BIODIVERSITAS
Volume 25, Number 9, September 2024
Pages: 2981-2989

ISSN: 1412-033X
E-ISSN: 2085-4722
DOI: 10.13057/biodiv/d250919

Estimating oil palm (*Elaeis guineensis*) production potential using Unmanned Aerial Vehicle

CHARLOQ[1,♥], ACHMAD SIDDIK THOHA[2], ABU YAZID[3], AGUNG MUAMMAR SIDIQ[4], OPPIE APRILIA LUBIS[5]

[1]Faculty of Agriculture, Universitas Sumatera Utara. Jl. Dr. A. Sofian No. 3, Kampus USU Padang Bulan, Medan 20155, North Sumatera, Indonesia. Tel.: +62-618-213-236, ♥email: charloq@usu.ac.id

[2]Faculty of Forestry, Universitas Sumatera Utara. Jl. Durin Tunggal, Deli Serdang 20353, North Sumatera, Indonesia

[3]Faculty of Vocational, Institut Teknologi Sawit Indonesia. Jl. William Iskandar, Medan 20226, North Sumatera, Indonesia

[4]Faculty of Agriculture, Graduate Program, Universitas Sumatera Utara. Jl. Dr. A. Sofian No. 3, Kampus USU Padang Bulan, Medan 20155, North Sumatera, Indonesia

[5]Faculty of Forestry, Graduate Program, Universitas Sumatera Utara. Jl. Durin Tunggal, Deli Serdang 20353, North Sumatera, Indonesia

Manuscript received: 23 April 2024. Revision accepted: 12 September 2024.

Abstract. *Charloq, Thoha AS, Yazid A, Sidiq AM, Lubis OA. 2024. Estimating oil palm* (Elaeis guineensis) *production potential using Unmanned Aerial Vehicle. Biodiversitas 25: 2981-2989.* The vast expanse of oil palm (*Elaeis guineensis* Jacq.) plantations utilized Unmanned Aerial Vehicle (UAV) technology, identified as a suitable tool for mapping the health condition and production potential of oil palm plants. A plant census was conducted to confirm the correct number of plants, utilizing GPS to record each plant's coordinates, assess its health status, and estimate its production potential. This study aimed to estimate oil palm production potential with maximum accuracy using drone technology over a 22.23-hectare plantation. The research method involved drone based mapping of plant numbers and health, thereby estimating the potential production of oil palm. Orthomosaic data processed using Oil Palm Analysis (OPA) software were analyzed and compared with field survey data (plant census) through the Student t test with α = 5%. In conclusion, from the study of drone/UAV technology based estimation of oil palm (*E. guineensis*) production potential in the field on an area of 22.23 ha at PT. Eastern Indonesia Bukit Maradja Estate, North Sumatra Province, Indonesia, it can be concluded that the use of drone technology for oil palm production estimation through OPA is highly effective, with no significant discrepancies between drone results and traditional field census methods. This consistency confirms that UAVs are a reliable tool for assessing the production potential of oil palm plantations.

Keywords: C/N ratio, drone multispectral imagery, *Ganoderma boninense*, oil palm health, rejuvenation phase

Abbreviations: BSR: Basal Stem Rot; GPS: Global Positioning System; OPA: Oil Palm Analysis Software; SOC: Soil Organic Carbon; UAV: Unmanned Aerial Vehicle

INTRODUCTION

Oil palm plantations (*Elaeis guineensis* Jacq.) are one of the strategic commodities driving the Indonesian national economy. However, once oil palm plants exceed 25 years of age, their production potential generally decline, marking the onset of the plant rejuvenation period, during which they are no longer commercially productive (Fosch et al. 2023; Zhao et al. 2023). Rejuvenation efforts are typically undertaken to replace old plants with new plants. The vast area of oil palm plantations in Indonesia requires precise, accurate, fast, and efficient data input, and Unmanned Aerial Vehicle (UAV) has emerged as a valuable tool in this regard.

UAVs or drones, are unmanned aircraft controlled remotely and provided with tools for higher spatial resolution mapping compared to high-medium spatial resolution satellite imagery (Zheng et al. 2021; Putra et al. 2022; Thoha et al. 2022). Drone-based assessments have offered opportunities for automated tree counting, analysis of tree canopy metrics, and studies of oil palm canopy cover in relation to tree mortality. These results are further supported by research showing that UAVs could detect oil palm plants (Khokthong et al. 2019; Avtar et al. 2020; Gibril et al. 2021; Chowdhury et al. 2022; Muna et al. 2022), identify plant health and diseases (Husin et al. 2023; Kent et al. 2023), and offer faster, more efficient operational costs for mapping (Fawcett et al. 2019; Rashid et al. 2021; Yarak et al. 2021).

Indonesia's tropical climate, characterized by relatively high air temperatures and humidity, often trigger fungal attacks. Among the serious diseases affecting mature oil palm plants, Basal Stem Rot (BSR) is prevalent. This disease is caused by *Ganoderma boninense* Pat. fungus, which invades the plant stem through fungal mycelia, basidiospores, and pseudospores (Corley and Tinker 2008; Ho et al. 2019). The *G. boninense* is a significant pathogen that attack oil palm plants and deplete their nutrients (Daliesta et al. 2020; Rebitanim et al. 2020; Santoso 2020; Jazuli et al. 2022; Darlis et al. 2023). Symptoms of BSR infection include yellowing and necrosis of leaves, unopened spears, small crowns, and skirt-like crown shape. The pathogen's attack damage the stem xylem network, disrupting the tree's ability to distribute water and nutrients and ultimately compromising the tree's survival (Siddiqui et al. 2021; Kurihara et al. 2022). In Indonesia, the loss of oil palm production due to BSR disease is severe, exacerbating the decline in production potential as the plants age.

For disease identification, UAVs equipped with hyper and multispectral cameras has been widely used in various agricultural operations. These multispectral UAVs may assess plant health and detect early stages of disease (Nguyen et al. 2020; Rafezall et al. 2020; Neupane and Baysal-Gurel 2021). The Oil Palm Analysis (OPA) software has further facilitated the evaluation of plant numbers, health, and potential oil palm production. While commercial oil palm plants are typically productive between ages of 21 and 23 years, those at the research location of PT. Eastern Indonesia Bukit Maradja Estate, Simalungun District, North Sumatra, Indonesia, are 26 years old and should have entered the rejuvenation phase. Mapping using multispectral aerial data, which include stand counts, oil palm health assessments, and crop production estimates, forms the basis for analyzing production potential. The present study aimed to test the accuracy of estimating the production potential of oil palm (*E. guineensis*) using UAV technology.

