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Research Paper

Geospatial mapping and biophysical analysis of factors that affect oil palm (Elaeis guineensis) yields in Peninsular Malaysia

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ABSTRACT

Oil palm is regarded as one of the most important crops in the tropics, contributing significantly to economy of Malaysia. The objective of this study is to model oil palm yield distributions and investigate the factors that influence oil palm yields in Peninsular Malaysia using remote sensing and geographical information system (GIS) techniques. Herein, we investigate six factors that influence oil palm yield in Peninsular Malaysia, including mean annual minimum and maximum temperatures, mean annual rainfall, average number of rainy days per year, average annual relative humidity, and elevation. In order to model oil palm yield in Peninsular Malaysia, a large yield dataset covering Peninsular Malaysia for 37 years (1983 to 2020), as well as related explanatory variables, were collected. Areal interpolation was used to model the average yield distribution across the study area. The findings of this study show that oil palm yields vary across Peninsular Malaysia. Due to favourable climate and elevation, southern and southwestern Peninsular Malaysia, including Johor, Pahang, Melaka, and Selangor, recorded the highest amount of yield.

Keywords: Oil palm, modelling, yield, plantation, Peninsular Malaysia

The oil palm tree (Elaeis guineensis) is native to tropical rainforests on the coasts of 15^0 N and 15^0 S of West Africa. The Bogor Botanical Garden in Indonesia became the first to cultivate the plant in Southeast Asia in 1848 (Nambiappan *et al*., 2018). It is interesting to note that palms grow in areas with annual rainfall ranging from 640 mm to 4200 mm, with a dry season of 2-4 months (Paterson *et al*., 2013). In order to produce high oil palm yields, a minimum temperature range of 22-24^0 C and a maximum temperature range of 29-33^0 C is required (Zainal *et al*., 2012; Ahmed *et al.*, 2021). Oil palm's photochemical efficiency decreases when temperatures reach 35^0 C. At least 16 or 17 MJ m^{-1} d^{-1} of solar radiation should be available (Oettli *et al*., 2018). In a moist tropical soil with a pH of between 4 and 8, the plant grows well (Paterson *et al*., 2013).

In Malaysia, the oil palm planted area has grown significantly since 1980, reaching 1.02 million hectares in 1980, then 2.03 million hectares in 1990, and finally 5.74 million hectares in 2016. In 2020, Malaysian oil palm production covers approximately 5.9 million hectares, with over two million hectares in Peninsular Malaysia and the rest in East Malaysia (MPOB, 2020). In 1990, Fresh Fruit Bunch (FFB) yields averaged 18.53 tonnes per hectare, with yields ranging from 17.83 tonnes to 20.26 tonnes. A harvest of 17.19 tonnes per hectare was recorded in 2019, compared with 18.65 tonnes in 2014. Since the 1970s, Malaysian yields have fluctuated widely, with marked increases and decreases between the years (MPOC, 2020).

In order to adjust the current situation and plan for the future, there is need to understand how climatic parameters affect oil palm yield and distribution in Peninsular Malaysia. Modeling the impacts of climate on oil palm yield helps farmers and policymakers to provide a range of options for reducing the adverse impact of changing climate in the oil palm sector in Peninsular Malaysia. The aim of this study is to examine the climatic factors that influence oil palm yield distribution in Peninsular Malaysia.

MATERIALS AND METHODS

Peninsular Malaysia lies between latitudes 1^0 and 7^0 north and between 99^0 and 105^0 east. In this region, there are highlands,

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Table 1: Data types and sources

Data	Format	Resolution	Source	Date
Administrative boundary	Vector	-	DivaGIS	-
palm oil farm	Raster	30m		2016
Annual palm oil yield (t ha^{-1})	Excel			1983-2020
Digital elevation model (DEM)	Raster	30m	United State Geological Survey (USGS)	-
Rainfall (RF, mm)	Excel	-	Various metrological stations within Malaysia west	1983-2020
Number of rainy days (RD)	Excel	-	-	1983-2020
Mean temperature-Minimum (Tmin, °C)	Excel	-	-	1983-2020
Mean temperature-Maximum (Tmax, °C)	Excel	-	-	1983-2020
Mean relative humidity (RH, %)	Excel	-	-	1983-2020

floodplains, and coastal zones that cover an area of 132,000 km^2. With temperatures ranging from 25^0 C to 32^0 C throughout the year, the Peninsular has a warm and humid tropical climate. Two monsoon seasons occur in the region: "the southwest monsoon from May to September and the northeast monsoon from November to March, which is associated with high rainfall". Rainfall in the region ranges between 2,000 and 4,000 mm per year (Muhammad *et al*., 2020).

