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Mathematical Approach to Forecast Oil Palm Plantation Yield under Climate Change Uncertainties

Jaya Prasanth Rajakal[a], Viknesh Andiappan[b], Yoke Kin Wan[a,*]

[a]School of Computer Science and Engineering, Faculty of Innovation and Technology, Taylor's university, Lakeside Campus, No. 1 Jalan Taylor's, 47500 Subang Jaya, Selangor, Malaysia.
[b]School of Engineering and Physical Sciences, Heriot-Watt University Malaysia, 62200, Putrajaya, Wilayah Persekutuan Putrajaya, Malaysia
yokekin.wan@taylors.edu.my

Climate change is affecting crop yields and disrupting the global food system. Oil palm is one of the important vegetable oil crops and is widely cultivated in the tropical belt. Accounting the climate change effects while forecasting the oil palm yield is critical in building a resilient palm supply chain and ensuring food security. Though the productivity of oil palm plantations depends on various agroclimatic conditions and agronomic practices, the palm age, rainfall, and temperature are critical variables determining the yield. However, most works have failed to account for the age of palms. This work aims to account for the age of palms and also the impact of changing rainfall patterns and rise in temperature in forecasting the yield. A simple but robust mathematical approach is proposed to forecast yield at plantation level by accounting for the above-mentioned factors. An illustrative case study is solved to demonstrate the model. The results show that climate change effects results in 33.31 % - 8.18 % reduction in FFB yield. The proposed model allows effective planning and management of activities at plantations and can offset the impact of fresh fruit bunch yield uncertainties due to climate change effects on the downstream units of the palm supply chain.

1. Introduction

Oil palm is a humid tropical crop that thrives well under high rainfall and moderate temperatures. Palm oil is produced from the fresh fruit bunches (FFB) harvested from oil palm plantations. Palm oil production has increased from a mere 1.8 Mt in 1968 to 65.15 Mt in 2018 and currently contributes around 35 % of global vegetable oil production. It also accounts about 40 % of edible oil exports (Chong et al., 2017) and unlike other vegetable oils which have only regional relevance, palm oil is widely traded at the international market. Oil palm has positioned itself as one of the major oil crops. It has emerged as a crucial commodity in meeting global vegetable oil demand where a large population, especially in the developing countries, rely on cheap and available cooking oil. Given the significance of palm oil, any disruption in its production will not only affect the palm supply chain but also have large implications on global food security.

Climate change has negative impacts on oil palm plantations (Flesis et al., 2017). The major climate change effects at the tropics are erratic rainfall patterns resulting in floods or drought, rise in mean temperature, new pests and plant diseases, etc. It is expected that the frequency and intensity of such extreme events to increase in the coming years (Nelson et al., 2014). Under these circumstances, forecasting the FFB yield can help to improve the ability to respond to disruptions caused by climate change. Also, forecasting allows effective planning and management of activities at downstream units in the supply chain synchronising with the disruption in the yield at plantations (Feng, 2016). However, any such attempt can be successful only with a reasonably accurate forecast of the yield accounting for the climate change effects.

Most of the works in forecasting the FFB yields have used either statistical (Keong and Keng, 2012), artificial neural network (Kartika et al., 2016) or remote sensing (Carolita et al., 2017) methods. The statistical and artificial neural network methods require historical data while remote sensing requires high-level satellite imagery. Such requirements restrict the usage of these models by decision-makers at the plantation level. More often these models are used for forecasting at a regional or national level. Also, these works have not

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explicitly considered the climate change effects in forecasting the FFB yield. Oil palm is a perennial crop with a lifespan of 25 y – 30 y and the FFB yield from the tree varies with its age. The above-mentioned works have also failed to account this varying yield due to maturity. Apart from this, previous research works studied the impacts of climate change effects like rainfall (Christensen et al. 2013), temperature (Paterson et al. 2015), sea level rise (Siwar et al. 2013), increased atmospheric carbon concentration (Long et al. 2006), pests and diseases (Paterson et al. 2015) independently on the FFB yield. However, none of the works accounted for the cumulative impact of the different climate change effects on the FFB yield. The literature analysis has allowed to synthesis the following research gaps,

- Very limited works are focused exclusively on forecasting yield at plantation level.
- The previous works did not consider the varying yield due to maturity of the plantations in forecasting
- A comprehensive tool accounting the cumulative impacts of the different climate change effects on oil palm yield has not been developed.