MATERIALS AND METHODS

Research area

This study was conducted at PT. Eastern Indonesia Bukit Maradja Estate, specifically in block 96E19A, located in Gunung Malela Sub-district, Simalungun District, North Sumatra Province, Indonesia. The study site is situated at an altitude of 142 meters above sea level, as illustrated in Figure 1 below. The study commenced in July 2022 and was completed within the same year.

Research equipment and materials

Equipment used

The tools used in this research include DJI Mavic 2 Pro drone, laptop, and software for processing maps and data, including: ArcGIS 10.8 software for processing and displaying 3D maps, Agisoft Meta Shape to facilitate photogrammetry, Pix4D for digitizing reality and measuring images captured by drones, OPA for analyzing maps into accurate data, GPS device (Garmin 64s series) for providing location data. Microsoft Word was used for data presentation.

Materials used

The primary material utilized was a high-resolution aerial photo map of oil palm plantation at PT. Eastern Indonesia Bukit Maradja Estate captured using a drone.

Plant material

The plant material involved in the study was a 26-year old Socfin variety Oil palm plantation.

Research methods

Data collection

Pix4D software was utilized to create the flight path for the drone. This program enabled the drone to fly automatically along the predetermined path and capture photos of the plants, which were then combined and processed into an ortho mosaic image (Figure 2).

Identification of the area was initially conducted, followed by the determination of the boundaries of the observed location and the drone flight path. Pixel resolution, or Ground Sample Distance (GSD), was established through statistical processing of homogeneous pixel values. The drone was flown on a single mission at an altitude of approximately 100 m above ground level, capturing 690 photos of the study area.

Data processing

The captured images were processed into a Digital Elevation Model (DEM) and orthophoto. During orthophoto creation, each image was mosaicked after building geometry in Pix4D Mapper software. The completed ortho-mosaic data was then processed using the Oil Palm Application (OPA) software, which automatically calculates the number of plants by analyzing their crowns.

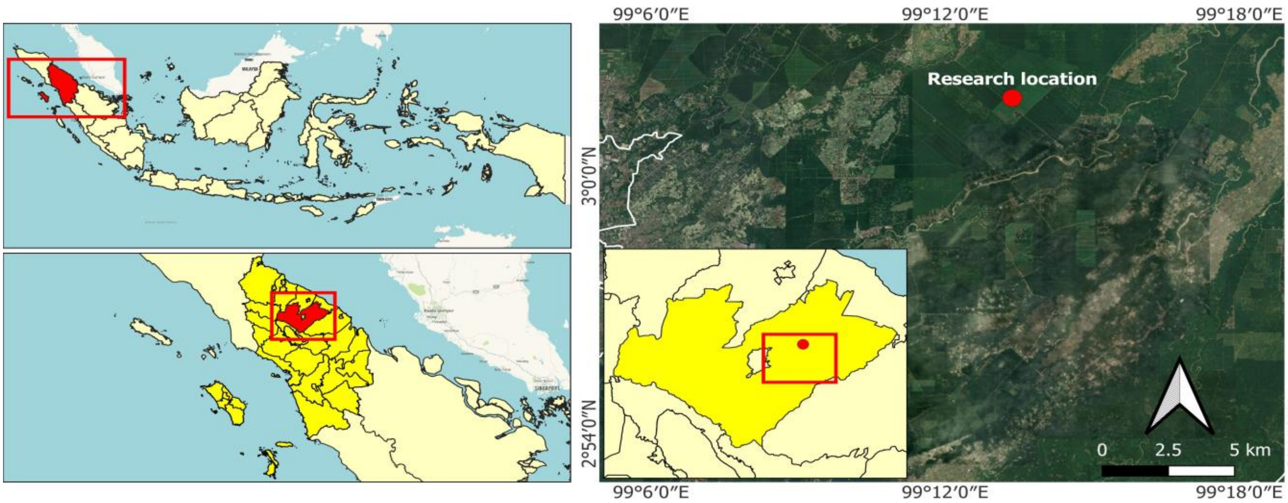

Figure 1. Map of research location

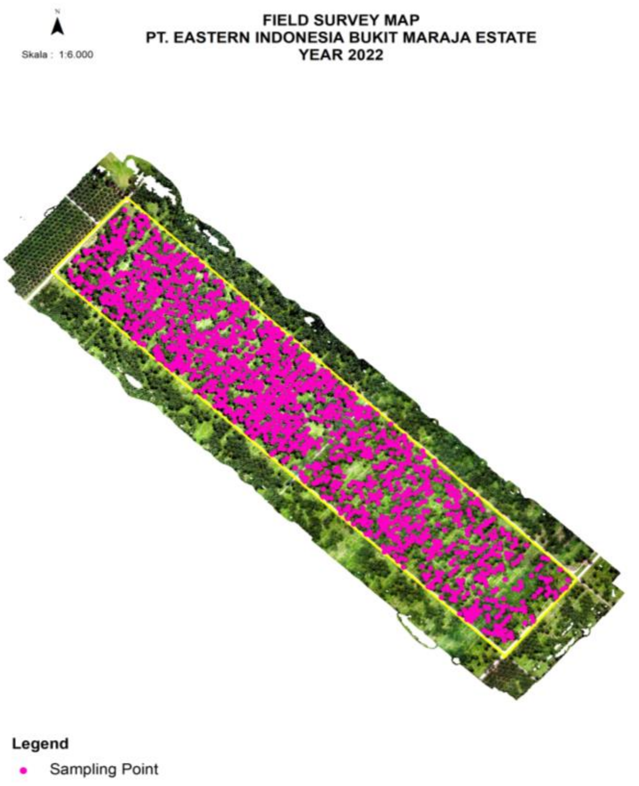

Figure 2. Map of sampling points in the study area

Map creation

After processing through OPA software, the plants were mapped using ArcGIS Arcmap 10.8 Software.

Census of plants

Once the map processing was complete, Global Positioning System (GPS) field checks were conducted to verify the plant population and assess the health status of the plants for comparison purposes. GPS was used as a primary tool for the census.

