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Development of Aerial Online Intelligent Plant Monitoring System for Oil Palm (*Elaeis guineensis* Jacq.) Performance to External Stimuli

Muhammad Makky[#], Delviyanti[#], Isril Berd[#]

[#]Department of Agricultural Engineering, Andalas University, Padang, 25163, Indonesia.
E-mail: muhmakky@ae.unand.ac.id

Abstract— **Researches in bio-robotics fields have been done en-masse. Development in intelligence monitoring systems for agricultural application have unfold the possibility to observe individual plant response upon receiving external stimuli. In this study, artificial Bio-pores, 30 cm in diameter, were introduced to the ranges of oil palm trees in three commercial plantations. Various applications methods of Bio-pores, in particular depths and numbers per plant were investigated. The Bio-pores drilled around the root zone of the trees using an earth auger, and filled with chopped semi-decomposed fronds and midribs from the plantation maintenance (pruning). A robotic quadcopter drone with 2.7K camera, operated with pre-set flight-plan, employed to record the crown image of oil palm trees under observation. The drone flown at the altitude of 23±0.1 meters above the crown, recording each crown individually. Focus and setting of drone's cameras was set to automatic, enabling unbiased image recording. The weather conditions (sun radiation, cloud covering, wing speed) upon images recording were measured and recorded. When recording the images, the drone's GPS-assisted hovering system maintained its position in both axes (horizontal and vertical), producing identical image acquisition for each crown. All plants' crown was observed at 0, 30, 60, and 120 days after Bio-pores introduced. Image processing software was developed to segment and extract vegetation index (Vis) information from the images. Plants' morphological conditions (height, radial, and new leaf) were measured and analyse by statistical methods to understand various Bio-pores applications influences to plants development. Crown images were processed, and its features extracted and correlated with chlorophyll in leaves. Models developed to predict chlorophyll contents (A, B, and Total) in crown and Vis analyses methods were used to compare individual plant responding to this external stimulus by means of rotational-pivot charts. Results showed that intensive Bio-pores introduction promote plant's radial development and the emergence of new leaves. Furthermore, chlorophylls contents in leaves of plants with substantial Bio-pores applications were greater compared to normal plants. Models showed that optical features extracted from crown images obtained high coefficient of correlation (R2) with leaves chlorophyll contents. This study has paved the way for wisdom agricultural application in Indonesian oil palm industry.**

Keywords— **oil palm; bio-pores; intelligent plant monitoring system; vegetation indices; drone; wisdom agriculture**

I. INTRODUCTION

Palm oil and its derivative products are among Indonesia's most profitable commodity. Since 2006, it became the leading export products, replacing other agricultural shipments [1]. Annual world consumption of oil products is growing, in particular from emerging world economy (i.e. India and China) [2]. In order to maintain their world market share, Indonesian oil palm industry exercising any plausibly action to expand their production.

Despite this opportunity, the Indonesian government took a drastic more pro-environment policy, issuing a five-year moratorium on new oil palm plantation concessions, limiting any further expansion [3]. The policy aimed to promote more sustainable oil palm production practices while at the same time reducing global criticism on environmental issues in Indonesia [4]. As a consequence, the only option to increase oil palm production in Indonesia is through sustainable intensification of oil palm production, particularly through increased crop productivity [5].

While new-breeds specific genetic-modified cultivars of oil palm can yield up to 42 tons per hectare [6] when accompanied by excellent plant management, in general, most of the aging oil palm trees in Indonesia are Marihat cultivar, planted in early 1990s [7]. These trees required more luxurious application of fertilizers, to decelerate its declining productivity [8]. Nonetheless, application of synthetic fertilizers has restrictions, and over-fertilization inhibit plant growth, and risk environmental contamination due to leaching and waste of resources [9].

Among recent innovative methods adopted by oil palm industry in Indonesia, the utilization of plantations and mills solid wastes to complement the enormous requirement for expensive synthetic fertilization in plantation is the most preferable solution opted. Traditional method by scattering the wastes around the trees is not efficient. Materials will be washed by rains, and only minuscule amount can be utilized by the plants. Introducing artificial Bio-pores [10] in the vicinity of roots provide better access to water and nutrients for the plants and enhanced plant growth. Previous study suggests that large Bio-pores provide favourable environment for roots to grew better, and when it filled with decomposed organic materials would be benefits for securing extra water and nutrients for the plants [11]. The change of the environment influences different plant responds, (i.e. stomatal conductance, cell expansion, cell division, and rate of leaf appearance) and in nature attuned the growth and development of a plant [12].

Altering soil conditions, by means of Bio-pores, may deliver various plants responds. The results may not readily be explained [12]. The implication of bio-pores influence is still not understandable, especially in terms of the ability of the plants to absorb nutrients and water. In common, this nature can be explained as feedforward reaction, and observable through the alteration in leaves appearances. Abiotic stimulation produces immediate symptoms in leaves such as wilting or withering, and visually observed. Change of leaf colour is caused by the chlorophyll breaks down, and subsequently followed by other chemical changes. Chlorophyll play important role in photosynthesis process. It is considered as the main vegetation indices to predict the productivity of plants [13].

Chlorophyll content can be easily determined by means of non-destructive methods using device such as Chlorophyll Content Meter. This device is accurate and reliable for in-situ measurements. In addition, it is proven for non-destructive evaluation for in-situ chlorophyll content measurements, beside its user-friendly features. However, for tall trees, such as oil palm, the method is not practical and require much efforts. Mature oil palm trees can grow up to 20 meters high and provide great challenge for manual chlorophyll measurement using such device.

