AF-715
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RESEARCH ARTICLE

Indian Journal of Agricultural Research, Volume Issue : ()

What does Modelling Tells us on the Influence of Certain Weather Parameters on Oil Palm Production in Peninsular Malaysia

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10.18805/IJARe.AF-715

ABSTRACT

Background: Oil palm has been recognized as one of the most important crops especially in Southeast Asia and the rest of the world. Palm oil production has recently been lowered as a result of the influence of various factors, which include weather and climate. The distribution of temperature, wind speed, relative humidity, solar radiation and rainfall all influence the growth and development of palms, which later reflects in the production quantity of the fresh fruit bunches and palm oil. The objective of this study is to investigate the impacts of various weather factors especially (temperature, wind speed, relative humidity, solar radiation and rainfall) on oil palm production in Peninsular Malaysia.

Methods: The Statistical Package for Social Sciences (SPSS) 20.0 version was used to analyse the data, which include descriptive statistics and multilinear regression (MLR). The MLR model evaluated the strength of the relationship between oil palm yield (as a dependent variable) and temperature, solar radiation, wind speed, relative humidity and precipitation. Temperature, wind speed, relative humidity, solar radiation and rainfall, on the other hand, have been shown to have little effect on oil palm production and yield.

Result: According to the R^2 value, the independent variables only explained 20.2% of the variation in palm oil production. This study recommends operating within a comprehensive framework that includes scientific research, planting improved varieties, enhancing regional intellectual and academic leadership, engaging the participation of private and public stakeholders, highlighting participatory initiatives with researchers in consumer countries and enhancing growers' ability to adapt best agroecological practises.

Key words: Climate, Humidity, Modelling, Oil palm, Rainfall, Solar radiation, Temperature, Wind.

INTRODUCTION

The oil palm (*Elaeis guineensis*) is native to West Africa, where it can be found between Angola and Gambia (Paterson *et al*., 2013). Oil palm was first planted in South-east Asia in 1848 at the Bogor Botanical Garden in Indonesia (Nambiappan *et al*., 2018). In the 1870s, Malaysia received its first batch of oil palm from the Royal Botanical Garden, United Kingdom (Singh *et al*., 2021). The first commercial oil palm plantation in Malaysia was established in 1917 at Tennamaran Estate, Selangor (Begum *et al*., 2018). In total, there are ten important oil palm producing countries, including Indonesia, Malaysia, Thailand, Nigeria, the Democratic Republic of the Congo, the Ivory Coast, Brazil, Colombia, Costa Rica and Ecuador (Ahmed *et al*., 2021; Abubakar *et al*., 2021). Indonesia and Malaysia produce approximately 83% of the world's palm oil, which makes a significant contribution to their economies (Paterson and Lima, 2018). Malaysian palm oil exports contribute to 45% of the global oil palm needs (Shevade and Loboda, 2019). The economy of Malaysia benefits greatly from the financial returns from the sale of palm oil (Tang and Al Qahtani, 2020). Crude palm oil is used in cooking, detergent, soap, plastics, oleo-chemicals, cosmetics, pharmaceuticals, biodiesel, *etc*. (Paterson *et al*., 2009). Large-scale oil palm cultivation has made a tremendous transformation in tropical regions, people's lives and the profits of palm oil companies (Maluin *et al*., 2020). The crop's high output, ease of establishment and low costs make it very profitable and the most economically efficient oil crop (Dislich *et al*., 2017).

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How to cite this article: Abubakar, A., Ishak, M.Y., Uddin, M.K., Abu Bakar, A. and Mohammed, M.U. (2022). What does Modelling Tells us on the Influence of Certain Weather Parameters on Oil Palm Production in Peninsular Malaysia. Indian Journal of Agricultural Research. DOI: 10.18805/IJARe.AF-715.