Implementation census

To conduct the census, GPS machine was powered on, and sufficient time was allowed for it to receive signal from minimum of three satellites. A waypoint was created for each tree by visiting each census principal (one by one). Accurate GPS positioning was ensured for each plant to obtain precise census results. Different waypoints were assigned based on condition of each tree. It crucial that the GPS location was consistent (uniform) for each tree during the census. The collected census data was then transferred to a computer, and a tree map was generated based on the census results.

Data analysis

The orthomosaic image processed using OPA software was analyzed and compared with field survey data (plant census) using a student's t test with α = 5%. The data used for the t-test comprised crop census data from the field, which was compared to the census data analyzed using drone imagery.

RESULTS AND DISCUSSION

Plant number mapping

The map of the number of plants at PT. Eastern Indonesia Bukit Maradja Estate plantation was created using data captured by a DJI Mavic 2 Pro drone, flown at an altitude of approximately 100 m. Aerial photos were taken between 10.00 and 10.40 a.m. to ensure optimal lighting conditions. The photo data (map) was then processed using specialized software to count the number of plants. According to data from PT. Eastern Indonesia Bukit Maradja Estate plantation, the research area is characterized by flat topography and sandy loam soil. Soil pH measurements indicated a value of 4.58 at depth of 0-20 cm, and 4.26 at a depth of 20-40 cm.

The results from OPA software indicated the presence of empty areas within the population of oil palm plants that were planted in 1996. The map highlighted regions where oil palm plantations had died, as well as areas where remaining oil palm plants had been cleared. However, in some locations, the growing points of the oil palms were still evident (Figure 3).

The location of the research object at the PT. Eastern Indonesia Bukit Maradja Estate, specifically in block 96E19A covering an area of 23.3 hectares, was initially determined using satellite imagery. The coordinate positions were then set at several points. Following this, a field census survey was conducted based on these predetermined coordinate points, utilizing GPS equipment. The results of the field census, were then compared with the OPA analysis results derived from drone imagery, which was captured based on the same GPS coordinates. The accuracy of the area measured in the field was found to be consistent with the area determined by the drone analysis.

The plant census in the field revealed a total of 2,139 plants, whereas the map analysis using UAV and OPA software indicated 2,104 plants (Table 1). This demonstrates that 98% of the plants were accurately counted using OPA software in comparison to the actual field count. To further enhance the accuracy, replacing digital cameras with multispectral cameras could optimize UAVs usage in oil palm plantations. The use of drones has proven effective in rapidly and efficiently mapping the land and counting the number of plants. These findings align with previous studies (Pathak et al. 2020; Reckling et al. 2021; Chowdhury et al. 2022), which state that drone technology simplifies plantation maintenance and monitoring by enabling efficient mapping and plant counting.

Production potential through plant health maps

Figure 4 presents a map illustrating plant the health status of plants within a 22.23 ha plantation area. The map highlights varying health conditions, including healthy plants and those infected with *G. boninense*. The production potential of these plants will be evaluated and supported by data from PT. Eastern Bukit Maradja Estate, as discussed in Table 2.

Oil palm pest and disease attacks were observed in the field, with *Ganoderma* affecting 743 plants, representing 34% of the total population (Table 2). The palm oil industry faces a significant threat from Basal Root Stem

(BSR) disease, which is particularly problematic in oil palm plantations across Southeast Asia due to its considerable economic impact. This aligns with the findings of Santoso (2020) and Husin et al. (2021), who noted that BSR is closely associated with rootstock rot disease, manifesting in severe symptoms such as flattened and unopened spear shaped leaves.

Table 1. Comparison amount plant

Method	Census plant
Drones + OPA	2,104
Census plant	2,139

Note: The comparison amount for the plant; using the drone method + OPA is 2,104; whereas plants in the field are 2,139

Table 2. Pest and disease attacks

Pest/disease	Number of attacks	Percentage
Setothosea asigna (van Eecke, 1929) (Fireworm)	0	0 %
Thyridopteryx ephemeraeformis (Haworth, 1803) (Bagworms)	0	0 %
Oryctes rhinoceros (Linnaeus, 1758) (Coconut Rhinoceros Beetle)	0	0 %
Ganoderma boninense Pat. (Fungus *Ganoderma*)	743	34 %

Note: Data source of PT. Eastern Indonesia Bukit Maradja Estate (2021)

Table 3. Soil analysis of PT. Eastern Indonesia Bukit Maradja Estate, Simalungun District, North Sumatra Province, Indonesia

Soil parameter	Unit	Value
Depth	cm	0-20
pH	H_2O	4.58
Soil organic material	%	1.39
C Organic	%	1.39
N total	%	0.12
C/N Ratio		11.6
Extr. P Bray 2		
P_2O_5	%	73.2
Exch Cation (m.e/100 g)		
Al+H	%	2.14
K	%	0.6
Mg	%	0.5
Ca	%	1.6
Soil Texture		
Sand	%	81.10
Clay	%	8.50
Dust	%	10.40
Texture		Sandy Loam

Note: Data source from PT. Eastern Indonesia Bukit Maradja Estate, block 96E19A, Gunung Malela Sub-district, Simalungun District, North Sumatra Province, Indonesia (2021)