On the other hand, development in intelligence monitoring systems for agricultural application have unfold the possibility to quantify chlorophyll content in plant. The system employed unmanned aerial vehicle (drone) equipped with camera or other sensing devices [14]. Other intelligence monitoring systems utilized airborne hyperspectral imaging to provide a sensitive and high-resolution tool to map the health condition in individual palm trees [15]. In this study, similar low-cost system was developed to enable smart monitoring application for oil palm plantation in Indonesia.

This research aimed to understand oil palm trees morphological responds to various artificial Bio-pores introduction. Moreover, an intelligent monitoring system was developed to observe the trees crown, and quantified the chlorophyll content in its leaves through non-destructive manner. The study will pave the way for wisdom agriculture adoption in Indonesian oil palm industry.

II. MATERIAL AND METHOD

The study performed at three oil palm plantations, located in West Sumatra, Indonesia. The first site located in Kinali district (-0.0867332, 99.8860441), while the second and third location were in Bawan (-0.1703710, 99.9493757), and Manggopoh district (-0.2824046, 99.9597891). The elevations in all location range between 100 to 150 meter above sea level. On the first site, the soils are Alluvial, while the Andosols and Peat soils present on the second and third locations respectively [16]. The trees samples were 8 to 20 years, represented equally as samples in all three location. The samples cultivars are Marihat, produced by IOPRI [7]. All demo-plots covered by wireless mobile telecommunications technology networks (EDGE and GPRS) [17].

The trees were cultivated according to the standard of oil palm plantation [18]. Fertilizer applied at minimum level, half of normal application doze (Urea, KCL, Kieserite, SP-36, Borax, Sodium, Phosphorus, Potassium, Magnesium, Boron). The application done six months prior to the experiments.

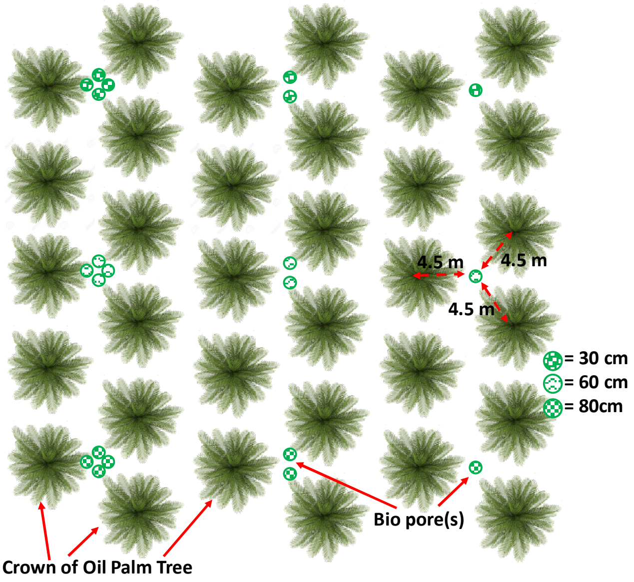

Fig. 1 Bio-pores application arranged in the demo-plot. For each location, 5 demo-plots, with 36 samples plants per plot, were setup. In total, there were 15 demo plots for this study. The experiment was set up as a randomized complete block design (RCBD) with five replications for each object. In this study, artificial Bio-pores prepared in three different depth; 30, 60, and 80cm

The Bio-pores created by drilling the soil around the perimeter of critical root zone, using an earth auger (MS 520+ 300mm, Tasso, PRC), approximately 450 centimetres from the stems' centre axis (Fig. 1). This distance is set according to the average half-way space between two adjacent trees. The Bio-pores drilled at various depth (30, 60, and 80 cm), representing upper, middle and lower root zone. The factors were setup in order to see different plants respond. In addition, the second factor in this study was set by differentiating the number of Bio-pores applied per tree (1, 2, and 4 holes), in order to observe how the plant, respond to different Bio-pores density. After drilled, the holes were filled with chopped semi-decomposed midribs and fronds, obtained from the pruning process, with density of 0.6 kg.cm-3. These bio-material wastes normally placed around the oil palm trees in oil palm plantation, and slowly decomposed naturally, allowing additional carbon stocks to the soils. In this study, the decomposition process of the bio-materials performs naturally without any bio-activator addition. Each Bio-pores treatments were replicated 5 times.

In order to avoid interplay between plants and Bio-pores treatments, each sample was punctuated by untreated trees. In total, 150 oil palm trees were used as samples in this study, and arranged according to Table 1. Control plants were specified at each study site, and selected randomly, five trees per location (Table 1). The samples were placed according to the Randomized Complete Block design, a standard design for agricultural experiments. The field is divided into units to account for any variation in the field. Treatments are then assigned at random to the subjects in the blocks-once in each block.