In this study, a large yield dataset covering Peninsular Malaysia for 37-year period from 1983 to 2020, and related explanatory variables were collected (Table 1) for modelling palm oil yield using remote sensing and GIS techniques. The ArcGIS 10.5 was used for the extraction of the administrative area of interest (AOI)-Peninsular Malaysia as well as preparation of vector and raster (DEM) data sets. However, the oil palm plantation raster data was classified into "1 and 0" (where "1" signifies areas of oil palm plantation and "0" represents other land used). The output was converted from "feature" to "shapefile". Preliminary calculations for the average annual oil palm yield and the explanatory variables (total rainfall, mean temperature-minimum, mean temperature-maximum, average number of rainy days, average annual relative humidity) was performed in Microsoft Excel (comma delimited format). Areal Interpolation was employed to model the average yield distribution throughout the study area as well as downscale the data to predict the yield within the oil palm plantations. The meteorological station data were also interpolated using an "Inverse distance weighted interpolation (IDW)" technique.

Technique of data analysis

To learn about the pattern of oil palm yield in the study area, a grouping analysis tool was used in ArcGIS. In this study, attributes such as rainfall, yield quantity by plantation and temperature were used. The algorithm selects natural groupings based on connectivity graphs (minimum spanning tree). In the absence of spatial constraints, the grouping analysis tool uses the K Means algorithm. In order to determine grouping effectiveness, the Calinski-Harabasz pseudo F-statistic is used, which is a ratio based on inside-group similarity and outside-group difference (equation 1): Fig. 1 shows the group-wise determinant that distinguished those similarities and differences.

$$(R^2/ nc-1)/(1-R^2/n-nc) \quad (1)$$

Where: n = the number of features

n_c = the number of classes (groups)

R^2 = SST – SSE/SST

SST is a reflection of between-cluster differences and SSE reflects within-cluster similarity, expressed as:

$$SST = \sum^{nc}_{i=1} \sum^{ni}_{j=1} \sum^{nv}_{k=1} (V^k_{ij} - \tilde{V}^k)^2$$

$$SSE = \sum^{nc}_{i=1} \sum^{ni}_{j=1} \sum^{nv}_{k=1} (V^k_{ij} - \tilde{V}_t^k)^2$$

ni = the number of features in group i

n_v = the number of variables used to group features

V_{ij}^k = the value of the k^{th} variable of the j^{th} feature in the i^{th} group

$\tilde{V}^k$ = the mean value of the k^{th} variable

$\tilde{V}_t^k$ = the mean value of the k^{th} variable in cluster

$$Y = \beta_0 + \beta_1X_1 + \beta_2X_2 + \ldots\ldots\ldots \beta_nX_n + e \quad (2)$$

Where: Y = Dependent variable

$\beta_0, \beta_1, \beta_2 \ldots\ldots \beta_n$ = coefficient

$X_0, X_1, X_2 \ldots\ldots X_n$ candidate explanatory variables

e = Random error term/residuals

An exploratory regression technique was further computed (Eq.2) using the output of the grouping analysis. This tool looks for the ordinary least-squares (OLS) model that explains the dependent variable (the groups created) best within the context