To address the above discussed research gaps, this paper aims to develop a simple but robust mathematical approach to forecast the FFB yield of plantations accounting for the age of the plantation and climate change effects. This work restricts in considering water deficit and rise in temperature due to their significant impact on yield and availability of established data. This work intends to integrate the cumulative impacts from the physiological (oil palm maturity) and climate change factors (rainfall and temperature) in yield forecasting as shown in Figure 1a.

2. Problem statement

The formal problem definition is as follows: Given are a set of plantations $g \in G$ with area A_g producing fresh fruit bunches (FFB). The FFB production from the plantation *g* depends on its age or maturity ($F_{g,t}^{\mathrm{MTY}}$) at the period *t*. Also, climate change effects like water deficit ($\mathrm{WD}_{g,t-1}$) and rise in temperature ($T_{g,t-1}$) have a significant negative impact on the FFB yield. This work aims to account these factors in forecasting the FFB production ($X_{g,t}^{\mathrm{FC}}$) from the plantations $g \in G$ during the year *t*.

3. Mathematical formulation

3.1 Modelling oil palm yield profile

As discussed in Section 1, the yield of the oil palm depends on its age. Typically, the yield from an oil pam varies every year. A yield profile plots the age of the palm against its maximum yield under optimal agro climatic condition as shown in Figure 1b. This section presents the mathematical technique to model Figure 1b and is referred to as the yield profile model.

(a) (b)

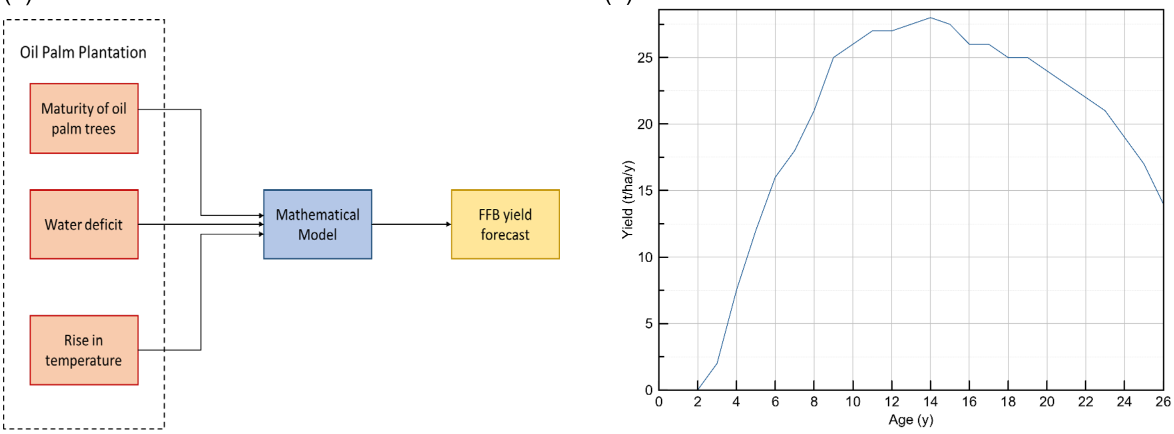

Figure 1: Illustration of a) Overview of FFB forecasting and b) Typical yield profile of an oil palm tree (Tan, 2014)

The FFB yield of an oil palm tree (w) is a function of its age (m) as shown in Eq(1). It can be noted that age or maturity is the independent variable and yield is the dependent variable.

$$w = f(m) \tag{1}$$

A set of discrete points $m_{g,i}$ $(i = 1,2,3,...I)$ are identified with $m_{g,1}$and $m_{g,I}$ as the lower and upper limits. The points $m_{g,i}$ are taken along the horizontal axis as shown in Figure 2. The points $m_{g,i}$ are identified such that to segmentize each linear section of the curve. It can be noted that the oil palm yield profile curve has linear sections or approximate linear sections from age 0 - 2, 2 - 5, 5 - 7, 7 - 9, 9 - 11, 11 - 14, 14 - 19 and 19 - 26. Therefore, the points $m_{g,1}$, $m_{g,2}$, $m_{g,3}$, $m_{g,4}$, $m_{g,5}$, $m_{g,6}$, $m_{g,7}$, $m_{g,8}$ and $m_{g,9}$ are identified at age 0, 2, 5, 7, 9, 11, 14, 19 and 26 as shown in Figure 2. On substituting $m_{g,i}$ in Eq(1), corresponding yield values for each point can be determined, obtaining another set of discrete points referred to as $w_{g,i}$ $(i = 1,2,3,...I)$ as shown in Figure 2.