TABLE I
THE RANDOMIZED COMPLETE BLOCK DESIGN FOR THE BIO-PORES APPLICATION IN EACH LOCATION

Treatment	**Bio-Pores (30 cm Diam.)**		**Number of Samples**		
	Depth (cm)	**Density (per plant)**	**Sites**		
			1	**2**	**3**
Control	-*	-*	5	5	5
1	30	1	5	5	5
		2	5	5	5
		4	5	5	5
2	60	1	5	5	5
		2	5	5	5
		4	5	5	5
3	80	1	5	5	5
		2	5	5	5
		4	5	5	5

*Assigned as control

Prior to the Bio-pores application, each individual tree's crown was recorded, using ultra-high definition digital-camera, suspended below a robotic quadcopter drone. It flown above the tree crown, positioned at the crown centre, and subsequently record the image, while the camera is set perpendicularly toward the ground. The drone's camera-view was set to cover the whole crown spread (from dripline to dripline), enable image recording for all parts of the crown. The drone position upon recording is set at 23 ± 0.1 meter above the ground. The drone equipped with a built-in camera 2.7k with Complementary Metal Oxide Semiconductor (CMOS) image sensor. The sensor is coated with Bayer-filter-mosaic in the form of colour-filter array. The filter produces red-green-blue (RGB) colour picture, with resolution of 2704 by 1524 pixels [19]. The Bayer pattern filter mosaic-sensitive utilized luminance and chrominance-sensitive elements [20]. The camera's image sensor is layered with Ultra Violet and infra-red filter glasses in order to avoid false-colour image produce by the sensor.

The drone operated with the pre-set flight plan to record the crown of trees under observation. Each plant's crown recorded individually, using drone's stabilized 3-axis rotating camera. Upon recording, the location recorded by the drone's Global Positioning System (GPS), with accuracy up to ±0.1m (vertical) and ±0.3m (Horizontal) [21] the information included in the image as geo-location data.

Focus and setting of the camera were set auto-mode, for producing consistent image recording results. Auto white balance in camera's sensor was set to compensate different intensity and colour of sunlight during recording. The setup enabling drone's camera chromatic aberration and lens distortion to be reduced by 56% and 36% respectively [22]. Each crown recorded three times, and the best image produce among them was selected.

The drone controlled remotely using an Android™ based mobile-phone (Asus, Zenphone 2, Taiwan). Android (Ver. 6.0.1) [23] mobile application software platform (DJI, USA) in the phone provide live-view option, enables the operator to directly observe the scenery viewed by the drone's camera. The image for each recorded crown transferred from the drone to the mobile phone through a wireless local area networking technology [24], based on the IEEE 802.11 standards [25]-[27]. The network uses 2.4 gigahertz (12 cm) Ultra High Frequency (UHF) radio bands [24]. The mobile phone itself can connect to the Internet via a wireless access point, mostly using wireless mobile telecommunications technology [28]. Using this connection, the crown images and its geo-information were uploaded to a cloud computing service platform, whenever possible [28]. Using wireless and internet connection, remote access computer was set up to download these images. The retrieved file then processed using a C# based programming to segment object and backgrounds in the image.

The surroundings conditions when the crown recorded are observed. The sun radiation was measured between 16 and 17 MJ/m2. Climatic conditions relatively similar in all locations, with precipitation measured between 2372.3 mm and 3267 mm annually. All study locations accommodated optimum growth conditions for oil palm cultivation [29]. The wind speeds condition was measured between 2.5 and 3 m/s. While recording the image, the GPS-assisted hovering system automatically work to maintain drone flight position, both in horizontal (±0.3m) and vertical (±0.1m) condition, thus image acquisition condition was similar for every crown recorded.

The trees crown recorded every 30 days for the next 120 days. The image recorded process with a developed software platform. The image processing software developed based on C# programming language, segmenting object from the background, and extract vegetation indices information (RGB) from the images. The vegetation indices selected based on the colour response of the leaves, as observed by the drone camera, when recording the plants' crown.

Several methods used for extracting and analysing vegetation indices features in the image [30]-[31]. Extractions and analyses methods [32]-[40] were used to compare every plant vegetation indices, from its crown images. A rotational-pivot chart created based on the features data to explain the image texture for further analyses [33], [36]-[38]. The changes in crowns' image textures are used to understand how each individual plant copes with stimulation caused by the bio-pores introductions.

For every crown, the leaves were analysed to estimate chlorophyll content, corresponding to the plant N-status. The leaves sampling used the 17th frond leaves of oil palm [41]. The selection of the 17th frond leaves for analysing the N status suggested due to its sensitivity to indicate nutrient content [41]. Furthermore, the nutrient status in the 17th frond leaves provide better correlation to oil palm production [42] compare to other leaves. The total chlorophyll content of the leaves samples determined using acetone extraction method described by Arnon [43], Hiscox & Israelstam [44], and Richardson et al. [45].

The plants total chlorophyll content influences its photosynthesis rate [46], which correlated to the productivity [47]. The chlorophyll content results from the measurements then compared with the leaf greenness as observed by the drone camera.

Plants morphological development was measured. Plant height, stem diameter and number of fronds (leaves) measured and calculated every 30 days. Data were averaged over the replications for all measurements and their mean were used in deriving relationships between treatments. Duncan's Multiple Range Test (DMRT; $p<0.05$ and $p<0.01$) was used to detect significant grouping among treatments. The index of Plants morphological development calculated based on the differences of three morphological features observed in this study. The higher index indicating stronger positive influence on treatments to plants development, and selected as a reference for determining the best treatment on each study site.

III. RESULTS AND DISCUSSION

The plants growth was observed based on the changes of the leaves on the tree crown, stem radial increment, the stem high, and changes of the concentration of chlorophyll in the leaves. The oil palm trees are Arecaceae (Palmae), and its cylindrical trunk can grow up to 75 cm in diameter, for old trees [48]. The tree can reach 25 m with ordinary increment up to 1 $m.yr^{-1}$ [48]-[49].