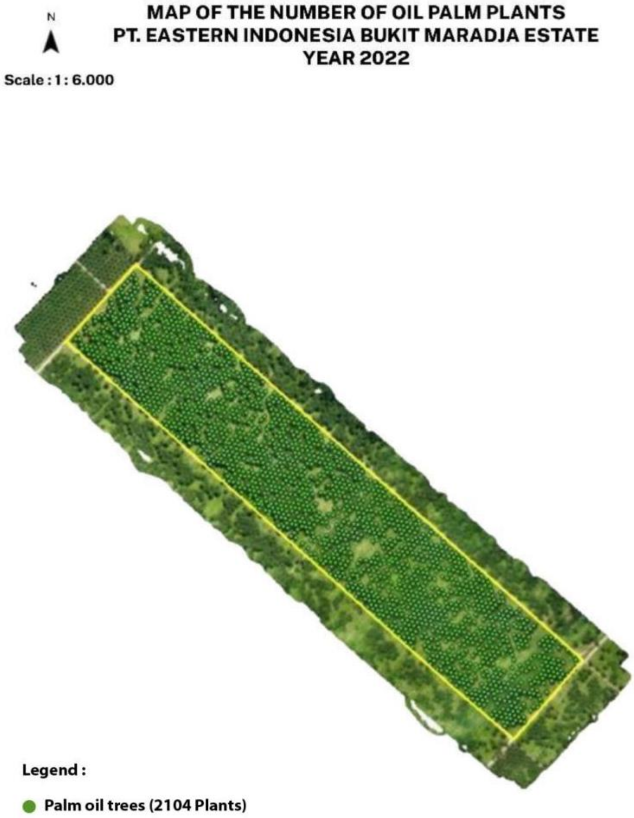

Figure 3. Map of oil palm plants created using OPA

Figure 4. Map of heath of oil palm plants

The soil analysis results from the PT. Eastern Indonesia Bukit Maradja Estate plantation indicated that the soil type to be ultisol with sandy clay texture, a pH of 4.58, and organic carbon content of 1.39% (Table 3). The soil pH, although slightly acidic, was within a safe range for oil palm plantation, especially given the nutrient availability supported by a C/N ratio of 11.6. This falls within the optimal range of 10-12, which is essential maximizing oil palm production, as noted by Lehmann and Joseph (2015) and Uke et al. (2021). They emphasized that oil palm plants thrive in soils with C/N ratio between 10-12 and pH 5.0-7.0, with C/N ratio being a critical factor influencing fine root decomposition. For oil palm plants, optimal C/N levels are vital for enhancing production through effective organic material decomposition.

Ultisol soil typically present challenges such as high acidity (average pH<4.50), high aluminum content (Al saturation), significant Phosphorous (P) fixation, and vulnerability to erosion. However, increase in soil pH to 4.58 and optimal C/N ratio observed in this study suggest a reduction in Al saturation and increased nutrient availability to plants. While ultisols generally have low organic carbon content (<1%), the plantation's organic carbon content increased to 2.40%, thus enhancing microbial activity and nutrient availability, contributing to a fertile soil classification.

The plantation management has addressed soil fertility by returning organic material from Palm Oil Factory waste, particularly charcoal from palm oil Fruit Bunches (EFB), into the soil. This practice, maintained by PT. Eastern Indonesia Bukit Maradja Estate for decades, has effectively preserved soil fertility, even in 26-year-old oil palm plants that would typically be approaching rejuvenation stage. These findings align with studies by Biruntha et al. (2020), Nguyen et al. (2020), and Hao et al. (2022), which demonstrate that the reintegration of organic plant waste enhances soil fertility. The application of EFB charcoal is widely recognized as a sustainable soil management practice, significantly contributing to the increase of Soil Organic Carbon (SOC) storage in the intensively managed plantation ecosystems. SOC is crucial for nutrient availability, greenhouse gas emissions, and the detoxification of harmful substances in the soil.

Further supporting this, Corley and Tinker (2008) and Koishi et al. (2020) reported that organic matter amendments positively impact SOC storage. SOC, particularly humic substances, can detoxify Al monomers in acidic soils and strongly bind toxic heavy metals, making them less available to plant roots, as well as binding harmful organic pollutants (Gerke 2022; Rashad et al. 2022). The mineralization of organic matter in soil, through practices like plant cover maintenance and organic waste recovery, is a key factor influencing soil carbon conservation. High levels of litter decomposition as observed by Findlay (2021) and García-Palacios et al. (2021), ultimately lead to significant carbon fixation from the atmosphere and enhance soil organic production. The decomposition of dead organic material is essential for the carbon and nutrient cycles within an ecosystem.

Based on the results of the plant census on this plantation, 1,396 plants exhibited an average production potential of 2.92 bunches per plant, while a drone census identified 1,380 plants with an average production potential of 2.91 bunches per plant (Table 4). The Black Bunch Count (BBC) method, used to estimate the number of bunches for the next four months, is essential for preparing a budget for harvest costs in a given quarter. The BBC Drones/Plant presents the Black Bunch Count production data per plant obtained from Oil Palm Analysis (OPA), which also helps determine the level of *Ganoderma* attack. The average production potential by attack was as follows: Normal (N1) 2.91, Stage 1 (G1) 2.00, Stage 2 (G2) 1.70, Stage 3 (G3) 1.19 Stage 4 (G4) 0.00. These findings align with previous studies (Avtar et al. 2020; Chowdhury et al. 2022; Muna et al. 2022; Sukarman et al. 2022), which emphasized that UAVs could effectively detect oil palm plants and evaluate production potential using drone-based remote sensing technology.

At PT. Eastern Indonesia Bukit Maradja Estate, the soil type is Ultisol, with organic carbon content of 1.39%, a C/N ratio of 11.60, and a soil pH of 4.58 (Table 3). According to Charloq et al. (2023a) and Zhao et al. (2023), the quality of organic material is determined not only by nutrient content but also by the rate of decomposition, which is influenced by lignin content and the C/N ratio.

The *G. boninense* stage 1 attack affected 361 plants, with an average production potential of 2.01 bunches per plant, while the drone census identified 350 plants with an average production potential of 2.00 bunches per plant. Eris et al. (2022) reported similar findings, indicating that in plantations affected by *G. boninense* stage 1, there are typically 15 plants per ha, with a potential production of 5-6 tons per ha for plants aged 26 years.

The stage 2 *G. boninense* attack affected 181, resulting in an average production potential of 1.70 bunches per plant, while the drone census idemntified 173 plants with same average production potential. These findings are consistent with the guidelines provided by Jazuli et al. (2022), which state that the root rot disease caused by *G. boninense* significantly deteriorates plantation conditions and negatively impacts production, with further declines expected in the future.

Table 4. Attack rate of *Ganoderma* and Black Bunch Count (BBC)

Attack rate	Census field/plant	BBC	Drones/ plants	BBC
Normal (N)	1396	2.92	1380	2.91
Stage 1 (G1)	361	2.01	350	2.00
Stage 2 (G2)	181	1.70	173	1.70
Stage 3 (G3)	172	1.19	172	1.19
Stage 4 (G4)	29	0.00	29	0.00

Note: N: Normal; G1: *Ganoderma* stage 1; G2: *Ganoderma* stage 2; G3: *Ganoderma* stage 3; and G4: *Ganoderma* stage 4

For the stage 3 *G. boninense* attack, 172 plants were surveyed, both in the field and by drone, with an average production potential of 1.19 bunches per plant. The *G. boninense* can cause economic losses in oil palm plantations of up to 43%, as noted by Siddiqui et al. (2021) and Khoo and Chong (2023), who described the severe impact of stem rot disease in oil palm plants.

