitable for oil palm growing. On a wide scale temperature and radiation of oil palm growing areas rarely change but in new areas where the crop is to be introduced it's often important to identify whether the two parameters are optimal to support oil palm growth. The study areas were found to be suitable for oil palm growing because they experienced optimal range of temperature (24-28 ^{o}C) and radiation (14-16 MJ/M^3) that Goh (2000) earlier reported as ideal ranges under which oil palm's critical growth stages such as vegetative growth, sex determination, fruit formation, and ripening mostly occur. These stages play a critical role in determination of quality and yield of oil palm (Forero et al., 2012). Since optimal temperature and solar radiation are known to be closely correlated (Haris et al., 2020) with positive effect on oil palm yield (Woittiez et al., 2017), the observed temperature and radiation partly confirmed that studied areas had potential for oil palm growing.

Relative humidity and dry season length where all study areas were appropriate to moderately favorable for oil palm growing based on Goh (2000) who recommended optimal relative humidity of and dry season period of not more than 3 months. Rainfall received in the study sites was also moderately acceptable for oil palm growing because according to Goh (2000) annual rainfall suitable for oil palm growing should be between 2000 and 2500 mm especially in Asia. However, this range depends on the region, for instance compared to Asia; Africa's oil palms can survive with significantly less rain as seen in some locations in Benin where, 1230mm of rainfall provide a respectable oil palm production output (Quencez, 1996). Similarly in Columbia, moderately suitable areas for oil palm cultivation receive 1000-1600 mm (Villalobos et al., 1992) which falls within the range the studied sites received. In East Africa, East Africa, palms have been found to grow in areas around lakes and watercourses which receive reasonable rainfall (Verheye, 2005). Relatedly, Kalangala in Uganda were oil palm is currently grown, receives rainfall within a range of 1000-1600 mm annually. Since the study sites also receive rainfall within the same range as received by Kalangala it possibly justifies why rainfall in Masaka, Mayuge, Kibaale, Bugiri Buvuma and Mukono optimally support oil palm growing in the study areas. However, for study sites with less rainfall they could be amended with irrigation or rain saving systems in order to support oil palm growth.

4.1 Oil Palm Yield Increment Based on Years

As a consequence of oil palm's physiological growth, a rise in oil palm yield and its yield components (bunch number and weight) was observed in the study. The average bunch weight increased from 14 to 24 kg in the different study areas with corresponding increases in years (2017-2021) during the study period. The increase in bunch weight is as a result number of bunches produced per palm which drops as the palm ages resulting into increase in bunch weight to Madhavi Latha et al. (2016). This fact explains our findings, which showed that bunch numbers decreased but bunch weight increased over the study period. However, the fact that oil palm trees have an economic life span of up to 25 years, beginning at the time the tree reaches maturity (at about three years) and increase up to 12th year (Tan et al., 2013), may help to explain the increase in oil palm yield over the years the study was conducted According to Corley and Gray (1976), oil palm yield peaks at roughly the 10th year and then starts to decline. However, in this study yield augmentation was seen to persist after the 10th year, indicating that different locations may have different oil palm yield peaking period.

4.2 Oil Palm Yield Increment Based on Sites

The findings showed heterogeneity in yield across different locations, which was potentially attributable to varying rainfall and nutrient status which differed throughout the research sites. Yield is important in assessing agronomic appropriateness for producing oil palm. When compared to other sites, Mukono's high yield was linked to the high rainfall totals during the study period. This supports past research showing that enough water improves photosynthesis, making photosynthates accessible for fruit growth, causing the creation of female inflorescences, and reducing abortion rates (Corley & Tinker, 2016). Furthermore, soil organic matter enhances soil organic carbon, which enhances soil quality including structure, and quality through higher retention of water and nutrients, improving oil palm production. Lal (2006) observed similar findings.