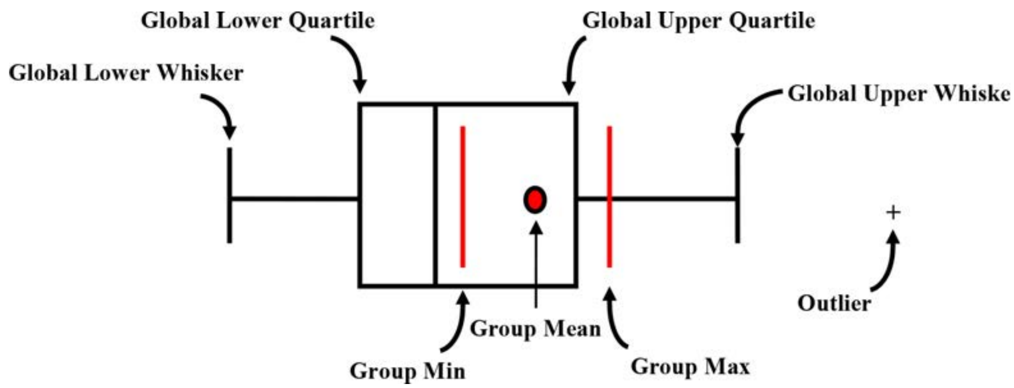

Fig. 1: Group-wise summary determinant

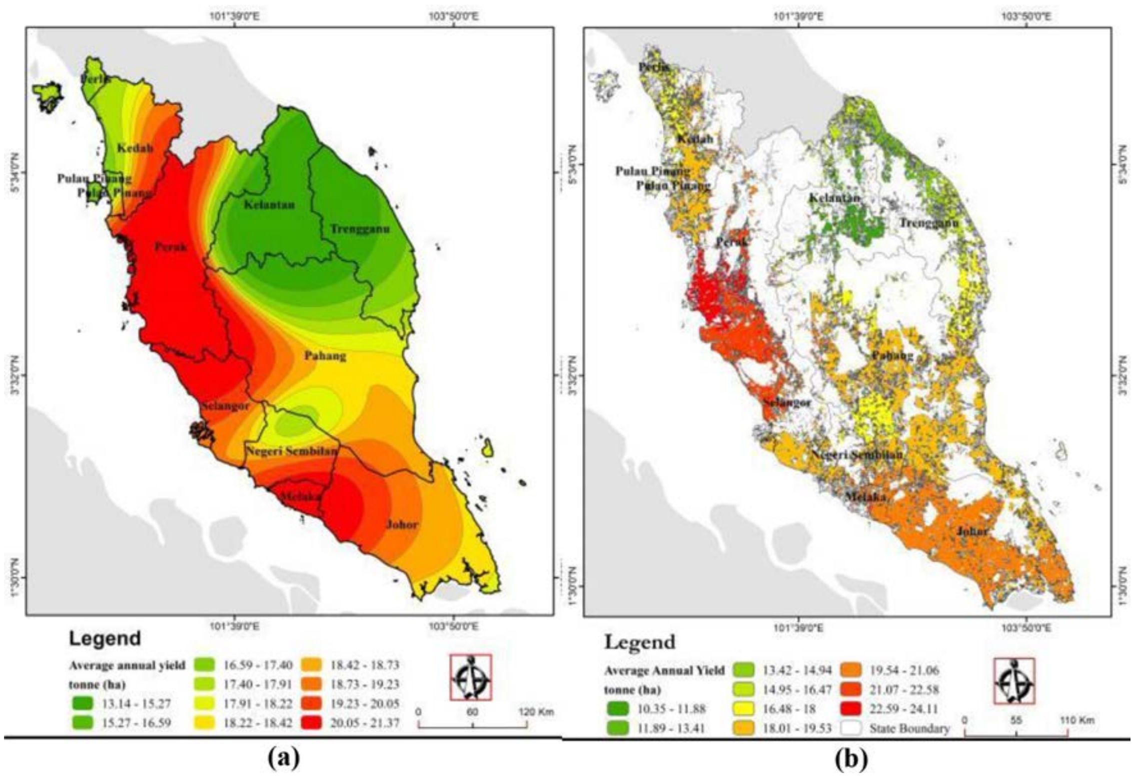

Fig. 2: Average annual distribution of oil palm yield by: (a) state and (b) plantation (t ha^{-1})

of the user-specified criteria. Specific explanatory variables to this study are: temperature (Tmax, Tmin), rainfall (RF), number of rainy days (RD), relative humidity (RH), and elevation. However, in exploratory regression, only when it finds a model that meets a given threshold criteria for minimum acceptable adjusted R^2, maximum coefficient p-value cutoff, maximum VIF value cutoff, and minimum acceptable Jarque-Bera p-value will it run the spatial autocorrelation (Global Moran's I) tool on the model residuals to see if the under/over-predictions are clustered or not.