The stage 4 *G. boninense* attack affected 29 plants, both in the field and by drone, with an average production potential of 0.00 bunches per plant. This confirms that *G. boninense* is a significant pathogen for oil palm plants, as reported by Hamzah et al. (2021) and Sukariawan et al. (2021). The fungus leads to plant mortality, reducing stand count and oil palm production. It spreads through infected roots and airborne basidiospores, degrading cell wall components, including lignin. BSR results in reduced Fresh Fruit Bunch (FFB) yields and eventual collapse of oil palm trees (Abubakar et al. 2022; Darlis et al. 2023).

Remote sensing technologies, such as UAVs, have proven effective in assessing the health of oil palm plants based on *G. boninense* infection. The level of infection of infection is identified by calculating the vegetation index from UAV multispectral images and mapping the distribution of BSR infection. Infected leaves typically exhibit a yellowish hue and reduced frond count, as noted by Ahmadi et al. (2022), who stated that UAVs are highly effective for aerial monitoring of oil palm plant health, particularly in identifying *G. boninense* infections. Additionally, Rafezall et al. (2020), Sheriza et al. (2020), and Meivel and Maheswari (2021), reported that remote sensing sensors mounted on UAVs could detect oil palm health effectively.

Despite the age of the oil palm plants being 26 years, the production potential remains high, with an oil yield of 24%. The estimated yield for the next four months is projected to reach 156,489 tonnes (Table 5). This sustained productivity is supported by favourable conditions, including a C/N ratio of 11.6 and a pH of 4.58, which are optimal for oil palm growth in the Ultisol prevalent in the plantation (Table 3). The company's effective plant maintenance regime plays a crucial role in this productivity. They consistently utilize empty oil palm fruit bunches, which are processed into compost and biochar, serving as vital soil improvement materials and nutrient sources, especially potassium. On average, each tree produces about 2.48 (rounded to 3 bunches). The soil organic carbon derived from biochar is particularly beneficial as it detoxifies Al monomers in acidic soil, binds toxic heavy metals strongly to prevent their absorption by plant roots, and securely binds various harmful organic pollutants. These factors collectively contribute to sustaining high yield levels, even as the plants approach the typical age of rejuvenation. Supporting studies by Bhuvaneshwari et al. (2019) and Pulingam et al. (2022) emphasize that the use of waste products like palm oil bunches fosters soil biodiversity, which is important for maintaining the primary global biogeochemical cycles, including those of carbon, nutrients, and water. Consequently, vital organic material services, such as compost and biochar, provided by the soil not benefit multiple ecosystems. However, it is noted that as oil palm plants age, their population naturally decreases, and yields decline - by 22% in this case - which typically marks the end of their economic life. Despite this, the plantation remains valuable due to its continued productive output, as corroborated by Smith et al. (2015), Sari et al. (2021) and Zhao et al. (2023).

Table 5. Black Bunch Count (BBC)

Calculation forecast production block	: **96E19A covering an area of 22,23 ha**
Bunch weight	
Previous June (Jun 2021)	: 28.5 kg
Average bunch weight Jul- Aug previous (Jul- Aug 2021)	: 29.0 kg
Average bunch weight June 2022	: 29.5 kg
+/- difference a & b	: + 0.5 kg
Average bunch weight estimate Jul-Aug 2022	: 29.5 kg
Rendement oil	: 24%
Number of bunches per plant	
Total plants counted	: 2,139
Total number of bunches	: 5,309
Average number of bunches per plant (b/p)	: 2,48
Fresh fruit bunches results in the next 4 months	
Amount plant in blocks	: 2.139
Total number of bunches harvested in the next 4 months:	: 2.139 × 2,48
	: 5.304,72
Forecast results for the next 4 months	: 5.304,72 × 29.5
	: 156.489,24 kg
	: 156.489 tons

Note: Data Source PT. Eastern Indonesia Bukit Maradja Estate, Simalungun District, North Sumatra Province, Indonesia; Average number of bunches per plant = Total number of bunches : Total plant counted; Forecasted fresh fruit bunch yield for the next four months = Total number of bunches harvested in the next four months/Average number of bunches per plant. Data source of PT. Eastern Indonesia Bukit Maradja Estate (2021)

Table 6. Analysis using student's t test on counts of plants

Attack rate	Census field /plant	Drones /plant	Correlation	t-test	Sig.
Normal (N)	1396	1380	1.00	0.02	0.984 ns
Stage 1 (G1)	361	350			
Stage 2 (G2)	181	173			
Stage 3 (G3)	172	172			
Stage 4 (G4)	29	29			

Note: ns: not significant

Table 7. Analysis using student's t test on Black Bunch Census (BBC) height per plant

Attack rate	BBC census field/plant	BBC drones/plant	Corr.	t-test	Sig.
Normal (N)	2.92	2.91	1.00	0.01	0.995 ns
Stage 1 (G1)	2.01	2.00			
Stage 2 (G2)	1.7	1.70			
Stage 3 (G3)	1.19	1.19			
Stage 4 (G4)	0	0.00			

Note: ns: not significant

The correlation between field census and drones-based plant counts is highly significant, with a correlation coefficient of 0.984 (Table 6). This indicates that there is no significant difference in crop attack rates between the field census and drone assessments. The findings suggest that drone technology is highly effective for counting plant numbers and assessing plant health (Table 6). This is in accordance with the studies of Suab et al. (2019), Nazir et al. (2021), and Charloq et al. (2023b), which emphasize the utility of UAVs (drones) in oil palm plantations for plantation areas, counting plants, and monitoring tree health. These studies highlight how UAVs simplify plant maintenance and monitoring, making the estimation of oil palm production potential more accurate. Further support in this respect comes from the studies of Kalamkar et al. (2020) and Srinarta (2022), which stated that the UAVs can be reliably used to automatically count oil palm plants and monitor their health, demonstrating the practicality and accuracy of this technology in agricultural applications.

The Black Bunch Count (BBC) method serves as an important tool for estimating the number of bunches expected in the next four months, crucial for budgeting harvest costs for the quarter. The BBC/Plant drones data is derived from Oil Palm Analysis (OPA), providing insights into the level of *Ganoderma* infestation with specific production potential at specific stages: Normal (N1) 2.91, Stage 1 (G1) 2.00, Stage 2 (G2) 1.70, Stage 3 (G3) 1.19, and Stage 4 (G4) 0.00. The use of drone technology with OPA enables highly accurate estimations of Palm Oil production potential. The correlation between BBC Census Field/Plant and BBC Drones/Plant is significant, with a correlation coefficient of 0.995 (Table 7). This indicates that there is no significant difference between the field census and drone-based assessments in determining crop attack levels. Thse findings are in accordance with the studies of Avtar et al. (2020), Chowdhury et al. (2022), Muna et al. (2022), and Sukarman et al. (2022), which emphasize the capacity of UAVs to detect oil palm plants accurately through drone-based remote sensing technology, enabling precise evaluation of production potential.