Submitted: 17-12-2021 **Accepted:** 25-06-2022 **Online:** 23-07-2022

Tropical countries, in particular, are negatively affected by climate change, which also has a detrimental impact on oil palm agronomy, whereas the cultivation of oil palm increases the impact of climate change (Uning *et al*. 2020). Climate has changed over centuries and will undoubtedly continue to change in the future and affect crop production worldwide (Chen *et al*., 2004; Corley and Tinker, 2015). Although awareness of the effects of climate change on crop production and disease has grown (Lobell *et al*., 2006), the effects on tropical crops are less understood (Ghini *et al*., 2011). As noted by Paterson (2020) climate change threatens the sustainability of oil palm production. Various factors influence oil palm production, including planting material, cultivation management, soil and the environment, or climate, usually rainfall, temperature, relative humidity, wind and solar radiation (Herdiansyah *et al*., 2020).

Weather and climate are prominent drivers that influence oil palm production systems. In spite of advances in technology and crop science, a fluctuation in oil palm yield has been noticed recently (Kukal and Irmak, 2018; Sarkar *et al*., 2020). Oil palm requires at least 2000 mm of rainfall distributed evenly throughout the year, which equates to about 167 mm per month (Rhebergen *et al*., 2016). Furthermore, minimum temperatures should be between 22 and 24°C and maximum temperatures should be between 29 and 33°C, with relative humidity greater than 85% (Zainal *et al*., 2012). The solar radiation level should be at least 16 or 17 MJ m^{-1} d^{-1} (Oettli *et al*., 2018). Variation in the climatic variables might have been responsible for the substantial changes. The distribution of rainfall affects the growth and development of palm trees, which in turn affects FFB production (Kamil and Omar, 2016). Excessive rainfall also harms the fresh fruit bunch (FFB), stifles harvest activity and causes flooding. Oil palm yield is limited by the length of the annual dry season, so areas with consistent high rainfall throughout the year, such as parts of Southeast Asia, have particularly high yields (Munévar and Munévar, 2004; Pirker *et al*., 2016; Fleiss *et al*., 2017). Preceding studies have shown that a 100-mm increment in water shortfall in a year can reduce output by 8-10% in the following year and also by 3-4% in the following year (Caliman and Southworth, 1998). Ambar Suharyanti *et al*. (2020) stated that a 100 mm water shortfall might affect FFB output during the flowering stage. Specifically, floral initiation, yield might be lost by about 1-3%, whereas sex determination and floral abortion might experience 3-4% and 8-10% yield loss, respectively.

When the temperature rises by 1-4°C, oil palm cultivation is expected to decline by 10-40% in Malaysia (Sarkar *et al*., 2020). The number of dry periods is expected to increase as the temperature rises, resulting in a loss of oil palm yield. Because soil water vaporises more rapidly as temperatures rise, the effects of dry spells become more severe (Merten *et al*., 2016). The average monthly temperature of 27.83°C, eight months prior to harvest, led to a low FFB yield (Shanmuganathan *et al*. 2014). In addition, wind speed was also found to have an impact on oil palm cultivation (Sasirat *et al*., 2019). The solar radiation hours are not only the site-specific factors influencing oil palm production (Keong and Keng, 2012). The simultaneous availability of soil moisture also plays an important role in determining the effective solar radiation hour for maximizing FFB yield (Lim *et al*., 2011). Direct sunlight boosts palm productivity. The lower incidence of cloud over greater parts of Southeast Asia is thought to be one of the reasons why oil palm yields are mostly higher than in West Africa (Sheil *et al*., 2009). Photoperiod response regulates oil palm flowering (Legros *et al*., 2009). In 2014, 2015 and 2016, the palm oil yield dropped by 0.3%, 1.9% and 17%, respectively, to 3.84, 3.78 and 3.21 t ha^{-1}, compared to the previous year's record of 3.84, 3.78 and 3.21 t ha^{-1} (Hilal *et al*., 2018). The decrease in palm oil yield has been attributed to a decrease in FFB yield in recent years (Darmawan *et al*., 2016).