In this study, the trees morphological developments were measured for 120 days. The observation to all samples showed different plants responds according to the treatments (Table 2). In the first and second sites, significant stem growth ($p < 0.01$) at 30 days after treatments were observed on plants with four 80 cm depth Bio-pores application. Significant growth also observed in the first location when plants treated with two 80 cm depth Bio-pores. However, in subsequent observations, (days 60 and 120) the plants obtained similar high with control. Thus, bio-pore application provided no significant influence to the plants height increment. According IOPRI [50] and Lubis [51], on average, different cultivars have distinguished morphological growth, and not necessarily influence to the plants age (Table 3).

In contrast to the stem growth, stem radial development has a strong correlation with the Bio-pores treatments (Table 2). Bio-pores application promote acceleration of radial stem increment in all sites. On the other hand, density and depth of Bio-pores introduced to the sample plants failed to show a general trend. The acceleration of radial growth can be observed at 30 days after application. In all experimental sites, most plants treated by bio pore(s) showed extended growth of stem diameter compare to control, with the exception of plants with single or two 30 cm deep bio-pores application in site 1. Similarly, plants with single 60 and 80 cm deep Bio-pores, grow on the second site, did not produce better radial increment compare to control. At 60 days, most plants produce higher radial growth compare to controls, nevertheless, some plants only obtained similar results to controls. Along with the observation time, the radial development was progressing. By the end of this study, plants with higher density of deeper Bio-pores produce significantly larger stem diameter, compare to all control.

While the trend was consistent with the samples at location one and three, the treated plants at location two were similarly responsive when applied by shallower Bio-pores, although Bio-pores density did not principally determine the results. The results suggested that deeper Bio-pores (80 cm) application is more suitable when applied to the oil palm trees grown on Alluvial and Peat soils, while for the Andosols soils, medium depth Bio-pores (60 cm) was enough to stimulate the plants to enhanced its radial development.

On average, oil palm plants treated with deeper and denser Bio-pores have their stem diameter increased by 2.2 mm after 120 days. While this was still lower than the growth of stem diameters of treated plants at location one (4.1 mm) and three (3.6 mm), but when compared with the controls, plants in the location two have 57.14% larger stem diameter growth in comparison to the plants without Bio-pores introductions. The value suggested that oil palm plants cultivated in alluvial soils responds better when introduced by more Bio-pores, when compared to the similar plants grown in Andosols and Peat soils. Oil palm plants grown in both soils only produce 28.13% and 20% greater stem diameter growth respectively compared to the control plants.

In previous studies, stem radial growth in oil palm trees occurred due to development of the meristem cells. This activity was more visible in their early development stages (age 6 to 9 yrs.) [41]. In this development stages, plants stem increased radially, in particular at the base section. Previous studies suggested that the diameter of the stem can reach up to 60 to 100 cm [41], [50]-[52]. Thus, in this study, Bio-pores introductions on oil palm plantations were able to stimulate an increase in radial growth of the plants' stems, up to 4.1 mm in 120 days, equivalent to 123 mm per annum, 23% greater than average radial development of normal plants.

The oil palm belongs to the cocoideae species, and grows actively throughout its life span. The leaves produced by the plants every 12-14 days [41], from its primordial point. The spear-shaped leaves development requires two years from initiation until fully grown. The healthy leaves of the oil palm able to perform photosynthesis effectively for 24 months, before it become degraded. Each leaf is para-pinnate in form, and produced with a uniform number on each variety. However, environmental factors, in particular precipitation and soil fertility, will determine the number of leaves developed.

In the most favourable environment, an oil palm can produce up to 48 new leaves annually [41]. For younger plants (3-4 years), the new leaves emerge 20 to 30 fronds per year, and decreased along with the age of the plants. On the adult trees, the number of new leaves decreased to 18 fronds per year [52]. Furthermore, in less vapourable condition, the new leaves only emerge 16 - 18 per year.

In this study, the emergence of new leaves on oil palm trees differed according to its bio pore(s) application (Table 2). Results suggested that, after Bio-pores introduced, the new leaves development increase 23.33% higher than control plants. The rapid growth can be achieved when the deeper and denser Bio-pores introduced to the oil crops grown in the alluvial soil (site 1). Introduction of Bio-pores treatment also promoted new-leave developments in second

(Andosols soils) and third location (Peat Soils). These obtained through quad 80cm Bio-pores application per plant, with greater results compared to controls. Results of this study provide different finding, when compared to others [51], [53]-[54]. The average number of new leaves emerging from the oil palm trees, cultivate in peat soils, and treated with Bio-pores obtained better results. Quad 80cm deep Bio-pores when applied to oil palm plants, result in 22 new fronds per year, as extrapolated from 120 day observations. This result successfully promotes better plants growth condition, in particular, when the cultivation located on peat soils [53]-[54].