RESULTS AND DISCUSSION

Distribution of oil palm yield

The trend of plantation distribution and oil palm yield (t ha^{-1}) vary across Peninsular Malaysia. As a result of the variation of oil palm production factors (climate, soil, cultivar, and management), the yield of oil palm varies across Peninsular Malaysia. The southwestern region comprising Melaka and the northwestern region comprising Selangor and Perak recorded the highest yield, ranging between 19.23 and 21.37 t ha^{-1} (Fig. 2a). In the year 2019, Selangor recorded (19.26 t ha^{-1}), Johor (19.41 t ha^{-1}), Melaka (20.03 t ha^{-1}), and Perak (19.0 t ha^{-1}) (MPOB, 2020). According to Woittiez *et al*. (2017), peak oil yields of 12 t/ha^{-1} yr^{-1} have been achieved in small plantations, and maximum theoretical yields calculated with simulation models are 18.5 t ha^{-1} yr^{-1}, yet global average productivity has remained stagnant around 3 t ha^{-1} yr^{-1}. Plantations around Perak, Selangor, and Johor recorded the highest amount of yield, usually around 21.07–24.11 t ha^{-1} (Fig. 2b). In 2020, the corporate plantation sector accounted for approximately 72.2 % of Malaysian oil palm distributions (MPOB, 2020). The independent smallholder sector

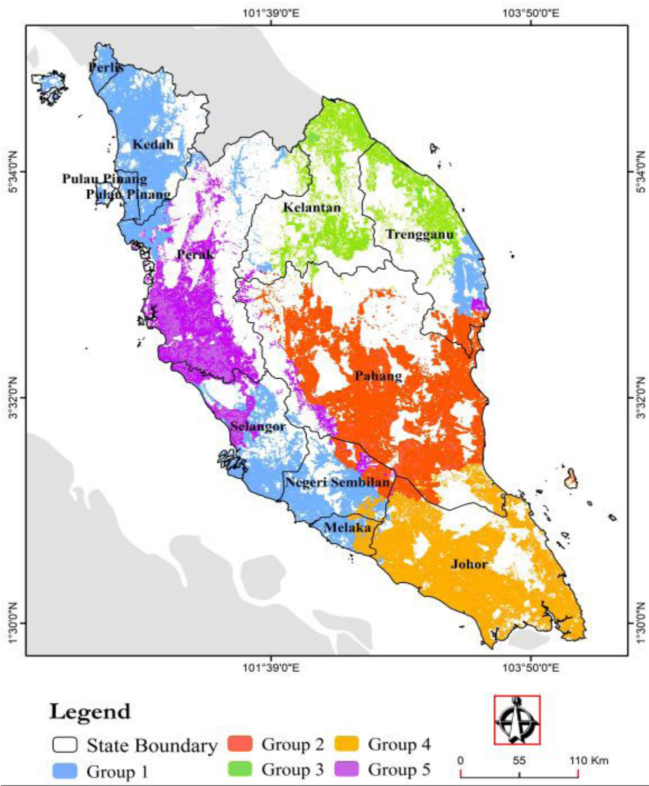

Fig. 3: Spatial pattern of oil palm yield

better. The box plot (Fig. 4) graphically depicts nine (9) summary values for each analysis field and group: minimum data value; lower quartile; median; upper quartile; maximum data value; data outliers (values smaller or larger than 1.5 times the in-quartile range); group minimum; group mean; and group maximum. Any dark line at either edge of the box falling outside the upper or lower whisker represents a data outlier (Fig. 1). From Fig. 3, the pattern shows that group 1 and 5 are the plantation areas where oil palm yield quantity is significantly high, whereas plantations within group 3 show the lowest yield quantity. Group 2 and 4 represent plantations in the study area with intermediate oil palm yield quantities. Climate, yields, and the region where production takes place all have a strong relationship (Chiarawipa *et al.*, 2020).

In the parallel box plot graph, the variables of each group are summarized, as well as their relations to the yield quantity values. From Fig. 3, group 1 (blue) reflects tracts with an area of peak yield and reflects the highest values for yield quantity. Similarly, group 5 (purple) represents tracts with the most full-grown plantation area. However, falls outside the upper quartile, and thus the vertical line (representing the lowest value for the group tracts) is greater than the global upper quartile for yield quantity (Fig. 4). These are the groups with a high quantity of oil palm in the study area. The group with the lowest quantity, on the other hand (group 3), is observed to fall outside the lower whisker, representing an oil palm yield outlier. Generally, group 1 and 5 have the highest range of values compared to the other groups (Fig. 3). The global R^2 values is 0.8315, which is equivalent to approximately 83% (Table 2).

