Modelling the Effects of Environmental Factors on the Spread of Black Pod Disease on Cocoa in Nigeria

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***Abstract* — This study concerns modelling effect of weather and climate on the spread of black pod diseases in cocoa using both classical Ordinary Least Squares techniques (OLS) and Bayesian Regression Techniques (BRT). Comparison between the two estimates were considered in this study. The data used in this study were collected from Cocoa Research Institute of Nigeria (CRIN), Ibadan between the years 1990–2016. The independent variables considered are Maximum Air Temperature, Minimum Air Temperature, Morning Relative Humidity, Afternoon Relative Humidity, Soil Temperature and Rainfall while the dependent variable is the number of cocoa pods infected with black pod diseases. A Normal-Gamma conjugate prior distribution was employed to fit a Bayesian normal linear regression model. It was observed that Maximum Air Temperature, Afternoon Relative Humidity, Soil Temperature and Rainfall contributes positively to the spread of black pod diseases in Nigeria while Minimum Air Temperature and Morning Relative Humidity contributed negatively to the spread of black pod diseases in Nigeria. However, it was discovered that the parameter estimates obtained under Bayesian techniques are better than that of the OLS techniques. The R programming Language was employed for the analysis in this study.**

Keywords- *OLS Method, Bayesian conjugate normal linear method, Maximum Air Temperature, , Black pod diseases.*

I. Introduction

Weather and climate plays an important role in productivity of crops which may be increased by the reduction of many kinds of loss resulting from unfavourable weather and climate and also by the more rational use of labour and equipment. Greater economy of effort is achieved on the farm, largely by the reduction of activities that have little value or are potentially harmful.

Black pod disease is a disease caused by *Phytophthora* which affect crops like palm tree, citrus, cocoa, coconut etc. The followings are the effects of black pod disease in cocoa such as: reduction in the number of beans/pod, colour changing partially or wholly from yellow to black and it causes canker of some branches and they die off. The major economic loss is from infection of the pod. Pods can be infected at any age, but most significant economic loss arises from infection during the two months prior to ripening. Pods infected at this stage can be a total loss because the fungus can easily pass from the pod husk to the seed-coat of the bean in a developing green pod.

[8] stated that, disease pressure from leaf and root pathogen increases humidity and frequency rainfall events are projected, and decrease in region projected to encounter more frequently drought.

Temperature is a single most factor affecting insect ecology, epidemiology, and distribution, while plant pathogen will be highly responsive to humidity and rainfall, as well as temperature [2].

A warmer climate would expand the ranges of pests and diseases, could also increase vulnerability and result in greater use of greater fungicides, pesticides, etc [3]. 20% – 30% global yield loses through black pod rot, and killing up to 10% of trees annually through stem cankers due to unfavourable condition [5]. Disease of cocao account more than a 40% loss of the potential cocoa crop, and have caused a steady decline in production and reduction of beans quality worldwide [9].

Cocoa is grown in places that are hot, moist and partly shaded that allows fungi, disease and pesticides to live [4]. The disease is worst in the areas of heavy rainfall [10]. A warm globe will probably produce as much food as before, but not necessarily in the same place, crops may also be afflicted by more pest and disease [10].

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II. MATERIALS AND METHOD

A. Data Description

The data which covered twenty-six years (1990 – 2016) was collected from Economics/Statistics Division of Cocoa Research Institute of Nigeria, Ibadan. The data comprises summary of cocoa black pod (Y) and meteorology data which includes Maximum Air Temperature (X_1), Minimum Air Temperature (X_2), Morning Relative Humidity (X_3), Afternoon Relative Humidity (X_4), Soil Temperature (X_5) and Rainfall (X_6)

B. Methodology

This section presents an overview of the classical OLS and the Bayesian regression techniques for estimating regression model parameters.
Consider a multiple linear regression model with dependent variable Y and a set of independent variables X

$$Y = X\beta + \varepsilon \quad (1)$$

Where Y is the n x 1 vector of responses, X is the n x p matrix of independent variables, β is the p x 1 vector of the regression coefficients and ε is the n x 1 vector of a random variable with independent Gaussian probability density with mean μ = 0 and variance σ^2 ([6] , [7])