TABLE III
OIL PALM TREES MORPHOLOGICAL GROWTH ACCORDING TO BIO-PORES INTRODUCTION

Location	Treatment	Bio-pores Volume[*] (cm3)	Development of Plant Morphology[**]																										Growth Index[***]
			Average Height Increment (cm)									Average Radial Increment (cm)									New Leaves Emergence								
			30		60		90		120			30 d		60 d		90 d		120 d			30 d		60 d		90 d		120 d		
1	Control (A)	0	5.5	a	10.95	a	12.72	a	27.4	a		0.07	a	0.12	a	0.15	a	0.32	a		0.9	a	1.7	a	3.3	a	6.5	A	1
	1_30 cm _1	84823	5.54	a	10.96	a	12.74	a	27.49	a		0.08	a	0.12	a	0.16	a	0.32	a		1.0	a	1.8	a	3.4	a	6.6	A	1
	1_30 cm _2	169646	5.57	a	11.12	a	12.86	a	27.58	a		0.07	a	0.14	b	0.16	ab	0.32	a		1.1	b	1.9	b	3.3	a	6.7	A	1
	1_30 cm _4	226194.7	5.59	a	11.01	a	12.92	a	27.44	a		0.08	b	0.14	b	0.17	b	0.33	a		1.0	ab	2.0	b	3.6	ab	6.7	A	1
	1_60 cm _1	169646	5.62	a	10.99	a	12.74	a	27.51	a		0.09	b	0.13	a	0.16	ab	0.34	a		1.0	ab	1.8	a	3.4	a	6.6	A	1
	1_60 cm _2	339292	5.63	a	11.28	a	13.07	a	27.66	a		0.11	b	0.16	b	0.19	b	0.35	b		1.2	b	2.1	b	3.4	a	6.7	A	1.667
	1_60 cm _4	452389.4	5.79	ab	10.97	a	13.09	a	27.51	a		0.11	b	0.14	b	0.15	a	0.37	b		1.0	b	2.0	b	3.4	a	6.6	A	1.667
	1_80 cm _1	339292	5.71	a	11.23	a	12.82	a	27.55	a		0.11	b	0.14	b	0.18	b	0.32	a		1.0	ab	1.9	ab	3.4	a	6.9	ab	1.333
	1_80 cm _2	678584	6.05	b	11.6	ab	13.16	a	27.76	a		0.13	b	0.16	b	0.19	b	0.35	ab		0.9	a	1.9	b	3.5	ab	6.6	A	1.333
	1_80 cm _4	904778.8	6.38	b	11.3	a	13.11	a	27.6	a		0.13	b	0.20	b	0.24	b	0.41	b		1.6	b	2.7	b	3.4	a	7.3	B	2.333
2	Control (B)	0	5.83	a	9.083	a	14.99	a	26.62	a		0.03	a	0.05	a	0.07	a	0.14	a		0.9	a	2.1	a	3.8	a	6.0	A	1
	2_30 cm _1	84823	5.89	a	9.115	a	15.08	a	26.71	a		0.04	b	0.05	a	0.08	ab	0.15	a		0.9	ab	2.2	a	3.9	a	6.0	A	1
	2_30 cm _2	169646	5.85	a	9.261	a	15.15	a	26.65	a		0.04	b	0.05	a	0.09	b	0.15	ab		1.0	b	2.1	a	3.9	a	6.0	A	1.333
	2_30 cm _4	226194.7	6.01	a	9.216	a	15.21	a	26.63	a		0.04	b	0.05	b	0.10	b	0.16	b		0.9	a	2.2	ab	4.0	ab	6.0	A	1.667
	2_60 cm _1	169646	5.84	a	9.192	a	15.08	a	26.72	a		0.03	a	0.05	a	0.08	ab	0.16	b		1.0	b	2.2	ab	3.9	a	6.1	A	1.667
	2_60 cm _2	339292	5.85	a	9.432	a	15.35	a	26.78	a		0.05	b	0.08	b	0.10	b	0.16	b		0.9	ab	2.4	b	4.1	ab	6.4	ab	2
	2_60 cm _4	452389.4	5.84	a	9.568	ab	15.25	a	26.66	a		0.04	b	0.09	b	0.09	b	0.14	a		1.2	b	2.3	b	3.8	a	6.2	A	1
	2_80 cm _1	339292	5.94	a	9.149	a	15.26	a	26.91	a		0.03	a	0.06	b	0.09	b	0.15	ab		1.2	b	2.4	b	3.8	a	6.0	A	1.333
	2_80 cm _2	678584	6.22	ab	9.375	a	15.46	a	27.08	a		0.08	b	0.09	b	0.09	b	0.18	b		1.2	b	2.6	b	3.9	a	6.3	ab	2
	2_80 cm _4	904778.8	6.57	b	9.259	a	15.14	a	27.51	a		0.04	b	0.09	b	0.15	b	0.22	b		1.1	b	2.9	b	4.0	ab	6.6	B	2.333
3	Control (C)	0	6.08	a	8.426	a	12.53	a	24.6	a		0.07	a	0.08	a	0.16	a	0.30	a		1.0	a	2.3	a	4.0	a	6.0	A	1
	3_30 cm _1	84823	6.17	a	8.428	a	12.54	a	24.61	a		0.08	b	0.08	a	0.16	a	0.31	a		1.1	ab	2.4	a	4.1	a	6.1	A	1
	3_30 cm _2	169646	6.17	a	8.582	a	12.69	b	24.76	a		0.09	b	0.09	b	0.17	a	0.31	a		1.2	b	2.5	ab	4.1	a	6.1	A	1
	3_30 cm _4	226194.7	6.27	a	8.606	a	12.61	b	24.78	a		0.09	b	0.10	b	0.17	a	0.30	a		1.0	a	2.4	a	4.2	a	6.1	A	1
	3_60 cm _1	169646	6.18	a	8.54	a	12.54	b	24.61	a		0.09	b	0.09	b	0.17	a	0.31	a		1.1	b	2.4	a	4.1	a	6.1	A	1
	3_60 cm _2	339292	6.27	a	8.641	a	12.59	b	24.89	a		0.10	b	0.11	b	0.18	ab	0.31	a		1.2	b	2.6	b	4.3	ab	6.0	A	1
	3_60 cm _4	452389.4	6.44	ab	8.469	a	12.89	b	25	a		0.08	b	0.11	b	0.17	a	0.31	a		1.5	b	2.5	ab	4.5	b	6.4	ab	1.333
	3_80 cm _1	339292	6.44	ab	8.525	a	12.62	b	24.63	a		0.08	b	0.08	a	0.18	ab	0.31	a		1.0	a	2.5	ab	4.0	a	6.3	A	1
	3_80 cm _2	678584	6.61	ab	9.064	ab	13.08	b	24.87	a		0.14	b	0.15	b	0.23	b	0.35	b		1.3	b	2.7	b	4.4	ab	6.2	A	1.667
	3_80 cm _4	904778.8	6.6	ab	8.694	a	12.81	b	25.29	a		0.13	b	0.15	b	0.22	b	0.36	b		1.3	b	2.4	a	4.4	ab	6.8	B	2.333