With oil palm production accounting for the highest agricultural production in Malaysia, research into the effects of climatic elements on oil palm cultivation does not receive the same level of attention as cereal crops. As a result, this study seeks to investigate the effects of these climatic elements on oil palm cultivation in Peninsular Malaysia. The study also makes some recommendations to improve oil palm cultivation in Malaysia.

MATERIALS AND METHODS

The study area

Peninsular Malaysia is geographically located between latitudes 1° and 7° north and between 99^0 and 105^0 east. The region occupied a total land area of 132000 km^2 and was mainly composed of the highlands, floodplains and coastal zones. Overall, the Peninsular has a warm and humid tropical climate throughout the year, with temperature ranges from 25°C to 32°C. The region is characterized by two monsoon seasons: the southwest monsoon from May to September and the northeast monsoon from November to March, which is associated with high rainfall (Wong *et al*., 2009; Wong *et al*., 2016). The region records annual rainfall of 2000-4000 mm (Muhammad *et al*., 2020).

Methods

Secondary data was used for the purpose of this study. Data on oil palm yield in Malaysia between 1990-2020 was obtained from the Malaysian Palm Oil Board (MPOB). Climate historical data, particularly average annual temperature and rainfall, solar radiation, relative humidity and wind speed, were also downloaded from the climate-knowledge portal of the World Bank and the National Aeronautics and Space Administration (NASA) in July, 2021.

Data analysis

Multiple linear regression, an extension of simple linear regression which has more than one independent variable, was employed in this study (Uyanýk and Güler, 2013). The model was adopted because the dependent variable was interval scale. The independent variables should be mostly interval or scale level variables, but multiple regression can also have dichotomous independent variables called dummy variables (Matthews, 2017). In this study, the independent variables refer to relative humidity (%), wind speed (m/s), mean rainfall (mm), mean temperature (°C) and solar radiation (MJ/m^2/day). The dependent variable is the oil palm yield. In regression analysis, assumptions need to be considered as the samples are normally distributed and uncorrelated with the other variables (Wagschal, 2016). There is a linear relationship between the independent variables and the dependent variable and no multicollinearity issues (Daoud, 2018; Shrestha, 2020). As a result, this study analysed bivariate correlation to examine the linear relationship and continued to examine the variance inflation factor (VIF) and tolerance to confirm the presence of multicollinearity. The values of tolerance must be less than 5 and tolerance values greater than 0.2 (Jirakiattikul *et al*., 2021). The multiple linear regression equation is as follow:

$$Y = \beta_0 + B_1X_1 + B_2X_2 + \ldots\ BnXn + \varepsilon$$

The yield of oil palm is influenced by relative humidity, wind speed, mean rainfall, temperature and solar radiation. For multiple linear regression, the coefficient is estimated similar to simple linear regression. The error term is a random variable with a mean of zero and a constant variance. In the basic linear regression model, the error term reflects the fact that the regression is not perfect and will not fit the data absolutely. There are random factors other than the independent variables affecting the relationship. They are unknown and this study can only make basic assumptions about the factors in order for the model to work, such as soil types (land selection and topography), palm age, planting material (tissue culture, new varieties), machinery, manpower and available technology, technical management (financial, organizational, labour, transport, pest, disease, harvesting efficiency, unsuitable ground vegetation, etc.) (Woittiez *et al*., 2017).

For this case of study, the proposed model is:

$$\text{Yield tonne (Y)} = \beta_0 + B_1\text{RelativeH} + B_2\text{WindS} + B_3\text{Rainfall} + B_4\text{Temperature} + B_3\text{SolarR} + \varepsilon$$

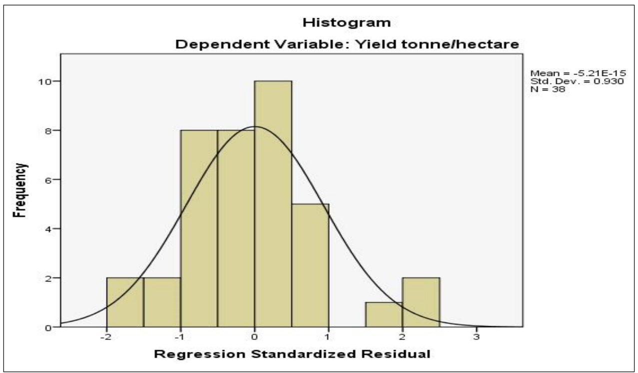

Fig 1: Regression standardized residual.