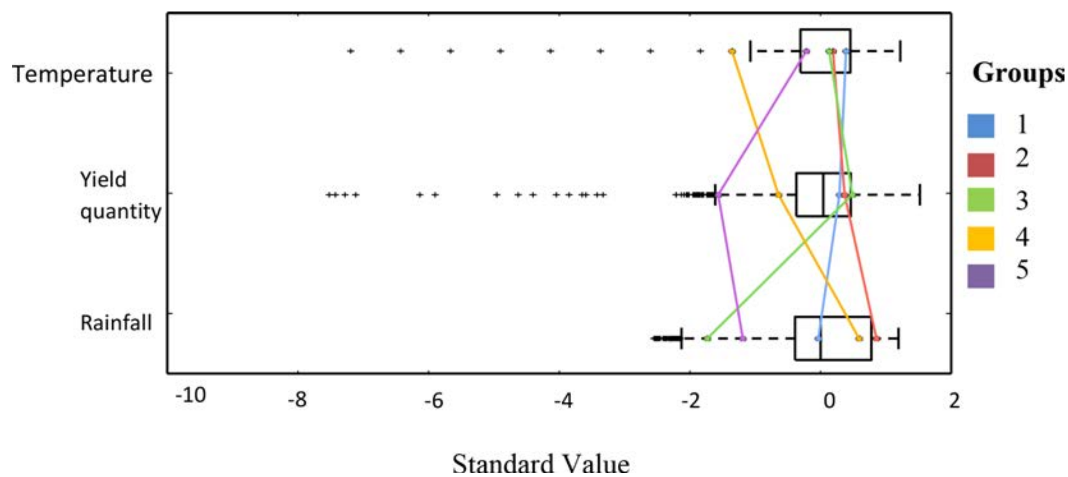

Fig. 4: Parallel box plot

made up 16.3% of the total, while the organised smallholder sector made up 11.5%.

Spatial pattern of oil palm yield

A grouping analysis was performed on the oil palm yield to create five groups. For each group, a different colour (blue, red, green, purple, and orange) is designated to represent the similarity of yield quantity across farming areas (Fig. 3). For each analysis field, the summary statistics (Table 2) include the mean, standard deviation (Std. Dev.), maximum, minimum, and R^2 values. In general, a variable that has a higher R^2 value can discriminate between features

Relationship between factors that influence of oil palm yield Peninsular Malaysia

Factors influencing pattern and distribution of oil palm yield in Peninsular Malaysia may includes mean annual minimum temperature, mean annual maximum temperature, mean annual rainfall, average annual number of rainy days, average annual relative humidity, and elevation. The significance of each computed variable is summarised in Table 3. The proportion of times it has been statistically significant is listed for each candidate explanatory

Table 2: Group-wise summary

Variable	Mean	Std. Dev.	Minimum	Maximum	R^2
Rainfall (mm)	2072.0	771.0	4.0	3116.0	0.8315
Yield quantity by farm (t ha^{-1})	18.0	2.0	2.0	21.0	0.5296
Temperature (^{0}C)	31.0	1.0	22.0	33.0	0.4590

Table 3: The model diagnostics and explanatory variables

					Exploratory groups		
	$AdjR^2$	VIF	X1	X2	X3	X4	X5
1	0.23	2.00	Min. temp.	Rainfall	Elevation	Min. temp.	Humidity
	0.08	2.00	Rainfall	Rainy days	Elevation	Min. temp.	Humidity
2	0.08	2.00	Humidity	Rainy days	Elevation	Min. temp.	Rainfall
	0.03	2.00	Rainy days	Rainy days	Elevation	Min. temp.	Rainfall
3	0.25	2.00	Rainfall	Rainfall	Min. temp.	Rainfall	Rainy days
	0.31	2.07	Min. temp.	Rainfall	Elevation	Rainfall	Rainy days
	0.31	2.07	Min. temp.	Rainfall	Min. temp.	Rainfall	Rainy days
	0.28	2.07	Min. temp.	Max. temp.	Elevation	Rainfall	Rainy days
4	0.09	2.07	Rainfall	Min. temp.	Elevation	Rainfall	Rainfall
	0.34	2.07	Rainfall	Min. temp.	Elevation	Rainfall	Rainfall
	0.09	1.06	Humidity	Elevation	Max. temp.	Humidity	Rainfall
	0.34	1.06	Humidity	Elevation	Max. temp.	Humidity	Rainfall
5	0.28	1.06	Rainy days	Elevation	Max. temp.	Rainfall	Rainy days
6	0.35	1.06	Min. temp.	Rainfall	Max. temp.	Rainfall	Min. temp.
	0.35	1.6	Min. temp.	Humidity	Max. temp.	Rainfall	Min. temp.
7	0.35	2.1	Rainfall	Rainy days	Max. temp.	Rainfall	Rainy days
	0.35	2.1	Humidity	Rainy days	Max. temp.	Rainfall	Rainy days
8	0.19	1.2	Rainfall	Rainfall	Elevation	Humidity	Rainfall
	0.19	1.5	Rainy days	Rainy days	Elevation	Humidity	Rainy days
	0.19	1.06	Rainfall	Rainfall	Elevation	Humidity	Rainfall
	0.19	1.06	Rainy days	Rainfall	Elevation	Humidity	Rainy days