The Least Squares Method

The least squares estimators are those values of β_i (where i = 0, 1… p-1) that minimize$\sum(y - x\beta)^2$.
The least squares normal equations for the general linear regression model (1) are

$$X'Xb = X'Y \quad (2)$$

And the least squares estimators are

$$b = (X'X)^{-1}(X'Y) \quad (3)$$

The Bayesian Linear Regression Model Estimation

Let $Y_1, Y_2, \ldots, Y_n$ be a set of iid random sample of size n from a density function $f(Y_i|\beta, \sigma^2)$ with unknown parametersβ, σ^2. Then the likelihood function can be expressed as

$$L(\beta, \sigma^2|y) = N(X\beta, \sigma^2 I)$$

$$= \left(\frac{1}{2\pi\sigma^2}\right)^{\frac{n}{2}} exp\left\{-\frac{1}{2\sigma^2}(y - X\beta)^T(y - X\beta)\right\} \quad (4)$$

where $\varepsilon \sim N(0, \sigma^2 I)$ and I is a unit matrix of dimension n
The prior distribution of (4) can be expressed as

$$\pi(\beta, \sigma^2) = \pi(\sigma^2)\pi(\beta|\sigma^2) = IG(a, b)N(\beta|\mu_\beta, \sigma^2 V_\beta{}^{-1}) = A\left(\frac{1}{\sigma^2}\right)^{a+\frac{p}{2}+1} \exp\left\{-\frac{1}{\sigma^2}\left[b + \frac{1}{2}(\beta - \mu_\beta)^T V_\beta{}^{-1}(\beta - \mu_\beta)\right]\right\} (5)$$

Where $A = \frac{b^a}{(2\pi)^{\frac{p}{2}}|V_\beta|^{\frac{1}{2}}\Gamma(a)}$

to obtain the posterior distribution, we combine (4) and (5)

$$= A\left(\frac{1}{2\pi}\right)^{\frac{n}{2}}\left(\frac{1}{\sigma^2}\right)^{a+\frac{p+n}{2}+1} exp\left\{\frac{1}{2\sigma^2}\left[(y - X\beta)^T(y - X\beta) + (\beta - \mu_\beta)^T V_\beta{}^{-1}(\beta - \mu_\beta)\right]\right\} exp\left\{-\frac{b}{\sigma^2}\right\} \quad (6)$$

Where

$$(y - X\beta)^T(y - X\beta) + (\beta - \mu_\beta)^T V_\beta{}^{-1}(\beta - \mu_\beta)$$
$$= tr\left[(y - X\beta)^T(y - X\beta) + V_\beta{}^{-1}(\beta - \mu_\beta)^T(\beta - \mu_\beta)\right]$$
$$= tr(V_\beta{}^{-1} + X^T X)\left[\beta\beta^T - \beta^T\mu^* + \beta\mu^* + \frac{V_\beta{}^{-1}\mu_\beta\mu_\beta{}^T}{V_\beta{}^{-1} + X^T X} + \frac{yy^T}{V_\beta{}^{-1} + X^T X}\right]$$
$$= tr\left[V^{*-1}(\beta - \mu_\beta{}^*)(\beta - \mu_\beta{}^*)^T + V^{*-1}\mu^*\mu^{*T} + V_\beta^{-1}\mu_\beta^*\mu_\beta + yy^T\right]$$
$$= (\beta - \mu_\beta{}^*)^T V^{*-1}(\beta - \mu_\beta{}^*) + \mu^{*T}V^{*-1}\mu^* + \mu_\beta^* V_\beta^{-1}\mu_\beta + yy^T \quad (7)$$

Where $\mu_\beta{}^* = \frac{V_\beta{}^{-1}\mu_\beta + X^T y}{V_\beta{}^{-1} + X^T X}$ and $V^* = (V_\beta{}^{-1} + X^T X)^{-1}$

Substituting (7) in (6) we have

$$p(\beta, \sigma^2|y) = A\left(\frac{1}{2\pi}\right)^{\frac{n}{2}}\left(\frac{1}{\sigma^2}\right)^{a^*+1} exp\left\{-\frac{1}{\sigma^2}\left[b^* + \frac{1}{2}(\beta - \mu_\beta{}^*)^T V^{*-1}(\beta - \mu_\beta{}^*)\right]\right\} \quad (8)$$

Where

$$b^* = b + \frac{1}{2}\left[\mu^{*T}V^{*-1}\mu^* + \mu_\beta^* V_\beta^{-1}\mu_\beta + yy^T\right]$$
$$a^* = \frac{n+p}{2} + a$$

Integrating (8) with respect to $\delta\mu_\beta{}^*$ and $\delta\sigma^2$ we obtained the marginal posterior distribution for y

$$p(y) = \iint A\left(\frac{1}{2\pi}\right)^{\frac{n}{2}}\left(\frac{1}{\sigma^2}\right)^{a^*+1} exp\left\{-\frac{1}{\sigma^2}\left[b^* + \frac{1}{2}(\beta - \mu_\beta{}^*)^T V^{*-1}(\beta - \mu_\beta{}^*)\right]\right\}\delta\mu_\beta{}^*\delta\sigma^2$$

$$p(y) = \frac{b^a\Gamma(a^*)\sqrt{|V^*|}}{(2\pi)^{\frac{n}{2}}\Gamma(a)\sqrt{|V_\beta|}} \quad (9)$$