Table 1: Descriptive analysis.

Variables	Mean	Std.	Skewness Deviation	Kurtosis
Yield tonne/hectare	18.719	1.391	0.612	1.195
Relative humidity (%)	87.120	1.429	-2.953	1.076
Wind speed (M/S)	0.502	0.020	0.022	-0.182
Mean rainfall (mm)	243.967	48.922	-2.564	1.401
Mean temperature (°C)	26.010	1.170	4.043	1.193
Solar radiation (MJ/m^2/day)	35.659	0.784	-2.454	4.541

RESULTS AND DISCUSSION

The mean yield of oil palm was 18.719 tonne per hectare, 87.120% of relative humidity and the mean wind speed was 0.502 m/s. In addition, the mean rainfall was 243.967 mm, 26.010°C mean temperature and 35.659 MJ/m^2/day was the mean of solar radiation (Table 1). The analysis indicates that the histogram was symmetrical, explained the normal distribution and met the following regression analysis assumption (Fig 1).

The linear relationship was conducted using bivariate correlation. The analysis showed that a linear relationship between solar radiation and temperature had a significant and inverse relationship. In addition, temperature and solar radiation did not present a significant correlation with yield (Table 2).

Table 3 revealed that when the combined effect of relative humidity, wind speed, mean rainfall, mean temperature and solar radiation was regressed on the oil palm yield of the sample under study, an F-value of 1.618 was obtained, with $p>0.05$ at 5 and 32 degrees of freedom (df). Based on the results obtained, the climatic parameters (relatived humidity, rainfall, temperature, wind speed and solar radiation) did not contribute significantly to the change in yield variation. Furthermore, the result explained by the combined effect of relative humidity, wind speed, mean rainfall, mean temperature and solar radiation did not significantly influence the yield of oil palm.

The multiple linear regression model obtained as follows:

Yield of oil palm (y) = 4.553 + 0.235 Relative H+2.451 WindS-0.001 Rainfall -0.380 Temperature + 0.071 Solar R

From the model, it is evident that the relative humidity (Relative H), wind speed (WindS), mean rainfall (Rainfall), mean temperature (Temp) and solar radiation (SolarR) have a low impact on the yield of oil palm. The R^2 value of 0.202 indicates that only 20.2% of the variation in the oil palm yield is explained by the independent variables (Table 4). This indicates that there are other variables

Table 2: Correlation analysis.

Variables	1	2	3	4	5	6
Yield tonne/hectare	1.000					
Relative humidity	.275	1.000				
Wind speed	.030	-.331	1.000			
Mean rainfall	.123	.208	-.142	1.000		
Mean temperature	-.381	-.112	-.213	-.278	1.000	
Solar radiation	.390	.375	.075	.326	-.827*	1.000

*Significance level at 0.05.

Table 3: ANOVA analysis.

ANOVA						
Model		Sum of squares	df	Mean square	F	Sig.
1	Regression	14.438	5	2.888	1.618	.184
	Residual	57.124	32	1.785		
	Total	71.562	37			

Table 4: Model summary.

Model summary[b]										
					Change statistics					
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	R Square Change	F Change	df1	df2	Sig. F Change	Durbin-Watson
1	.449[a]	.202	.077	1.33609	.202	1.618	5	32	.184	1.755

a. Predictors: (Constant), Solar radiation (MJ/m^2/day), Wind speed (M/S), Mean rainfall (mm), Relative humidity (%), Mean temperature (°C).
b. Dependent variable: Yield tonne/hectare.