On the other hand, low nutrient (NPK) contents and organic matter content, which were below the essential levels, might be the cause of the poor yield oil palm reported in Masaka, Bugiri, and Mayuge. The availability of adequate nutrients, much beyond critical levels, for absorption by palms is necessary for the desired oil palm production. In a similar line, Goh's (2005) research showed that levels of N, P, and K below the threshold levels restrict oil palm nutrient absorption, hence lowering oil palm production. This knowledge could help to explain why poor oil palm output was recorded at sites with nutrient levels below critical limits. Oil palm plantations can be mulched with organic materials to maintain soil moisture and prevent evaporation, especially in marginal regions, to help with this and upon decomposition, nutrients are released. According to Loong et al. (1987), empty fruit bunch mulching at a rate of 30 t/ha resulted in greater vegetative development and ultimately higher yields as compared to control receiving standard estate inorganic fertilizers.

5. Conclusion

A crucial stage in ensuring the successful establishment of oil palm plantations is the agronomic suitability assessment. The sites studied are appropriate to moderately favorable for oil palm growth based on the assessment made on agro-climatic characteristics. Furthermore, it can be stated that Bugiri, Buvuma, Kibaale, Masaka, Mayuge, and Mukono are agronomically favorable for growing oil palm in Uganda based on the oil palm yield experiments done in the study sites. The confirmed areas are within Lake Victoria (Islands), a 30-kilometer radius off-shore of Lake Victoria and in Kibaale district, where the experiments were conducted. However, to ensure sustainable oil palm production, environmental impact assessments would be necessary in the confirmed sites to ensure oil palm establishment, expansion and production does not negatively impact the ecosystem.

References

Anderson, J. M., & Ingram, S. J. (1993). *Tropical soil biology and fertility: A handbook of methods*. CABI International, Wallingford, UK. https://doi.org/10.1097/00010694-199404000-00012

Corley, R. H. V., & Gray, B. S. (1976). *Oil Palm Research, Development in Crop Science I: Yield and Yield Component*. Amsterdam: Elsevier.

Corley, R. H. V., & Tinker, P. B. (2016). *The oil palm* (5th ed.). John Wiley & Sons Ltd. https://doi.org/10.1002/9781118953297

Ddamulira, G., Asiimwe, A., Masika, F., Amugoli, M., Ddumba, G., Nambuya, A., … Maphosa, M. (2020). Growth and Yield Parameters of Introduced Oil Palm Crop in Uganda. *Journal of Agricultural Science, 12*(11), 299. https://doi.org/10.5539/jas.v12n11p299

Euler, M., Hoffmann, M. P., Fathoni, Z., & Schwarze, S. (2016). Exploring Yield Gaps in Smallholder Oil Palm Production Systems in Eastern Sumatra, Indonesia. *Agricultural Systems, 146*, 111-119. https://doi.org/10.1016/j.agsy.2016.04.007

Fleiss, S., Hill, J. K., McClean, C., Lucey, J. M., & Reynolds, G. (2017). Potential impacts of climate change on oil palm cultivation. *A science-for-policy paper by the SEnSOR Programme* (pp. 1-17).

Forero, D. C., Hormaza, P., & Romero, H. M. (2012). Phenological growth stages of African oil palm (*Elaeis guineensis*). *Annals of Applied Biology, 160*(1), 56-65. https://doi.org/10.1111/j.1744-7348.2011.00520.x

Goh, K. J. (2000). Climatic requirements of the oil palm for high yields. In K. J. Goh (Ed.), *Managing oil palm for high yields: Agronomical principles*. (pp. 1-17). Malaysian Society of Science and Para Agricultural Surveys, Kuala Lumpur.

Goh, K. J. (2005). Fertilizer recommendation systems for oil palm: Estimating the fertilizer rates. In C. P. Soon & T. Y. Pau (Eds.), *Proceedings of MOSTA Best Practices Workshops: Agronomy and Crop Management, March to August 2004* (pp. 235-268). Petaling Jaya, Malaysia: Malaysian Oil Scientists' and Technologists' Association.

Harris, I., Osborn, T. J., Jones, P., & Lister, D. (2020). Version 4 of the CRU TS monthly high-resolution gridded multivariate climate dataset. *Scientific Data, 7*(1), 109. https://doi.org/10.1038/s41597-020-0453-3

Loong, S. G., Nazeeb, M., & Letchumanan, A. (1987). Optimising the use of EFB mulch on oil palms on two different soils. In H. Abdul Halim, P. S. Chew, B. J. Wood, & E. Pushparajah (Eds.), *Proc. of the 1987 Int. Oil Palm/Palm Oil Conf. on Progress and Prospects. Conference I: Agriculture. June 23-26, 1987* (pp. 605-639). PORIM, Kuala Lumpur.