Where

$\int exp\left\{-\frac{1}{2\sigma^2}\left[(\beta - \mu_\beta{}^*)^T V^{*-1}(\beta - \mu_\beta{}^*)\right]\right\}\delta\mu_\beta{}^*$ is a scaled $N(\beta|\mu_\beta{}^*, \sigma^2 V^*)$ and is equal to $\sqrt{2\pi|V^*|}$ and also $\int\left(\frac{1}{\sigma^2}\right)^{a^*+1} exp\left\{-\frac{b^*}{\sigma^2}\right\}\delta\sigma^2$ is a scaled $IG(a^*, b^*)$ which is equal to $\frac{\Gamma(a^*)}{b^{*a^*}}$.

To obtain the marginal posterior distribution of β, we integrate out σ^2 from the NIG joint posterior distribution (8) as follows

$$\int \left(\frac{1}{\sigma^2}\right)^{a^*+1} exp\left\{-\frac{1}{\sigma^2}\left[b^* + \frac{1}{2}\left(\beta-\mu_\beta{}^*\right)^T V^{*-1}\left(\beta - \mu_\beta{}^*\right)\right]\right\}\delta\sigma^2$$

$$\propto \left[1+\frac{\left(\beta-\mu_\beta{}^*\right)^T V^{*-1}\left(\beta-\mu_\beta{}^*\right)}{2b}\right]^{-\left(a^*+\frac{p}{2}\right)}$$

$$MVST_{v^*}(\mu^*,\Sigma^*) = \frac{\Gamma\left(\frac{v^*+p}{2}\right)}{\Gamma\left(\frac{v}{2}\right)\pi^{\frac{p}{2}}|v^*\Sigma^*|^{\frac{1}{2}}}\left[1+\frac{\left(\beta-\mu_\beta{}^*\right)^T\Sigma^{*-1}\left(\beta-\mu_\beta{}^*\right)}{2b}\right]^{-\left(\frac{v^*+p}{2}\right)} \quad (10)$$

Where $v^* = 2a^*$ and $\Sigma^* = \left(\frac{b^*}{a^*}\right)v^*$

and to obtain the marginal posterior distribution of $\sigma^2$is immediately to be an IG(a^*, b^*) with density

$$p(\sigma^2|y) = \frac{b^{*a^*}}{\Gamma(a^*)}\left(\frac{1}{\sigma^2}\right)^{a^*+1} exp\left\{-\frac{b^*}{\sigma^2}\right\} \quad (11)$$

III. RESULTS AND DISCUSSION

A. *Results*

In this section, we present the results of the OLS and the Bayesian estimators for the linear regression model (1) based on Monte Carlo study.

The results obtained for the classical OLS and Bayesian regression method using R software are displayed in Tables 1 and 2. The density plots of the parameters over a number of iterations are provided by Fig 1.

Table: Results of OLS and Bayesian Regression Model

Method	β_0	β_1	β_2	β_3	β_4	β_5	β_6	σ^2
Bayesian	-35000	1159.0	-140.9	43.37	-2.682	16.14	101.0	1721.0
OLS	-36150.808	1205.008	-138.730	42.193	-3.138	16.306	99.592	2734137

Fable 2: Table of Bayesian 95% credible interval and 95% confidence interval of parameters' estimates.

Parameter	95% C. I. FOR BAYES		Frequentist (ML) 95% C.I.	
	Lower	*Upper*	*Lower*	*Upper*
β_1	-519.6	1164.0	-455.1889	2865.205
β_2	-540.5	256.7	-534.3808	256.92
β_3	-319	403.2	-317.8599	402.2465
β_4	-338.7	335.9	-337.8979	331.6213
β_5	-22.85	55.08	-22.68438	55.29712
β_6	-790.7	994.4	-785.0056	984.1888
σ^2	1602756	5721664	NA	NA