In conclusion, from the study of drone/UAV technology based estimation of oil palm (*E. guineensis*) production potential in the field on an area of 22.23 ha at PT. Eastern Indonesia Bukit Maradja Estate, it can be concluded that the use of drone technology for oil palm production estimation through OPA is highly effective, with no significant discrepancies between drone results and traditional field census methods. This consistency confirms that UAVs are a reliable tool for assessing the production potential of oil palm plantations.

ACKNOWLEDGEMENTS

We would like to thank PT. Eastern Indonesia Bukit Maradja Estate, Mountain Malela Sub-district, Simalungun District, North Sumatra Province, Indonesia, for allowing us to conduct research in this plantation area.

REFERENCES

Abubakar A, Ishak MY, Bakar AA, Uddin MK. 2022. *Ganoderma boninense* basal stem rot induced by climate change and its effect on oil palm. Environ Sustain 5: 289-303. DOI: 10.1007/s42398-022-00244-7.

Ahmadi P, Mansor S, Farjad B, Ghaderpour E. 2022. Unmanned Aerial Vehicle (UAV)-Based remote sensing for early-stage detection of *Ganoderma*. Remote Sens 14 (5): 1239. DOI: 10.3390/rs14051239.

Avtar R, Suab SA, Syukur MS, Korom A, Umarhadi DA, Yunus AP. 2020. Assessing the influence of UAV altitude on extracted biophysical parameters of young oil palm. Remote Sens 12 (18): 3030. DOI: 10.3390/rs12183030.

Bhuvaneshwari S, Hettiarachchi H, Meegoda JN. 2019. Crop residue burning in India: Policy challenges and potential solutions. Intl J Environ Res Public Health 16 (5): 832. DOI: 10.3390/ijerph16050832.

Biruntha M, Karmegam N, Archana J, Selvi BK, Paul JAJ, Balamuralikrishnan B, Chang SW, Ravindran B. 2020. Vermiconversion of biowastes with low-to-high C/N ratio into value added vermicompost. Bioresour Technol 297: 122398. DOI: 10.1016/j.biortech.2019.122398.

Charloq, Simbolon PE, Vinolina NS. 2023a. Amelioration of peat soil for changes in C/N levels through palm oil empty bunch ash utilization in *Mucuna bracteata* plantatione. IOP Conf Ser: Earth Environ Sci 1188: 012042. DOI: 10.1088/1755-1315/1188/1/012042.

Charloq, Thoha AS, Putra, DY, Muammar A. 2023b. Unmanned Aerial Vehicles (UAV) utilization for mapping the health of oil palm plants (*Elaeis guineensis* Jacq.). IOP Conf Ser: Earth Environ Sci 1241: 012072. DOI: 10.1088/1755-1315/1241/1/012072.

Chowdhury PN, Shivakumara P, Nandanwar L, Samiron F, Pal U, Lu T. 2022. Oil palm tree counting in drone images. Pattern Recognit Lett 153: 1-9. DOI: 10.1016/j.patrec.2021.11.016.

Corley RHV, Tinker PB. 2008. The Oil Palm. John Wiley & Sons, US. DOI: 10.1002/9781118953297.ch13.

Daliesta NFT, Muhammad AS, Gatot P. 2020. Studi peremajaan tanaman kelapa sawit di areal lahan tanah mineral dan lahan gambut. Jurnal Teknik Pertanian Lampung 9 (3): 201-212. DOI: 10.23960/Jtep-L.V9i3.201-212. [Indonesian]

Darlis D, Jalloh MB, Chin CFS, Basri NKM, Besar NA, Ahmad K, Rakib MRM. 2023. Exploring the potential of Bornean polypore fungi as biological control agents against pathogenic *Ganoderma boninense* causing basal stem rot in oil palm. Sci Rep 13: 10316. DOI: 10.1038/s41598-023-37507-0.

Eris DD, Widiastuti H, Suharyanto, Panjaitan K, Taniwiryono D. 2022. *Ganoderma* stem rot disease mapping and the chemical and biological characteristics of endemic lands. IOP Conf Ser: Earth Environ Sci 974: 012049. DOI: 10.1088/1755-1315/974/1/012049.

Fawcett D, Azlan B, Hill TC, Kho LK, Bennie J, Anderson K. 2019. Unmanned Aerial Vehicle (UAV) derived structure-from-motion photogrammetry point clouds for oil palm (*Elaeis guineensis* Jacq.) canopy segmentation and height estimation. Intl J Remote Sens 40 (19): 7538-7560. DOI: 10.1080/01431161.2019.1591651.

Findlay SEG. 2021. Organic matter decomposition. In: Weathers KC, Strayer DL, Likens GE (eds). Fundamentals of Ecosystem Science, Second Edition. Academic Press, US. DOI: 10.1016/B978-0-12-812762-9.00004-6.

Fosch A, Ferraz de Arruda G, Aleta A, Descals A, Gaveau D, Morgans C, Santika T, Struebig MJ, Meijaard E, Moreno Y, 2023. Replanting unproductive palm oil with smallholder plantations can help achieve Sustainable Development Goals in Sumatra, Indonesia. Commun Earth Environ 4: 378. DOI: 10.1038/s43247-023-01037-4.

García-Palacios P, Tanya Handa I, Hättenschwiler S. 2021. Plant litter decomposition in terrestrial ecosystems compared to streams. In: Swan CM, Boyero L, Canhoto C (eds). The Ecology of Plant Litter Decomposition in Stream Ecosystems. Springer, Cham. DOI: 10.1007/978-3-030-72854-0_6.

Gerke J. 2022. The central role of soil organic matter in soil fertility and carbon storage. Soil Syst 6 (2): 33. DOI: 10.3390/soilsystems6020033.

Gibril MBA, Shafri HZM, Shanableh A, Al-Ruzouq R, Wayayok A, Hashim SJ. 2021. Deep convolutional neural network for large-scale date palm tree mapping from UAV-based images. Remote Sens 13 (14): 2787. DOI: 10.3390/rs13142787.