Acronyms: $AdjR^2$ = Adjusted R-Squared; VIF = Max Variance Inflation Factor

variable. The % negative and % positive columns defined the stability of the variable relationships. Thus, strong predictors are consistently significant, and the relationship would be stable (primarily negative or primarily positive). Table 3 provides the model diagnostics and explanatory variables, where a higher adjusted R^2 value indicates a higher degree of importance of one variable over the other within and outside the designated groups.

From Table 3, there are eight (8) categories of orderedly arranged $AdjR^2$ values. The range of all values falls between 0.23 (1st category) and 0.19 (8th category) Recall (Fig. 3) that group 1 and 5 are the farming areas where oil palm yield quantity is significantly high, whereas group 3 was the lowest, while the intermediates were group 2 and 4. Further analysis of Table 3 corroborates that, among the groups, the variables with the highest $AdjR^2$ value of 0.35 were temperature-minimum, rainfall and relative humidity (group 1); temperature-minimum, rainfall and number of rainy days (group 5); temperature-maximum (group 3); rainfall, relative humidity and number of rainy days (group 2); and rainfall (group 4). This was closely followed by the $AdjR^2$ values of 0.34 (indicating significance of rainfall in group 5 but, maintained consistency with group 1, where rainfall amount and humidity are dominant). More so, temperature-maximum is consistent and in addition to elevation in group 3 as well as rainfall (which also maintain regularity), along with relative humidity in group 4 collectively exhibits a high degree of importance.

Furthermore, within the groups, temperature-minimum, relative humidity and rainfall were the dominant explanatory variable of the high oil palm yield quantity in group 1 plantation areas ($AdjR^2$ value = 0.35 respectively). Whereas, in group 5, it was more about temperature-minimum, rainy days ($AdjR^2$ value = 0.35) and rainfall ($AdjR^2$ value = 0.34). These findings are consistent with those of Chiarawipa *et al.* (2020) show that oil palm yields are likely to increase at optimal temperatures. However, temperature-maximum ($AdjR^2$ value = 0.35) and elevation ($AdjR^2$ value = 0.34) were found to be the main explanatory factors for oil palm in Group 3 (where yield quantity was low) (Fig. 4). Group 2 and 4 with the intermediate oil palm yield quantity were due to mainly rainfall, relative humidity, rainy days ($AdjR^2$ value = 0.35) as well as temperature-minimum and elevation (AdjR^2 value = 0.34) for Group 2. In Group 3, however, the explanatory factors were temperature-maximum (AdjR^2 value = 0.35) and elevation (AdjR^2 value = 0.34). From the results, yield quantity is hence directly proportional to temperature-minimum, rainfall amount and relative humidity for a given oil palm farming season in Peninsular Malaysia.

CONCLUSION

In spite of the fact that countries such as Malaysia are increasingly aware of the role climate plays in oil palm production, they fail to address it with the urgency it deserves. A variety of climatic factors have affected oil palm yield distribution in Peninsular Malaysia. Suitable climate and elevation seem to be key to high FFB yields, according to the findings of this study. A variety of climatic factors affect oil palm yield distribution, with temperature and rainfall having the most impact. This study recommends conducting institutional research on modeling the current and future impact of climate change on oil palm yield, and narrowing the research to include planters in oil palm-climate studies. In order to improve the modeling performance, further research should be focused on integrating more site-specific including (planters socio-economic characteristics) factors into yield prediction modelling.

Conflict of Interest Statement: The author(s) declare(s) that there is no conflict of interest.

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