[a] nonsignificant at the 0.05 probability level.

[ab] Significant at the 0.05 probability level.

[b] Significant at the 0.01 probability level.

[*] Re-filled with chopped semi decomposed fronds and leaves of oil palm trees

[**] Within columns, means followed by the same letter are not significantly different according to Fisher's LSD (0.05)

[***] Higher values indicating stronger positive influence to plants development

TABLE IIIII
MORPHOLOGICAL DEVELOPMENT OF OIL PALM TREES AT 12 YEARS [50]

Morphological Development	Cultivar													
	Dolok Sinumbah	Bah Jambi	Marihat	AV ROS	La Me	Yangambi	Simalungun	Socfindo (L)	Socfindo (Y)	SP-1 Dumpy	PPKS 540	PPKS 718	PPKS 239	Langkat
Height Increment (cm/annum)	65	65	53	68	58	70	75-80	50	50	40-55	72	75	62.5	60-70
Stem Diameter (cm)	98.37	97.72	98.37	106.30	98.37	98.53	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
New Leaves (/Month)	2.25	2.25	2.17	2.25	2.33	2.33	n.a.	2.58	2.67	n.a.	n.a.	n.a.	n.a.	n.a.

[n.a.] data not available

According to the previous study [55], plants that grow in soil that is too soft or in the which the roots are forced to grow in very large pores can also induce certain conservative responses. The roots that grow in this Bio-pores will produce stimulant signals that may influence stomatal conductance, cell expansion, cell division and the rate of leaf appearance [55]. Although introduction of artificial bio pore(s) to plants had been studied, the nature the plants responding to these external stimuli is still believed as a complex probability of a network of hormonal and other responses involved in attuning the growth and development of a plant to its environment [55]. Most plants respond to the change in their soil environment in ways that cannot readily be explained, in terms of the ability of the roots to take up water and nutrients. Roots that sense favourable conditions in its environment may produce the acceleration signals to the shoots [56], stem [57] as well as to the leaves [58].