Table 5: Coefficient.

	Unstandardized Coefficients		Standardized coefficients	t	Sig.	Collinearity statistics	
	B	Std. error	Beta			Tolerance	VIF
(Constant)	4.553	28.432		.160	.874		
Relative humidity	.235	.190	.241	1.238	.225	.657	1.522
Wind speed	2.451	12.112	.036	.202	.841	.806	1.241
Mean rainfall	-.001	.005	-.024	-.142	.888	.859	1.164
Mean temperature	-.380	.366	-.320	-1.038	.307	.263	3.801
Solar radiation	.071	.581	.040	.122	.904	.233	4.297

besides relative humidity, wind speed, mean rainfall, mean temperature and solar radiation that influence the yield of oil palm, such as farm management, soil characteristics and type of seed, among others. This is consistent with studies conducted at various locations in Malaysia and found that climatic elements have less impact on oil palm production and the determination of fresh fruit bunch yield (Nda *et al*., 2018; Kota Shafiq, 2017).

Based on the results in Table 5, relative humidity (0.225), wind speed (0.841), mean rainfall (0.888), mean temperature (0.307) and solar radiation (0.904) all the values are greater than 0.05, therefore this study failed to reject the null hypothesis (H_0) and concluded they are all statistically insignificant. The Variance Inflation Factor (VIF) of relative humidity (1.522), wind speed (1.241), mean rainfall (1.164), mean temperature (3.801) and solar radiation (4.297) were less than 5. For the tolerance value, relative humidity (0.657), wind speed (0.806), mean rainfall (0.859), mean temperature (0.263) and solar radiation (0.233) were greater than 0.2. From the analysis, the results confirmed that there were no issues with multicollinearity. However, Hair *et al*. (2010) states that "multicollinearity occurs when two or more predictors in the model are correlated and provide redundant information about the response. Multicollinearity was measured by variance inflation factors (VIF) and tolerance. If VIF value exceeding 4.0, or by tolerance less than 0.2 then there is a problem with multicollinearity".

CONCLUSION

This study concludes that climatic elements had no significant effect on oil palm production, with the model indicating that only 20.2% of the variability in monthly oil palm yield was represented by the regression equation. Future research will most likely include the delineation of climatic regions using statistical analysis of Malaysia's monthly grided data set using various climatic indices. It will be useful to further explore the relationship between oil palm yield, climatic and cultural factors aside. This will give the oil palm growers insight into the agricultural practices suitable for oil palm production.

ACKNOWLEDGEMENT

I wish to acknowledge Tertiary Education Trust Fund (TETFUND) for sponsoring this original research. Grant number TETF/UNIV/ JIGAWA STATE/TSAS/2019.

Authors contribution

Ahmed Abubakar, Mohd Yusoff Ishak, Murtala Uba Mohammed: Conceptualization, methodology, writing-review and editing.; Ahmed Abubakar, Mohd Yusoff Ishak, Md Kamal Uddin, Aisyah Abu Bakar: software, validation, formal, analysis; Ahmed Abubakar, Mohd Yusoff Ishak, Mohd Kamal Uddin: investigation Ahmed Abubakar: resources Mohd Yusoff Ishak, Murtala Uba Mohammed, Aisyah Abu Bakar, Ahmed Abubakar: data curation, writing-original draft, preparation, visualization, supervision, project administration.; Ahmed Abubakar: funding acquisition.

Declaration

Ethics approval and consent to participate

This study neither involved human/animal participation, experiment, nor human data/tissue.

Consent for publication

This study did not involve children or individual details, but 100% data usage.

Data availability statement

All data generated or analysed during the study are included in the published article(s) cited within the text and acknowledged in the reference section.

Competing interest

All authors declare no competing interest.

Funding

The study was funded by the Tertiary Education Trust Fund, Nigeria (TETFUND).

