The Relationship between Cocoa Yield and Climate Variables in Oyo State, Nigeria Using Multiple Linear Regression and Support Vector Machine Analysis

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Abstract: - **This study was carried out to evaluate the relationship between cocoa yield and climate variables and examines the variations among them using multiple linear regression, principal component analysis and support vector machine. The climatic and cocoa yield data for thirty (30) years between 1985 and 2014 was used for the study. Cocoa yield exhibits a coefficient of variation of 39.39% with an average of 33637.13 t/ha. The highest coefficient of variation (CV) of 23.4% in the climatic variables was exhibited by wind speed with an annual mean value of 15.6 km/hr which was followed by Pan evaporation with a CV of 12.4% and with an average value of 1396.2 mm/yr. Rainfall has a coefficient of variation (CV) of 16.67% with a mean value of 1355 mm/yr. Solar radiation varied with a coefficient of variation (CV) of 10.3% and an average value of 15.14 MJ/m^2/day. The air temperature with a CV of 1.2% has the least variation out of the climatic series that was examined. Cocoa yield temporal trend shows a non-significant decrease at the rate of 0.026 t/ha/yr (P>0.05) decreasing trends. There was a sharp decrease in cocoa yield between 1988 – 1990 and short-term fluctuations of scores of PC1 which runs parallel to those of the yield. A sharp increase in the cocoa yield was noticed between 1990 – 2014. Using SVM regression analysis only rainfall, solar radiation and temperature were the variables that were best correlated with cocoa yield with an r^2 value of 0.52. The findings from this research work are expected to provide a baseline for knowledge in regional climate-yield studies. This will aid efforts at assessing high breeds cocoa that could positively respond to future climate actions at mitigating the effect of climate change in the study area. This research work could be extended to other cocoa-producing areas.**

Keywords: **climate variables; cocoa yield; linear regression; support vector machine, principal component analysis.**

I. INTRODUCTION

Cocoa is a major tree crop that has contributed to the growth and development of the economy of Nigeria for a number of years and has gained much relevance because of what people derive from its earnings and its contribution in terms of Gross Domestic Product (GDP) (Oyekale et al., 2009). Oluyole and Sanusi (2009) reported that at present, fourteen of the thirty-six states in Nigeria are producing cocoa which includes Ondo, Cross River, Osun, Ekiti, Ogun, Oyo, Edo, Delta, Kwara, Kogi, Abia, Taraba, Adamawa and Akwa Ibom. The significance attached to cocoa production and other cash crops in most of the states in Nigeria has been discouraging. These have made the level of cocoa production to reduce drastically. The discovery and exploitation of petroleum resources in Nigeria have led to the neglect of cocoa sub-sector thereby depriving it of maintaining its leading role as a non-oil export crop. This situation is further aggravated by the behavior and changes of global climatic variables which tend to reduce cocoa production due to its negative impact. Adaptations and mitigation strategies towards these changes by cocoa farmers have become necessary in view of its implications for production and sustainability of cocoa. The favorable climatic condition has been discovered as one of the factors affecting the modest growth in cocoa subsector owing to the fact that Cocoa is being noticed to be highly sensitive to changes in climate, most especially temperature because of its impact on evapotranspiration (Anim-Kwapong and Frimpong, 2005). Cocoa has been noticed to do well with minimal but consistent water availability throughout the year (Obatolu et al., 2003).

Management practices and climatic conditions are the two major factors affecting crop yield (Wright, 1993). However, in order to improve the production of any crop, there is need to study the climatic conditions of such area, where climatic parameters such as temperature, rainfall, humidity as well as sunshine hours affect the agricultural output of any region. To an extent, the daily, seasonal, or annual variations values of the climatic variables are of greater significance in determining the performance of crop (Ayoade, 2004; Ajewole and Iyanda, 2010).

A lot of climatic of factors has been discovered to have a negative impact on the growth of the cocoa plant and this includes rainfall, temperature, sunlight, and humidity. Ayoade (2004), observed that the higher the temperature (Maximum of 32^{0}c), the higher the yield, while the lower the relative

humidity, the better the yield. However, the yearly variation in the cocoa yield is affected more by rainfall than any other climatic factors (Adeniyi and Ogunsola, 2014).