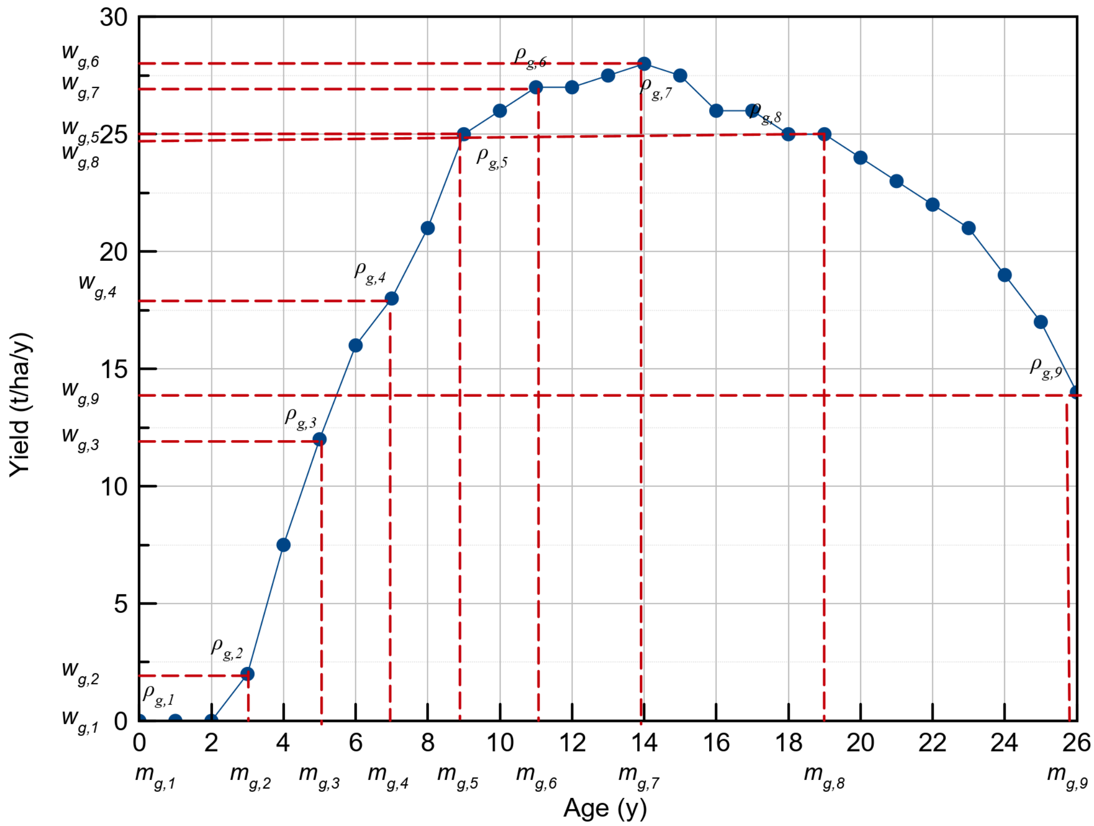

Figure 2: Modelling oil palm yield profile

$X_{g,t}^{\mathrm{MTY}}$ (y) and X_{g}^{YLD} (t) are the age and maximum FFB yield of the plantation $g \in G$ with area $A_g$during the year t. $\rho_{g,i,t}$ is a set of variables that relates $X_{g,t}^{\mathrm{MTY}}$and $F_{g,t}^{\mathrm{YLD}}$ as shown in Eq(2) and Eq(3).

$$X_{g,t}^{\mathrm{MTY}} = \sum_{i=1}^{I} m_{g,i} \times \rho_{g,i,t} \qquad \forall g \forall t \qquad (2)$$

$$X_{g,t}^{\mathrm{YLD}} = \sum_{i=1}^{I} w_{g,i} \times \rho_{g,i,t} \qquad \forall g \forall t \qquad (3)$$

$X_{g,t}^{\mathrm{MTY}}$ might not necessarily be amongst the selected discrete points $m_{g,i}$. It can be any value in-between two adjacent $m_{g,i}$points. $\rho_{g,i}$ is constrained as shown in Eq(4) and Eq(5).