REFERENCES

Abubakar, A., Ishak, M.Y. and Makmom, A.A. (2021). Impacts of and adaptation to climate change on the oil palm in Malaysia/ : A systematic review. Environmental Scieence and Pollution Research. 28: 1-23.

Ahmed, A., Mohd, Y.B.I. and Abdullah, A.M. (2021). Oil Palm in the Face of Climate Change: A Review of Recommendations. IOP Conference Series: Earth and Environmental Science. 646: 1-10.

Ambar Suharyanti, N., Mizuno, K. and Sodri, A. (2020). The Effect of Water Deficit on Inflorescence Period at Palm Oil Productivity on Peatland. E3S Web of Conferences. 211: 2-11.

Begum, H., Siwar, C., Alam, A.S.A.F., Choy, E.A., Ishak, S. and Alam, L. (2018). Enhancing sustainability amongst oil palm smallholders in Malaysia. International Journal of Agricultural Resources. Governance and Ecology. 14: 62-79.

Caliman, J.P. and Southworth, A. (1998). Effect of Drought and Haze on the Performance of Oil Palm. International Oil Palm Conference. In: IOPRI international oil palm conference: Commodity of the past, today and the future. Bali, Indonésie. 23-5 September. 1-30.

Chen, C.C., McCarl, B.A. and Schimmelpfennig, D.E. (2004). Yield variability as influenced by climate. Climatic Change. 66: 239-261.

Corley, R.H.V. and Tinker, P.B. (2015). The Oil Palm. World Agricultural Series. Wiley Blackwell. London.

Daoud, J.I. (2018). Multicollinearity and Regression Analysis. Journal of Physics: Conference Series. 949: 1-6.

Darmawan, S., Takeuchi, W., Haryati, A., Najib, R.A.M. and Na'Aim, M. (2016). An Investigation of Age and Yield of Fresh Fruit Bunches of Oil Palm Based on ALOS PALSAR 2. IOP Conference Series: Earth and Environmental Science. 37: 1-8.

Dislich, C., Keyel, A.C., Salecker, J., Kisel, Y., Meyer, K.M., Auliya, M., Barnes, A.D., Corre, M.D., Darras, K., Faust, H., Hess, B., Klasen, S., Knohl, A., Kreft, H., Meijide, A., Nurdiansyah, F., Otten, F., Pe, G., Steinebach, S., Wiegand, K. (2017). A review of the ecosystem functions in oil palm plantations, using forests as a reference system. Biological Reviews. 49: 1539-1569.

Fleiss, S., Hill, J.K., Mcclean, C., Lucey, J.M. and Reynolds, G. (2017). Potential Impacts of Climate Change on Oil Palm Cultivation A science-for-policy paper by the SEnSOR programme. 1-17.

Ghini, R., Bettiol, W. and Hamada, E. (2011). Diseases in tropical and plantation crops as affected by climate changes: Current knowledge and perspectives. Plant Pathology. 60: 122-132.

Hair, J.F., Black, W.C., Babin, B.J. and Anderson, R.E. (2010). Multivariate Data Analysis. Seventh Edition. Prentice Hall, Upper Saddle River, New Jersey.

Herdiansyah, H., Negoro, H.A., Rusdayanti, N. and Shara, S. (2020). Palm oil plantation and cultivation: Prosperity and productivity of smallholders. Open Agriculture. 5: 617-630.

Hilal, Y.Y., Ishak, W., Yahya, A. and Asha'ari, Z.H. (2018). Development of genetic algorithm for optimization of yield models in oil palm production. Chilean Journal of Agricultural Research. 78: 228-237.

Jirakiattikul, S., Lan, T.T. and Techato, K. (2021). Advancing households' sustainable energy through gender attitudes towards rooftop pv installations: A case of the central highlands, vietnam. Sustainability. 13: 1-15.

Kamil, N. and Omar, S. (2016). Climate variability and its impact on the palm oil industry. Oil Palm Industry Economic Journal. 16: 18-30.