A weather condition is said to be extreme as described by ICCO (2003) as an extreme of the historical distribution, such as severe or unfavorable weather and two important factors that impact optimum yield are precipitation and temperature. Thus as a result of the extreme climatic event that results into crop losses, low crop yield which also has a resultant effect on socio-economic variables such as income of the farmers, their way of life and farm level decision making. However, optimum motivation coupled with basic skill in crop production is the requirements that are sensitive to best practices and increased cocoa production (Ajewole and Iyanda, 2010)

Therefore, the aim of this study is, therefore, is to examine the relationships between the climatic variables and cocoa yield using a multiple linear regression and support vector machine analyses together with principal component analysis for the study area.

II. MATERIALS AND METHODS

2.1 Study area

Oyo State is one of the states in southwestern Nigeria. It covers a total land mass of 27,249 square kilometers and bounded in the north with Kwara State, in the south by Ogun State, in the in the west it is partly bounded by Ogun State and partly by the Republic of Benin, while in the East by Osun State. It has a landscape which consists of old hard rocks and dome-shaped hills, which rise gently from about 500 meters in the southern part and reaching a height of about 1,219 metres above sea level in the northern part. It is located on latitude 8.00'N and longitude 4.00'E and situated near forest grassland. It also has a sub-humid climate which is characterized by rainforest and slightly heavy rainfall. Its rainfall is bimodal with mean annual rainfall of 1250 mm.

Oyo State is located on and situated near the forest-grassland boundary of Southwestern, Nigeria. It also has a sub-humid climate which is characterized by rainforest and slightly heavy rainfall. The crop mainly grown in the area because of the climate includes: Maize, Yam, Cassava, Millet, Rice, Plantain, Cocoa tree, Palm tree and Cashew (www.oyostate.gov.ng)

Oyo state also has different vegetation pattern namely: rain forest in the southern part and guinea savannah in the northern part of the state. The average temperature ranges between 25 °C and 35°C) coupled with equatorial climate with dry and wet seasons and relatively high humidity. The wet season starts from April and ends in October while the dry season lasts from November to March with average daily temperature ranges between, almost throughout the year. Oyo state has an average relative humidity ranging from 51-82 % during the wet season and 56-59 % during the dry season and vegetation which is humid rain forest (Jagtab and Alabi, 1997; IITA, 2002).

2.2 Data Source

The meteorological data; solar radiation (S), rainfall (R), evaporation (E), temperature (T), relative humidity (H), and wind speed (w) used for this study were obtained from the archives of the International Institute of Tropical Agriculture (IITA), (7° 30' N, 3o 54' E, 243 m *amsl*) Ibadan. The climate data covers a period of thirty (30) years between 1985 and 2014. Data collections were done by IITA trained personnel and their weather instruments installations conform to WMO standard. Agro-ecological characteristics of the site and instrumentation are presented in Jagtap and Alabi (1997). In addition, annual cocoa yield data for the same period (1985 – 2014) was obtained from the Oyo State Cocoa Development Unit, Ministry of Agriculture, Natural resources and Rural Development, Ibadan, Oyo state and cocoa research Institute (CRIN), Ibadan.

2.3 Data Analysis

2.3.1 Pre-analysis data treatment

To determine the degree of association between cocoa yield and the climatic variables, climatic data for every month were correlated with the yield of cocoa before multiple linear regressions and support vector machine analysis was carried out to generally remove the variables that have a low relationship with cocoa yield. The variables were then sorted to seasonal and annual values. The seasons were divided into four as designated with: December to February (DJF), March to May (MAM), June to August (JJA) and September to November (SON).

Principal component analysis (PCA) which has been widely used in agro-meteorology and other disciplines (Lisheid et al., 2010) was also introduced to further reduce the list of climate variables having principal components with eigenvalues greater than one (Jollife,1990; Oguntunde et al., 2017). PCA break down the eigenvalue of the covariance matrix of the dataset and then make it a low-dimensional representation of the data which are not correlated (Thomas et al. 2012; Oguntunde et al., 2014a).

2.3.2. Multiple linear regressions analysis

Multilinear regression analysis is a technique used in the estimation of the relationship between a dependent variable and one or more independent variables is the regression analysis. It relates to Y (e.g cocoa Yield) to a function of X_i (independent variables e.g seasonal and annual values of climatic variables) and β (vector of weight) as follows:

$$y = f(Xi, \beta) \qquad + e_i \qquad\qquad (1)$$

2.3.3 Support vector machine analysis

Cocoa yield data were provided for 30 years and the total number of the predictor variables is 30 as shown in Table 1. The SVM model stepwise pruning of double iterative procedure was carried out with the set of predictor variables by systematically skipping single variables in order to

recognize the variable that has the least association with the cocoa yield and those variables were excluded from further analysis. The annual values of the predictor variables were used by averaging the respective seasonal values and then carried out stepwise pruning on them. However, here only the most relevant predictor was skipped per iteration step. After the number of predictor variables was reduced by principal component analysis (PCA) and the use of only the scores of principal components with an eigenvalue greater than 1 (Kaiser-Gutmann criterion, Jolliffe, 1990). Then stepwise pruning of the SVM model was performed on the annual and seasonal variables.