Hamzah A, Saputra R, Puspita F, Nasrul B, Irfandri, Depari NS. 2021. *Ganoderma* diversity from smallholder oil palm plantations in peatlands of Kampar District, Indonesia based on mycelia morphology and somatic incompatibility. Biodiversitas 22 (1): 16-22. DOI: 10.13057/biodiv/d220103.

Hao X, Han X, Wang S, Li L-J. 2022. Dynamics and composition of soil organic carbon in response to 15 years of straw return in a Mollisol. Soil Till Res 215: 105221. DOI: 10.1016/j.still.2021.105221.

Ho C-L, Tan Y-C, Yeoh K-A, Lee W-K, Ghazali A-K, Yee W-Y, Hoh C-C. 2019. Leaf transcriptome of oil palm (*Elaeis guineensis* Jacq.) infected by *Ganoderma boninense*. Trees 33: 943-950. DOI: 10.1007/s00468-019-01830-9.

https://www.bsigroup.com/globalassets/localfiles/en-my/rspo/Public%20Summary%20Report/2020/06-4.-public-summary-report-bukit-maradja-pom_rc.pdf. [Indonesian]

Husin NA, Abd Aziz MH, Khairunniza-Bejo S. 2023. Detection and classification of basal stem rot disease in oil palm using machine learning techniques: A mini review. Adv Agric Food Res J 4 (2): a0000365. DOI: 10.36877/aafrj.a0000365.

Husin NA, Bejo SK, Abdullah AF, Kassim MS, Ahmad D. 2021. Relationship of oil palm crown features extracted using terrestrial laser scanning for basal stem rot disease classification. Basrah J Agric Sci 34: 1-10. DOI: 10.37077/25200860.2021.34.sp1.1.

Jazuli NA, Kamu A, Chong KP, Gabda D, Hassan A, Abu Seman I, Ho CM. 2022. A review of factors affecting *Ganoderma* basal stem rot disease progress in palm oil. Plants 11 (19): 2462. DOI: 10.3390/plants11192462.

Kalamkar RB, Ahire MC, Ghadge PA, Dhenge SA, Anarase MS. 2020. Drone and its Applications in Agriculture. Intl J Curr Microbiol Appl Sci 9 (6): 3022-3026. DOI: 10.20546/ijcmas.2020.906.363.

Kent OW, Chun TW, Choo TL, Kin LW. 2023. Early symptom detection of basal stem rot disease in oil palm plant using a deep learning approach on UAV images. Comput Electron Agric 213: 108192. DOI: 10.1016/j.compag.2023.108192.

Khokthong W, Zemp DC, Irawan B, Sundawati L, Kreft H, Hölscher D. 2019. Drone-based assessment of canopy cover for analyzing tree mortality in an oil palm agroforest. Front For Glob Change 2: 12. DOI: 10.3389/ffgc.2019.00012.

Khoo YW, Chong KP. 2023. *Ganoderma boninense*: General characteristics of pathogenicity and methods of control. Front Plant Sci 14: 1156869. DOI: 10.3389/fpls.2023.1156869.

Koishi A, Bragazza L, Maltas A, Guillaume T, Sinaj S. 2020. Long-term effects of organic amendments on soil organic matter quantity and quality in conventional cropping systems in Switzerland. Agronomy 10 (12): 1977. DOI: 10.3390/agronomy10121977.

Kurihara J, Koo V-C, Guey CW, Lee YP, Abidin H. 2022. Early detection of basal stem rot disease in oil palm tree using unmanned aerial vehicle-based hyperspectral imaging. Remote Sens 14 (3): 799. DOI: 10.3390/rs14030799.

Lehmann J, Joseph S. 2015. Biochar for Environmental Management: Science, Technology and Implementation. Second Edition. Routledge, UK. DOI: 10.4324/9780203762264.

Meivel S, Maheswari S. 2021. Remote sensing analysis of agricultural drone. J Indian Soc Remote Sens 49: 689-701. DOI: 10.1007/s12524-020-01244-y.

Muna MS, Nugroho AP, Syarovy M, Wiratmoko A, Sutiarso L. 2022. Development of automatic counting system for palm oil tree based on Remote Sensing Tourism. In: International Conference on Sustainable Environment, Agriculture and Tourism (ICOSEAT 2022). Tanjung Pesona Beach Resort, Sungailiat, Bangka, 21-23 July 2022. DOI: 10.2991/978-94-6463-086-2_68.

Nazir MNMM, Terhem R, Norhisham AR, Razali SM, Meder R. 2021. Early monitoring of health status of plantation-grown *Eucalyptus pellita* at large spatial scale via visible spectrum imaging of canopy foliage using unmanned aerial vehicles. Forests 12 (10): 1393. DOI: 10.3390/f12101393.

Neupane K, Baysal-Gurel F. 2021. Automatic identification and monitoring of plant diseases using unmanned aerial vehicles: A review. Remote Sens 13 (19): 3841. DOI: 10.3390/rs13193841.

Nguyen V-T, Le T-H, Bui X-T, Nguyen T-N, Vo T-D-H, Lin C, Vu T-M-H, Nguyen H-H, Nguyen D-D, Senoro DB, Dang B-T. 2020. Effects of C/N ratios and turning frequencies on the composting process of food waste and dry leaves. Bioresour Technol Rep 11: 100527. DOI: 10.1016/j.biteb.2020.100527.

Pathak H, Kumar G, Mohapatra SD, Gaikwad BB, Rane J. 2020. Use of drones in agriculture: Potentials, Problems and Policy Needs. ICAR-National Institute of Abiotic Stress Management 300: 4-15. ICAR-National Institute of Abiotic Stress Management. Retrieved from https://niasm.icar.gov.in/sites/default/files/pdfs/Use-of-Drone-in-Indian-Agriculture.pdf, accessed on 23.08.2024.

PT. Eastern Indonesia Bukit Maradja Estate. 2021. Bukit Maradja Palm Oil Mill Location of Certification Unit: Nagori Marihat Bukit Village, Gunung Malela Sub-district, Simalungun District, Sumatera Utara Province.

Pulingam T, Lakshmanan M, Chuah J-A, Surendran A, Zainab-L I, Foroozandeh P, Uke A, Kosugi A, Sudesh K. 2022. Oil palm trunk waste: Environmental impacts and management strategies. Ind Crops Prod 189: 115827. DOI: 10.1016/j.indcrop.2022.115827.