Keong, Y.K. and Keng, W.M. (2012). Statistical Modeling of Weather-based Yield Forecasting for Young Mature Oil Palm. APCBEE Procedia. 4: 58-65.

Kota Shafiq, M. (2017). The Effect of Rainfall Distribution to Production of oil Palm in Different Location. Desertation. University Teknologi Mara, Malaysia.

Kukal, M.S. and Irmak, S. (2018). Climate-Driven Crop Yield and Yield Variability and Climate Change Impacts on the U.S. Great Plains Agricultural Production. Scientific Reports. 8: 1-18.

Legros, S., Mialet-Serra, I., Caliman, J.P., Siregar, F.A., Clement-Vidal, A., Fabre, D. and Dingkuhn, M. (2009). Phenology, growth and physiological adjustments of oil palm (*Elaeis guineensis*) to sink limitation induced by fruit pruning. Annals of Botany. 104: 1183-1194.

Lim, K.H., Goh, K.J., Chiu, S.B. and Paramananthan, S. (2011). Agronomic Principles and Practices of Oil Palm Cultivation. (1st Edn.). Agricultural Crop Trust (ACT), Selangor. pp. 771.

Lobell, D.B., Field, C.B., Cahill, K.N. and Bonfils, C. (2006). Impacts of future climate change on California perennial crop yields: Model projections with climate and crop uncertainties. Agricultural and Forest Meteorology. 141: 208-218.

Maluin, F.N., Hussein, M.Z. and Idris, A.S. (2020). An overview of the oil palm industry: Challenges and some emerging opportunities for nanotechnology development. Agronomy. 10: 1-20.

Matthews, N.L. (2017). The International Encyclopedia of Communication Research Methods. The International Encyclopedia of Communication Research Methods (1st Edn.). Wiley-Blackwell, New Jersey. pp. 2048.

Merten, J., Röll, A., Guillaume, T., Meijide, A., Tarigan, S., Agusta, H., Dislich, C., Dittrich, C., Faust, H., Gunawan, D., Hein, J., Hendrayanto, A., Knohl, A., Kuzyakov, Y., Wiegand, K. and Hölscher, D. (2016). Water scarcity and oil palm expansion: Social views and environmental processes. Ecology and Society. 21: 1-21.

Muhammad, N.S., Abdullah, J. and Julien, P.Y. (2020). Characteristics of rainfall in Peninsular Malaysia. Journal of Physics: Conference Series. 1529: 1-12.

Munévar, F. and Munévar, F. (2004). Agroecologic criteria useful in land selection for new oil palm plantings in Colombia. Revista Palmas. 25: 148-159.

Nambiappan, B., Palm, M. and Board, O. (2018). Malaysia/: 100 years of resilient palm oil economic performance. Journal of Oil Palm Research. 14: 13-25.

Nda, M., Adnan, M.S., Suhadak, M.A., Zakaria, M.S. and Lopa, R.T. (2018). Effects of hydrological parameters on palm oil fresh fruit bunch yield. IOP Conference Series: Earth and Environmental Science. 140: 1-8.

Oettli, P., Behera, S.K. and Yamagata, T. (2018). Climate based predictability of oil palm tree yield in Malaysia. Scientific Reports. 8: 1-13.

Paterson, R.R.M. (2020). Oil palm survival under climate change in Malaysia with future basal stem rot assessments. Forest Pathology. 50: 1-8.

Paterson, R. Russell, M. and Lima, N. (2018). Climate change affecting oil palm agronomy and oil palm cultivation increasing climate change, require amelioration. Ecology and Evolution. 8: 452-461.

Paterson, R.R.M., Sariah, M. and Lima, N. (2013). How will climate change affect oil palm fungal diseases/ ? Crop Protection. 46: 13-120.

Paterson, Robert R.M., Moen, S. and Lima, N. (2009). The feasibility of producing oil palm with altered lignin content to control ganoderma disease. Journal of Phytopathology. 157: 649-656.