MAAIF. (2016). *Agriculture Sector Strategic Plan 2015/16-2019/20*. Ministry of Agriculture, Animal Industries and Fisheries, Kampala, Republic of Uganda.

Madhavi Latha, P., Kalpana, M., & Manorama, P. (2016). Influence of plantation age on production performance of oil palm in Andhra Pradesh. *The Journal of Research ANGRAU, 44*(3&4), 98-103.

NOPP (National Oil Palm Project). (2020). *NOPP supervision report (Main report and annexes)* (Project Number 200000148). National Oil Palm Project (NOPP), Uganda.

Okalebo, J. R., Gathua, K. W., & Woomer, P. L. (2002). *Laboratory methods of soil and plant analysis: A working manual* (2nd ed.). TSBF-CIAT and SACRED Africa, Nairobi, Kenya.

Olsen, S. R., & Sommers, L. E. (1982). Determination of available phosphorus. In A. L. Page, R. H. Miller, & D.R. Keeney (Eds.), *Method of Soil Analysis* (Vol. 2). Madison, WI: American Society of Agronomy.

Pegah, H. K., & Wataru, T. (2020). Assessment of oil palm yield and biophysical suitability in Indonesia and Malaysia. *International Journal of Remote Sensing, 41*(22), 8520-8546. https://doi.org/10.1080/01431161.2020.1782503

Quencez, P. (1996). La culture du palmerahuileen Africa intertropical: Les conditions du milieu physique. *OclOl. Crps Gras Lipides, 3*, 116-118.

Tan, K. P., Kanniah, K. D., & Cracknell, A. P. (2013). Use of UK-DMC 2 and ALOS PALSAR forstudying the age of oil palm trees in southern peninsular Malaysia. *International Journal of Remote Sensing, 34*(20), 7424-7446. https://doi.org/10.1080/01431161.2013.822601

USDA (United States Department of Agricuture). (2019). *Oilseeds: World Markets and Trades*. Retrieved from https://apps.fas.usda.gov/psdonline/circulars/oilseeds.pdf

Verheye, W. (2005). *Soils, plant growth and crop production; growth and production of oil palm* (Vol. 2, p. 32). Retrieved from http://www.eolss.net/Eolss-sampleAllChapter.aspx

Villalobos, E., Umana, C. H., & Chinchilla, C. M. (1992). Estado de hidratacion de la palmaaceitera, enrespuesta a la sequiaen. *Costa Rica Oleagineux, 47*, 214-223.

Woittiez, L. S., van Wijk, M. T., Slingerland, M., van Noordwijk, M., & Giller, K. E. (2017). Yield gaps in oil palm: A quantitative review of contributing factors. *Eur J Agron., 83*, 57-77. https://doi.org/10.1016/j.eja.2016.11.002

Acknowledgments

We greatly appreciate the farmers who provided the land for the on-farm oil palm trials for this study and also the team is grateful to National Coffee Research Institute for hosting on-station oil palm research.

Authors Contributions

Dr. Gabriel Ddamulira and Dr. Fred Masika were responsible for designing the study and drafting the manuscript, Alex Assimwe, Moses Otuba and Gerald Ddumba collected the data and Dr. Mcebisi Maphosa revised the edits and all the authors read and approved the final manuscript.

Funding

This research was funded by the International Fund for Agricultural Development (IFAD) and Government of Uganda [Project Number: 2000001484].

Competing Interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Informed Consent

Obtained.

Ethics Approval

The Publication Ethics Committee of the Canadian Center of Science and Education.

The journal’s policies adhere to the Core Practices established by the Committee on Publication Ethics (COPE).

Provenance and Peer Review

Not commissioned; externally double-blind peer reviewed.

Data Availability Statement

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

Data Sharing Statement

No additional data are available.