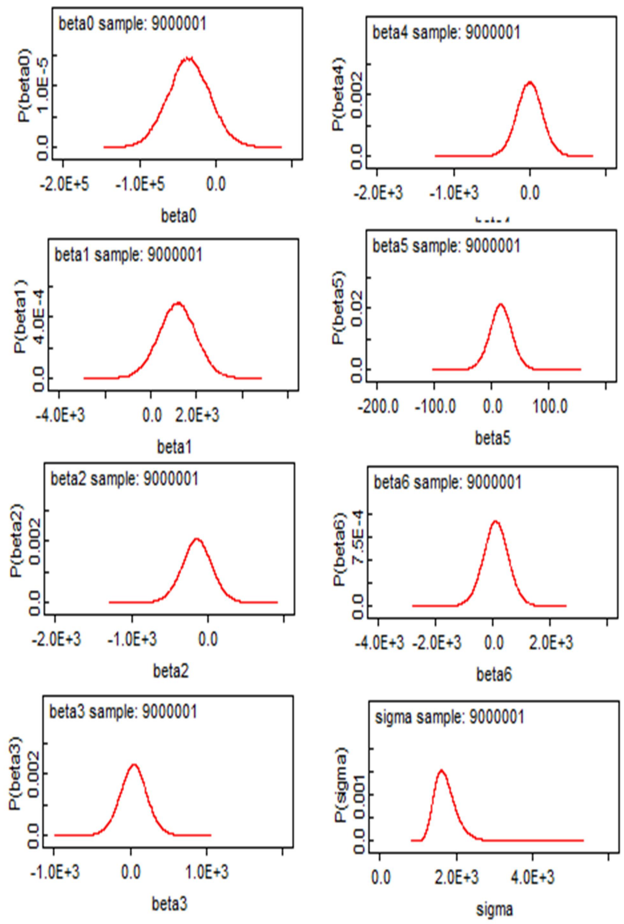

Figure 2: Density plots of parameters

B. *Discussions*

In this work, the classical ordinary least squares method and the Bayesian regression techniques were employed to model the effect of black pod diseases on the cocoa in Nigeria. Although, the two approaches used in estimating the parameters are quite efficient for modelling both simple and multiple linear regression. The advantage of classical OLS technique is its simplicity in the calculation and also it produces best linear unbiased estimates (BLUE). On the other hand, the Bayesian regression techniques produces a direct probability statement about a parameter, or hypothesis, as opposed to the somewhat awkward notions of confidence level or p-level, which are frequently misinterpreted by nonprofessional statistics users.

From the results obtained, it was noted that maximum air temperature, morning relative humidity, rainfall and soil temperature contributes to the spread of black pod diseases among cocoa in Nigeria positively. That is, for every unit increase in maximum air temperature, morning relative humidity, rainfall and soil temperature there is an increase in the number of cocoa pod effected with black pod diseases. Also, elements like afternoon relative humidity and minimum air temperature contributes negatively to the spread of black pod diseases among cocoa. That is, for every unit increase in like afternoon relative humidity and minimum air temperature leads to a decrease in the number of cocoa pod that will be effected which supports the findings of [1]. It was also observed that about 78% of the total variation are been accounted for by the model.

IV. Conclusion

In the end, which method is better? Ultimately, it is up to the statistician to choose which method he or she prefers to use based on any prior knowledge of the data. While the Method of Least Squares seems ideal because of its simple calculations, the Bayesian approach provides a "direct probability statement about the parameter." Both methods can be equally criticized for the flaws that each possess. Neither method is "better" than the other, it all depends on the prior knowledge of the data and the decision of the statistician as to which method he or she uses.

In addition, since relative humidity contributes positively to the spread of black pod disease, we recommend that cocoa should be grown with a light as a shade. Also, farmers should lower the densities of trees, so to lower the humidity within the canopy. In fact, the use of pruning to create an open canopy by cutting branches close to the fork and the removal the chupons should be encourage.

Farmers should be encouraged to cut off all pods which are infected with black pod disease and then be removed from the plantation; or, in case of large block of cocoa should be put into pits. Furthermore, all trees should be inspected at least every four weeks during the main production seasons; ideally it should be done weekly. Pods which are ripe and are partially black should be treated as good pods, while pods which are partially black and are unripe should be discarded. Also, early harvest of pods will help to prevent the build-up of spores in the orchard.
Government should assist farmers in subsidizing some agricultural inputs, especially fungicides as well as spraying humps. Although, the use of chemical control are also recommend to the farmers because it reduces black pod disease. Chemicals such as phosphorus acid, copper based fungicide, melataxyl, fosetyl-aluminium, potassium, etc. can be used to prevent black pod disease.

Finally, we recommend, breeding of cocoa varieties which are resistance to disease by the institutes. Resistant varieties are not only environment friendly, but also require little additional disease control inputs from farmers. We also recommend frequent and complete harvesting sanitation and appropriate disposal of pod mummies, infection pods and pod husks to reduce the spread of disease.

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