$$\sum_{i=1}^{I} \rho_{g,i,t} = 1 \qquad \forall g \forall t \qquad (4)$$

$$\rho_{g,i,t} \geq 0 \qquad \forall g \forall t \qquad (5)$$

However, not more than two adjacent $\rho_{g,i,t}$ values can be non-zero. This is achieved by introducing a new set of binary variables $\mu_{g,i,t}$ using the method previously discussed by Zhou et al. (2013) in optimising utility operations and is presented in Eqs(6) – (9).

$$\sum_{i=1}^{I} \mu_{g,i,t} = 1 \qquad \forall g \forall t \qquad (6)$$

$$\rho_{g,i,t} - \mu_{g,i,t} \leq 0 \qquad \forall g \forall t, i = 1 \qquad (7)$$

$$\rho_{g,i,t} - \mu_{g,i-1,t} - \mu_{g,i,t} \leq 0 \qquad \forall g \forall t, i < 1 < I \qquad (8)$$

$$\rho_{g,i,t} - \mu_{g,i-1,t} \leq 0 \qquad \forall g \forall t, i = I \qquad (9)$$

The age or maturity, $X_{g,t}^{\text{MTY}}$ is a parameter provided by the decision maker, based on which the corresponding maximum FFB yield $X_{g,t}^{\text{YLD}}$ is determined.

3.2 Modelling climate change effects on FFB yield

As discussed in Section 1, this work accounts for two climate change induced events - water deficit and rise in temperature. The climate change effects usually have no immediate impact on the FFB yield. There exists a lag period between the period of climate change effect and the impact on the FFB yield. Typically, the lag period for rainfall is from 9 - 12 months while for temperature changes is 12 months (Shanmuganathan and Narayanan, 2012). Therefore, a lag period of 1 y is considered in this work.

Figure 3a and Figure 3b presents the impact of water deficit (Carr, 2011) and temperature rise (Sarkar et al., 2020) on the losses in FFB yield. Figure 3a is referred to as water deficit curve while Figure 3b as temperature rise curve. These relationships obtained from literature are based on experimental studies conducted on mature oil palms which have a potential FFB yield of 30 t/y under optimal agroclimatic conditions. This value is taken as the benchmark value or potential yield of oil palm and is denoted as $X^{\text{PL\_YLD}}$.

The water deficit curve and temperature rise curve are modelled using the same technique presented in Section 3.1 and are referred to as water deficit model and temperature model. The water deficit ($WD_{g,t-1}$) and rise in temperature ($T_{g,t-1}$) for the plantation $g \in G$ for the year *t-1* are provided as input to get the corresponding losses in yield, $X_{g,t}^{\text{LS\_YLD\_WD}}$ and $X_{g,t}^{\text{LS\_YLD\_T}}$ for the year *t*.

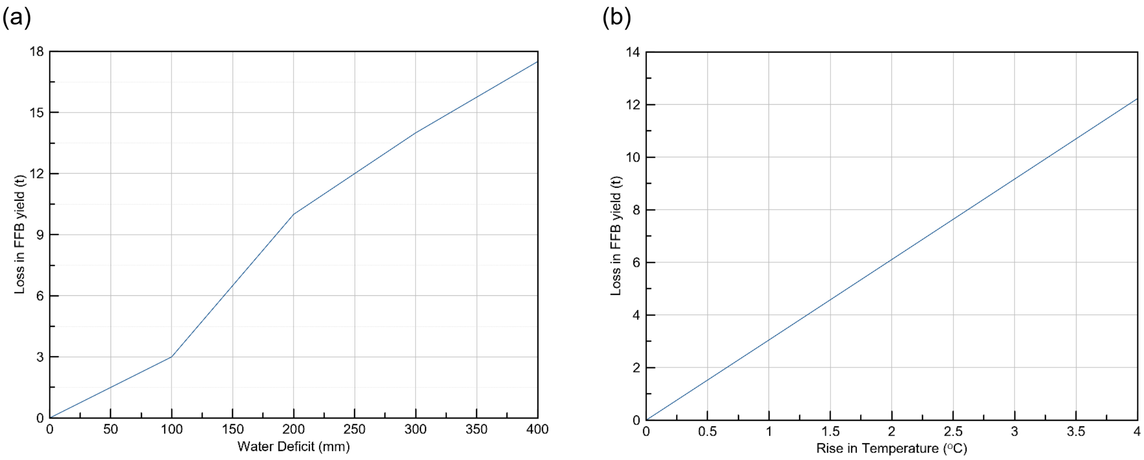

Figure 3: Illustration on a) Impact of water deficit on FFB yield (Carr, 2011) and b) Impact of rise in temperature on FFB yield (Sarkar, 2020)