Pirker, J., Mosnier, A., Kraxner, F., Havlík, P. and Obersteiner, M. (2016). What are the limits to oil palm expansion? Global Environmental Change. 40: 73-81.

Rhebergen, T., Fairhurst, T., Zingore, S., Fisher, M., Oberthür, T. and Whitbread, A. (2016). Climate, soil and land-use based land suitability evaluation for oil palm production in Ghana. European Journal of Agronomy. 81: 1-14.

Sarkar, M.S.K., Begum, R.A. and Pereira, J.J. (2020). Impacts of climate change on oil palm production in Malaysia. Environmental Science and Pollution Research. 27: 9760-9770.

Sasirat, P., Kheoruenromne, I., Suddhiprakarn, A. and Anusontpornperm, S. (2019). Influence of tropical climate parameters on properties of acid sulfate soils for sustainable oil palm cultivation. International Journal of Agronomy. 1-13.

Shanmuganathan, S., Narayanan, A., Mohamed, M., Ibrahim, R. and Khalid, H. (2014). A hybrid approach to modelling the climate change effects on Malaysia's oil palm yield at the regional scale. Advances in Intelligent Systems and Computing. 287: 335-346.

Sheil, D., Casson, A., Meijaard, E., van Nordwijk, M. Gaskell, J., Sunderland-Groves, J., Wertz, K. and Kanninen, M. (2009). The Impacts and Opportunities of Oil Palm in Southeast Asia: What do We Know and What do We Need to Know? Occasional paper no. 51. CIFOR, Bogor, Indonesia. 1-67.

Shevade, V.S. and Loboda, T.V. (2019). Oil palm plantations in Peninsular Malaysia: Determinants and constraints on expansion. PLoS ONE. 14: 1-22.

Shrestha, N. (2020). Detecting multicollinearity in regression analysis. American Journal of Applied Mathematics and Statistics. 8: 39-42.

Singh, R., Lee, K.T., Ooi, L.C.L., Low, E.T.L., Abdullah, M.O., Sambanthamurthi, R. and Azman, I. (2021). An overview of the development of the oil palm industry and impact of the shell gene innovation as a quality control tool to improve productivity. Journal of Oil Palm Research. 1: 1-15.

Tang, K.H.D. and Al Qahtani, H.M.S. (2020). Sustainability of oil palm plantations in Malaysia. Environment, Development and Sustainability. 22: 4999-5023.

Uning, R., Latif, M.T., Othman, M., Juneng, L., Hanif, N.M., Nadzir, M.S.M., Maulud, K.N. A., Jaafar, W.S.W.M., Said, N.F.S., Ahamad, F. and Takriff, M.S. (2020). A review of southeast Asian oil palm and its CO2 fluxes. Sustainability. 12: 1-15.

Uyanık, G.K. and Güler, N. (2013). A study on multiple linear regression analysis. Procedia - Social and Behavioral Sciences. 106: 234-240.

Wagschal, U. (2016). Regression analysis: In Handbook of Research Methods and Applications in Political Science. (1st Edn.). Edward Elgar, Cheltenham Glos. pp. 565.

Woittiez, L.S., van Wijk, M.T., Slingerland, M., Van Noordwijk, M. and Giller, K.E. (2017). Yield gaps in oil palm: A quantitative review of contributing factors. European Journal of Agronomy. 83: 57-77.

Wong, C.L., Liew, J., Yusop, Z., Ismail, T., Venneker, R. and Uhlenbrook, S. (2016). Rainfall characteristics and regionalization in peninsular malaysia based on a high resolution gridded data set. Water. 8: 1-11.

Wong, C., Uhlenbrook, S. and Zhou, Y. (2009). Variability of rainfall in Peninsular Malaysia. Hydrology and Earth System Sciences Discussions. 6: 5471-5503.

Zainal, Z., Shamsudin, M.N., Mohamed, Z.A. and Adam, S.U. (2012). Economic impact of climate change on the Malaysian palm oil production. Trends in Applied Sciences Research. 7: 872-880.