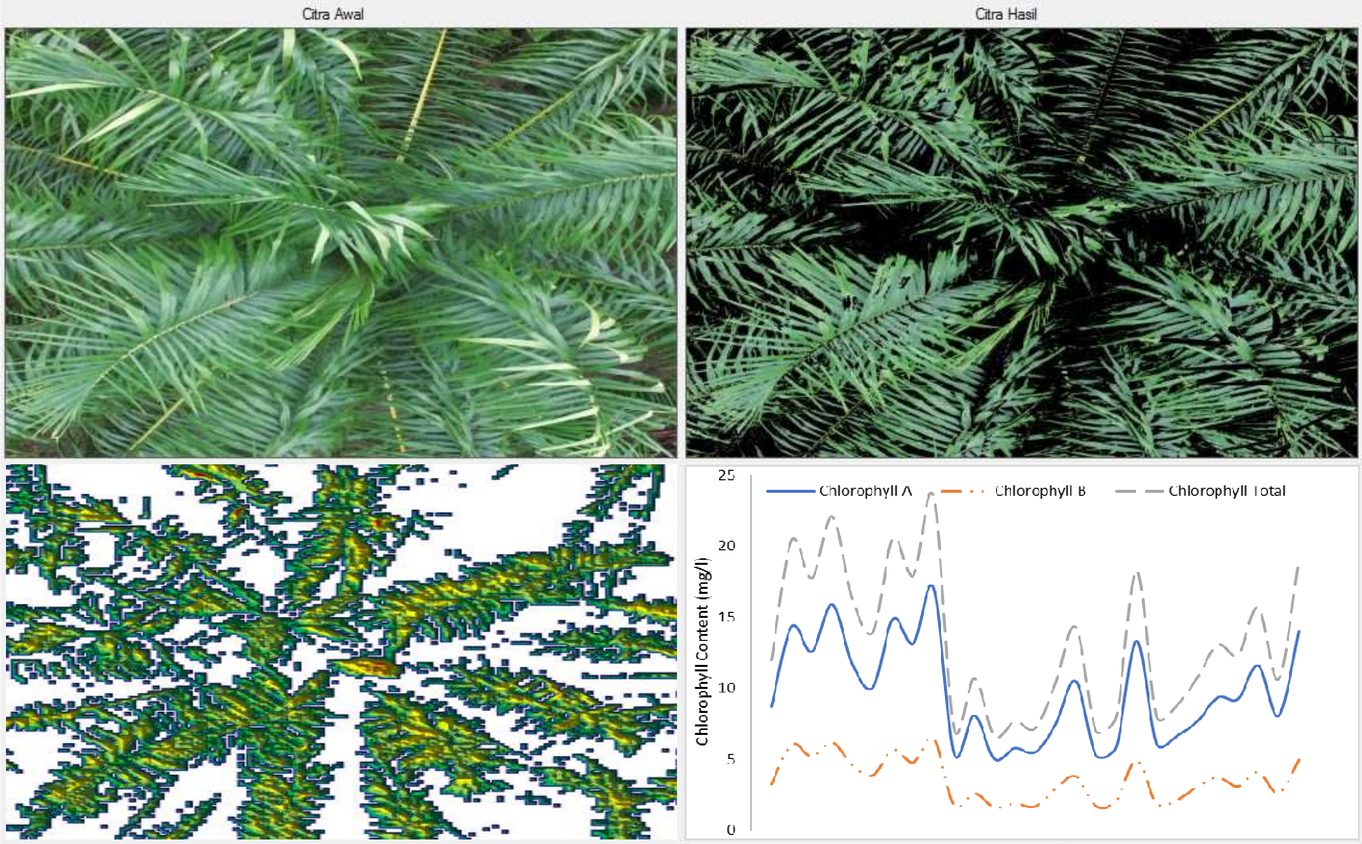

Fig. 2 Image processing software developed to extract distinguished features from crown image and modelled the chlorophylls content based on the established model

From this study, it was known that Bio-pores application alone cannot solely improved morphological development of the oil palm trees. Soil type and condition, depth of Bio-pores applications as well as the density of Bio-pores play crucial role to the plants responses, with different influences (Table 2). Nonetheless, in general, the introduction of Bio-pores produced positive responds from the plants in terms of its morphological development.

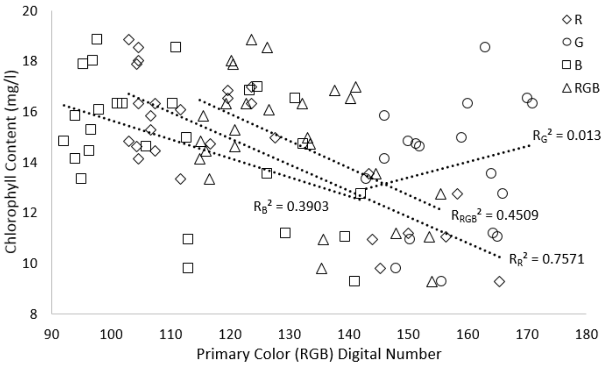

Fig. 3 Relationships of chlorophylls content and primary color (RGB) of the crown. the crown recorded by an UAV and the images subsequently processed to extract the primary color features (RGB). Leaves samples from the crown then analized to measured its cholorphyll concentration

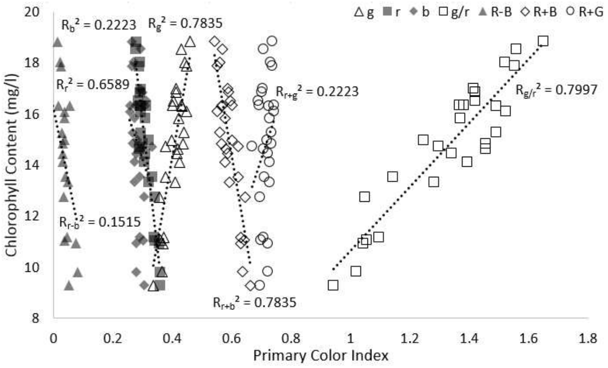

Fig. 4 Relationships of chlorophylls content and the ratio of normalized primary color (RGB) of the oil palm trees' crowns

The results also suggest that plants condition may have influenced by Bio-pores introductions. The Bio-pores provide channels for deep roots to water and nutrients and ease the overall crop access to both abiotic needs. The density of Bio-pores, number of Bio-pores per unit area, and proportion of Bio-pores occupied by roots were strongly enhanced the morphological development of a plant [11]. Previous study [11] suggest that the percentage of Bio-pores occupied by roots increased along with the size and depth of Bio-pores. Less roots grown in restricted Bio-pores (shallow and small), suggesting that roots opt to enter sizeable bio pore(s) and remained in it [11].

In the sustainable agriculture studies, it is important to identify plants that are efficient of utilizing artificial Bio-pores for better economic and management system in cultivation. While in their natural habitat, plant's conservative behaviour is likely to improve the plants' chances of success. In agriculture, the condition is reverse. The plants choose to prioritized generative results compare to their survival. Plants often transform their natural behaviour in wild, to achieved better production compare to their predecessor [59]. Frequent irrigation often required to increase yield, even when normal water application is sufficient [59]-[60].