Putra YC, Wijayanto AW, Chulafak GA. 2022. Oil palm plant detection and counting on Microsoft Bing Maps Very High Resolution (VHR) satellite imagery and Unmanned Aerial Vehicles (UAV) data using image processing thresholding approach. Ecol Inform 72: 101878. DOI: 10.1016/j.ecoinf.2022.101878.

Rafezall CM, Darwin N, Ariff MFM, Majid Z. 2020. Detection of palm oil health through multispectral UAV platform. In: 2020 IEEE 10th International Conference on System Engineering and Technology (ICSET). Shah Alam, Malaysia. DOI: 10.1109/ICSET51301.2020.9265374.

Rashad M, Hafez M, Popov AI. 2022. Humic substances composition and properties as an environmentally sustainable system: A review and way forward to soil conservation. J Plant Nutr 45 (7): 1072-1122. DOI: 10.1080/01904167.2021.2005801.

Rashid M, Bari BS, Yusup YB, Kamaruddin MA, Khan N. 2021. A comprehensive review of crop yield prediction using machine learning approaches with special emphasis on palm oil yield prediction. IEEE Access 9: 63406-63439. DOI: 10.1109/ACCESS.2021.3075159.

Rebitanim NA, Hanafi MM, Idris AS, Abdullah SNA, Mohidin H, Rebitanim NZ. 2020. GanoCare® improves oil palm growth and resistance against *Ganoderma* basal stem rot disease in nursery and field trials. Biomed Res Intl 2020: 3063710. DOI: 10.1155/2020/3063710.

Reckling W, Mitasova H, Wegmann K, Kauffman G, Reid R. 2021. Efficient drone-based rare plant monitoring using a species distribution model and ai-based object detection. Drones 5 (4): 110. DOI: 10.3390/drones5040110.

Santoso H. 2020. Surveillance and mapping of basal stem rot disease in oil palm plantation using Unmanned Aerial Vehicle (UAV) and multispectral camera. Jurnal Fitopatologi Indonesia 16 (2): 69-80. DOI: 10.14692/jfi.16.2.69-80. [Indonesian]

Sari DW, Hidayat FN, Abdul I. 2021. Efficiency of land use in smallholder palm oil plantations in Indonesia: A stochastic frontier approach. For Soc 5 (1): 75-89. DOI: 10.24259/fs.v5i1.10912.

Sheriza MR, Nurul MF, Ainuddin NA. 2020. Application of remote sensing to assess the biophysical characteristics of palm oil plant for ecological study. J Landsc Ecol 13 (3): 63-78. DOI: 10.2478/jlecol-2020-0017.

Siddiqui Y, Surendran A, Paterson RRM, Ali A, Ahmad K. 2021. Current strategies and perspectives in detection and control of basal stem rot of oil palm. Saudi J Biol Sci 28 (5): 2840-2849. DOI: 10.1016/j.sjbs.2021.02.016.

Smith P, Cotrufo MF, Rumpel C et al. 2015. Biogeochemical cycles and biodiversity as key drivers of ecosystem services provided by soils. Soil 1: 665-685. DOI: 10.5194/soil-1-665-2015.

Srinarta K. 2022. Analysis of calculating the number of palm oil plant based on the Canopy Height Model (CHM) and Local Maxima (LM) algorithms. Jurnal Geodesi Undip 11 (1): 51-60. DOI: 10.14710/jgundip.2022.32315. [Indonesian]

Suab SA, Syukur MS, Avtar R, Korom A. 2019. Unmanned Aerial Vehicle (UAV) derived Normalised Difference Vegetation Index (NDVI) and Crown Projection Area (CPA) to detect health conditions of young oil palm plant for precision agriculture. Intl Arch Photogramm Remote Sens Spat Inf Sci XLII-4/W16: 611-614. DOI: 10.5194/isprs-archives-XLII-4-W16-611-2019.

Sukariawan A, Febrianto EB, Sakiah, Ridho M, Karnando D. 2021. *Ganoderma boninense* control in palm oil plantations using *Trichoderma harzianum* in various media. IOP Conf Ser: Earth Environ Sci 819: 012001. DOI: 10.1088/1755-1315/819/1/012001.

Sukarman, Saidy AR, Rusmayadi G, Adriani DE, Primananda S, Suwardi, Wirianata H, Nugroho AP, Sutiarso L. 2022. Application of oil palm dissection method to predict bunch production in commercial-Scale oil palm plantation. In: International Conference on Sustainable Environment, Agriculture and Tourism (ICOSEAT 2022). Tanjung Pesona Beach Resort, Sungailiat, Bangka, 21-23 July 2022. DOI: 10.2991/978-94-6463-086-2_21.

Thoha AS, Lubis OAO, Hulu DLN, Sari TY, Mardiyadi Z. 2022. Utilization of UAV technology for mapping of mangrove ecosystems at Belawan, Medan City, North Sumatra, Indonesia. IOP Conf Ser: Earth Environ Sci 977: 012102. DOI: 10.1088/1755-1315/977/1/012102.

Uke A, Nakazono-Nagaoka E, Chuah J-A, Zain N-AA, Amir H-G, Sudesh K, Abidin NZHAZ, Hashim Z, Kosugi A. 2021. Effect of decomposing oil palm trunk fibers on plant growth and soil microbial community composition. J Environ Manag 295: 113050. DOI: 10.1016/j.jenvman.2021.113050.

Yarak K, Witayangkurn A, Kritiyutanont K, Arunplod C, Shibasaki R. 2021. Oil palm tree detection and health classification on high-resolution imagery using deep learning. Agriculture 11 (2): 183. DOI: 10.3390/agriculture11020183.

Zhao J, Elmore AJ, Lee JSH, Numata I, Zhang X, Cochrane MA. 2023. Replanting and yield increasing strategies for alleviating the potential decline in palm oil production in Indonesia. Agric Syst 210: 103714. DOI: 10.1016/j.agsy.2023.103714.

Zheng J, Fu H, Li W, Wu W, Yu L, Yuan S, Tao WYW, Pang TK, Kanniah KD. 2021. Growing status observation for oil palm plant using Unmanned Aerial Vehicle (UAV) images. ISPRS J Photogramm Remote Sens 173: 95-121. DOI: 10.1016/j.isprsjprs.2021.01.008.