3.3 FFB yield forecast

The water deficit index ($WD_{g,t}^{\text{INDEX}}$) and temperature index ($T_{g,t}^{\text{INDEX}}$) represent the percentage of the actual FFB yield with respect to the potential yield ($X^{\text{PL\_YLD}}$). Based on the yield loss, the water deficit index and temperature index are estimated as shown in Eq(10) and Eq(11).

$$WD_{g,t}^{\text{INDEX}} = \frac{(X^{\text{PL\_YLD}} - X_{g,t}^{\text{LS\_YLD\_WD}})}{X^{\text{PL\_YLD}}} \qquad \forall g \forall t \qquad (10)$$

$$T_{g,t}^{\mathrm{INDEX}} = \frac{\left(X^{\mathrm{PL\_YLD}} - X_{g,t}^{\mathrm{LS\_YLD\_T}}\right)}{X^{\mathrm{PL\_YLD}}} \qquad \forall g \forall t \qquad (11)$$

The maximum yield from the oil palm during the year *t* under optimal agro-climatic conditions is given by $X_{g,t}^{\mathrm{YLD}}$. The impact of water deficit and temperature rise on the maximum yield is provided by the water deficit index ($WD_{g,t}^{\mathrm{INDEX}}$) and temperature index ($T_{g,t}^{\mathrm{INDEX}}$). These indices are multiplied with the maximum yield to determine the actual yield. The forecast of the FFB production for the year *t* can be determined as shown in Eq(12).

$$X_t^{\mathrm{FC}} = \sum_{g=1}^{G} X_{g,t}^{\mathrm{YLD}} \times WD_{g,t}^{\mathrm{INDEX}} \times T_{g,t}^{\mathrm{INDEX}} \times A_g \qquad \forall t \qquad (12)$$

The developed mathematical model can be validated using historical data. The FFB forecast of a given year can be determined using the data on rainfall and temperature of the preceding year. The results from the model can be validated with the actual data. The accuracy of the model depends on factors like proximity of weather station to the plantation, accuracy of the climate variable readings, etc.

4. Case study

This section presents a case study to illustrate the proposed mathematical approach. It involves forecasting the total FFB production for a plantation company which owns plantation A, B and C for the year *t*. At first, the yield profile, water deficit curve and temperature rise curve are modelled as presented in Section 3.1 and 3.2. Later, the plantation age during *t*; water deficit and mean temperature rise values during *t-1* are provided as input parameters. Table 1 presents the area, plantation maturity, water deficit and mean temperature rise.
The maximum FFB yield from the plantations A, B and C are determined from the yield profile model. Similarly, the loss in FFB yield is determined from the water deficit and temperature rise model. Based on the FFB yield loss value, the water deficit index and temperature index are calculated using Eq(10) and Eq(11). Table 2 presents the maximum yield of the plantations at *t*; the water deficit and temperature index computed by the model. Finally, the forecast for FFB production is calculated using Eq(12). The case study which was solved in LINGO v18 contained 235 variables and 159 constraints with an elapsed run time less than 2 s. The solver was run-in a HP Pavilion x360 with Intel Core i5 8250 (1.80 GHz) processor and 8 GB RAM under a 64-bit operating system.

Table 1: Agroclimatic data of the plantation

Plantation	Area (ha)	Maturity at *t* (y)	Water deficit at *t-1* (mm)	Temperature rise at *t-1* (°C)
Plantation A	300	7	190	1
Plantation B	300	16	70	0.5
Plantation C	300	11	130	0.8

Table 2: Yield, water deficit index and temperature rise index

Plantation	Potential Yield at *t* (t)	Water deficit index	Temperature rise index
Plantation A	18	0.68	0.989
Plantation B	23	0.93	0.999
Plantation C	27	0.81	0.999

The maximum FFB yield determined from the yield profile model for Plantation A, B and C are 5,400 t, 6,900 t and 8,100 t during *t.* Though the plantations are of the same size (300 ha), the variations in maximum possible yield is due to their different maturity levels. Plantation A and B with maturity of 7 and 16 y produce 33.33 % and 14.80 % less FFB compared to Plantation C of maturity 11 y, independent of the impact due to water deficit and temperature rise. The FFB forecast estimated at the Plantations A, B and C accounting for the climate change effects for the period *t* is 3,602.50 t, 6,379.02 t and 6,618.87 t. The cumulative impact of water deficit and temperature rise has resulted in yield drop of 33.31 %, 8.18 % and 18.29 % at plantations A, B and C from their maximum possible yield.