Comparing to normal conditions, oil palm which introduced to external stimuli in this study (i.e. artificial Bio-pores) produce better morphological development in two aspects. First is the accelerate radial growth of the stem, and secondly is the more frequent emergence of new leaf. While different bio-pores application produced various responds to plants, the environment conditions, in particular the growth media, provide primary factor to the plants response to the external stimuli. These responds can be calculated into an Index, indicating how strong a plant responding its morphological development towards more favourable living conditions.

This study shown that, introducing artificial Bio-pores at the critical perimetry of the root zone, and filled it with decomposed plants wastes provide a feeding ground for the roots, in particular to absorb nutrients resulting from the decomposing process of the wastes materials. In addition, the holes filled by water during rainy days, act as a temporal water storage that can be utilized by the plants for their growth.

Moreover, the Bio-pores can act as a micro climate control to the root zone, enhancing aeration and ion exchange, thus providing a luxurious condition for the roots to grow, and provide precious minerals for photosynthesis process [13]. The process reacts the carbon dioxide from air around the leaves, with water absorb by roots, producing glucose, a form of sugar [46]. The glucose then used in respiration by plants, or in other way converted into starch and stored [47]. The photosynthesis process produced oxygen as a by-product. This condition can maintain the water status in leaf at high [60]-[61].

Since the chlorophyll in the leaves plays important role in the photosynthesis process [13], the concentration of chlorophyll in leaves of the sample plants is measured in this study and compared with the electromagnetically reflection of visible light from the leaves surface, as recorded by camera. The plants' crowns were recorded using camera, attached to a drone. The image then processed using a developed image processing software (Fig. 2). The results showed that difference Bio-pores application to oil palm trees produces different change in plants' chlorophyll content in their leaves. Three primary colours, namely red (R), green (G), and Blue (B) were extracted from each crown image, then correlated with the chlorophyll content of the corresponding leaves.

Among the mean brightness of three primary colours of the leaves of plants, R have high correlation with the measured chlorophyll content (Fig. 3), with negative coefficient. Furthermore, the correlation of the B and G value with measured chlorophyll content was observed to be poor and independent for each location. Similar to B, the average total mean brightness (RGB) have medium R2 when correlate with the chlorophyll content, with decreasing trend. Although it was poorly correlated with chlorophyll content, the primary colour of G and B may have influenced, to certain degree, with Bio-pores introduction. The results showed that R could be use as one of primary variable to estimate chlorophyll content in oil palm leaves. Nonetheless, using a single-color component for determining the chlorophyll content in oil palm plants leaves may not produce high accuracy, due to its R2 limitation.

In various studies, image processing techniques have been developed to monitor plant health using mainly the RGB (Red Green Blue) colour model [62]. Images of leaves under consideration were acquired by cameras, and the chlorophylls and nitrogen content of the plants were modelled according their RGB value. Adamsen et al. [63] stated that the relationships between G/R and SPAD were linear over most of the range of G/R and this ratio responded to chlorophyll concentrations. Finally, Hu et al. [64] showed that the RGB colour indices of R, G and R+G+B, R-B, R+B, R+G had significant relationship with chlorophyll content.

Both methods [63]-[64] were tested in this study, and the results (Fig. 4) suggested that the ratio of normalized g and r (g/r) produce better R2 to the leaves chlorophyll content, as contrast to other models [62]-[64]. The result indicated that for crown-level observation, normalization of colour model minimized the root mean square error (RMSE) for chlorophyll concentration determination model, thus promoting a new mean of non-destructive evaluation method for oil palm intelligent monitoring.

The plant monitoring system developed in this study may provide solution for real time estimation of leaf chlorophyll content, whenever manual measurement using chlorophylls meter is not possible. The mentioned cases already reported by Yadhav et al. [65] and Kawashima and Nakatani [66], and the results indicated that RGB based image analysis was a useful tool for chlorophyll estimation in regenerated plants.

Although several non-destructive methods already available to estimate the Nitrogen in plants, and subsequently provide the fertilizer recommendations, most of these methods are based on vegetation index observation through manual assessment. This study open the opportunity of aerial evaluation for remote sensing and plants performance. The use of multiple sensors from aerial platforms such as satellite, airborne, and unmanned aerial vehicles (UAV) have the potential for evaluating the plant performance in much wider area. The low-cost system used in this study remove the limitations of these technologies for commercial use at individual farmer's field or household.

IV. CONCLUSIONS

The study explained how the oil palm trees responded morphologically to the disruption of its environment condition, through the introduction of artificial bio-pores. The Bio-pores, 30 cm in diameter, and depth of 30, 60, and 80 cm arranged with different density (1, 2, and 4 per plant). The treatments gave different effects on the concentration of chlorophyll in the crown. Variations of soils as well as the density of Bio-pores applied on each individual plant determine significant differences between the treated and control plants. Deeper Bio-pores (80cm) when administered with denser numbers (4 pores per plant) brought positive significant influence to the morphological growth, peculiarly the stem diameter and the emerging of new leaves, when oil palm trees planted in alluvial and peat soils. However, when the trees planted in andosols soils, medium depth Bio-pores (60cm) produce better results in term of morphological features, when compared to control. The intelligent plant monitoring system developed in this study provide solution for real-time estimation of leaf chlorophyll content, notably whenever direct chlorophylls measurement using hand-held devices is not possible. The ratio of normalized primary colour from the image produce better coefficient of correlation for real-time estimation of chlorophyll concentration of the plants' crowns, with R2 of 0.7997 and 0.7835 for r/g and r+b respectively.

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