5. Conclusion

This work presents a mathematical approach to forecast FFB production for plantation companies. This work has focused on discussing the mathematical technique to represent the relationship of plantation maturity and different climate change factors on FFB yield. The technique provides the flexibility to update data emerging from future studies. Also, other climate change effects like CO_2 concentration, pest, diseases, etc can also be considered in forecasting by modelling their impacts using the same technique. The approach requires minimal data and user friendly to decision makers. The approach can aid in planning their activities like labour management, storage, marketing, etc. Unlike the other units in the palm supply chain, plantation is largely a biological unit which is highly vulnerable to disruption from climate change effects which are beyond management and operational intervention. This work can potentially improve the reliability and resilience of the palm supply change by mitigating the uncertainties in FFB production. Also, the current work can be extended to optimise the required plantation maturity based on the palm oil demand.

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References

Carolita I., Sitorus J., Manalu J., Wiratmoko D., 2017, Growth profile analysis of oil palm by using SPOT 6 the case of North Sumatra. International Journal of Remote Sensing and Earth Sciences, 12, 21-26.

Carr M.K.V., 2011, The water relations and irrigation requirements of oil palm (Elaeis guineensis): a review, Experimental Agriculture, 47(4), 629.

Chong M.Y., Ng W.P.Q., Ng D.K.S., Lam H.L., Lim D.L.K., Law K.H., 2017, A mini review of palm based fertiliser production in Malaysia, Chemical Engineering Transactions, 61, 1585-1590.

Christensen J.H., Kanikicharla K.K., Aldrian E., An S.I., Cavalcanti I.F.A., De Castro M., Dong W., Goswami P., Hall A., Kanyanga J.K. and Kitoh A., 2013, Climate phenomena and their relevance for future regional climate change, In Climate Change 2013 the Physical Science Basis: Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, 1217-1308.

Feng Y., 2016, Study on medium and long term power load forecasting based on combination forecasting model, Chemical Engineering Transactions, 51, 859-864.

Flesis S., Hill J.K., Mclean C., Lucey J.M., 2017, Potential impacts of climate change on oil palm cultivation, A science for policy paper by SENSOR programme, York, United Kingdom, 1-17.

Kartika N.D., Astika I.W., Santosa, E., 2016, Oil palm yield forecasting based on weather variables using artificial neural network, Indonesian Journal of Electrical Engineering and Computer Science, 3(3), 626-633.

Keong Y.K., Keng W.M., 2012, Statistical modeling of weather-based yield forecasting for young mature oil palm, APCBEE Procedia, 4, 58-65.

Long S.P., Ainsworth E.A., Leakey A.D., Nösberger J., Ort D.R., 2006, Food for thought: lower-than-expected crop yield stimulation with rising CO2 concentrations, Science, 312, 1918-1921.

Nelson G.C., Valin H., Sands R.D., Havlík P., Ahammad H., Deryng D., Elliott J., Fujimori S., Hasegawa T., Heyhoe E., Kyle P., 2014, Climate change effects on agriculture: Economic responses to biophysical shocks, Proceedings of the National Academy of Sciences, 111(9), 3274-3279.

Paterson R.R.M., Sariah M., Lima N., 2013, How will climate change affect oil palm fungal diseases?, Crop Protection, 46, 113-120.

Paterson R.R.M., Kumar L., Taylor S., Lima N., 2015, Future climate effects on suitability for growth of oil palms in Malaysia and Indonesia, Scientific reports, 5, 14457.

Sarkar M.S.K., Begum R.A., Pereira J.J., 2020, Impacts of climate change on oil palm production in Malaysia, Environmental Science and Pollution Research, 1, 1-11.

Shanmuganathan S., Narayanan A., 2012, Modelling the climate change effects on Malaysia's oil palm yield, IEEE Symposium on E-Learning E-Management and E-Services, 19^{th} – 21^{st} November, Penang, Malaysia, 1, 1-6.

Siwar C., Ahmed F., Begum R.A., 2013, Climate change, agriculture and food security issues: Malaysian perspective, Journal: Food, Agriculture and Environment, 11(2), 1118-1123.

Tan K.W., 2014. Plantation companies with best growth potential (Part 1/2), <klse.i3investor.com/blogs/kianweiaritcles/48513.jsp>, accessed 12.05.2020.