III. RESULTS AND DISCUSSION

3.1 Statistical Summary of Cocoa Yield and Climatic Variables

The summary statistics of temporal trends in the time series of the climatic variables: rainfall (R), air temperature (T) humidity (H), wind speed (W), solar radiation (S), pan evaporation (E), and cocoa yield (Y) are presented in Table 2. Cocoa yield exhibits a coefficient of variation of 39.39% with a mean value of 33637.13 tons/ha. The highest coefficient of variation (CV) of 23.4% in the climatic variables was exhibited by wind speed with an annual average value of 15.6 km/hr which was followed by pan evaporation with a CV of 12.4% and with an average value of 1396.2 mm/yr. Rainfall has a CV of 16.67% with an average value of 1355 mm/yr. Solar radiation varied with a CV of 10.3% with an average value of 15.14 MJ/m^2/day. The air temperature with a CV of 1.2% has the least coefficient of variation out of the climatic variables series that were examined. Cocoa yield temporal trend shows a non-significant decrease at the rate of 0.023 t/ha/yr (P<0.05) decreasing trends. E decreased significantly (P<0.001) at the rate of 0.122 mm/yr. However, air temperature and rainfall did not show a very statistically significant increasing trend (P<0.05).

3.2 Principal component analysis

Out of the entire component, Only the first seven principal components exhibited an eigenvalue > 1 in Figure 1a. The first component explained 24% while all the seven components explained 83% of the total variance of the predictor variables. Loadings on the first component are shown in Figure 1b. Most of the variables load positively on the component, especially evaporation and solar radiation which exhibit close correlation among themselves, and to a lesser extent Humidity and Wind speed.

3.3 Multiple linear regression analysis

The Performance of multiple linear regression models using predictor variables indicated for PCA, annual and seasonal datasets are presented in Table 3. The predictors are listed in the order of their relevance while those not listed have been excluded. Stepwise regression analysis picked three variables out of 25 seasonal predictor variables entered. R_5, S_5, and T_5

were the predictors of cocoa yield with a weak r^2 of 21 % in Table 3a.

3.4 Results of SVM regression analysis

Table 3b shows the values of r^2 between 0.37 and 0.67% for both the annual and seasonal data using the performance of the support vector machine. The best predictor of cocoa yield is R_5, S_5, and T_5 with an r^2 value of 0.52 in Table 3b i.e rainfall; solar radiation and temperature are the best predictors of cocoa yield on annual basis. While R_1, R_2, H_1, H_2, H_4, S_1, S_2, E_1, E_2, E_4, T_1, T_2, T_3 are the best predictors of cocoa yield on a seasonal basis which is in tandem with figure 2. This shows that these are the predictor variables that load the highest on the first principal component (Figure 1).

IV. DISCUSSIONS

The yields of cocoa exhibited a sharp increase between 1988 and 1993 and decreased from 1988 -1997. Cocoa yield also has a remarkably clear long-term increase between 1997 and 2014 in Figure 4. During the period under study, a decrease in solar radiation was observed in the study area. This observed decrease in solar radiation is in tandem with the widespread reported decrease in solar radiation (global dimming) over many locations which was linked with aerosol concentration and increased cloudiness (Stanhill and Cohen 2001, Oguntunde et al., 2012).

The amount of solar radiation received on the earth surface is a major component of the energy balance which controls large extent different processes, such as evaporation and its associated hydrological processes including diurnal and seasonal course of surface temperatures (Wild, 2009). Leaf conductance to gas exchange decreases when some plants are exposed to high light conditions thereby limiting the plant activity by soil water availability. A significant climatic factor regulating the opening and closing of stomata is Global irradiance (Oguntunde and Alatise, 2007). Crop water balance and evapotranspiration are closely related to solar radiation (Monteith 1965). Thus, evapotranspiration and water use are likely to be reduced by a decrease in solar radiation (Cohen et al. 2002; Oguntunde and van de Giesen, 2005).

The roles played by the climatic variables on cocoa yields cannot be overemphasized. For instance, Oyekale et al. (2009) reported that rainfall, temperature and sunshine hour are the major climatic variables which have a significant effect on cocoa yield which is in line with the results of this study except for solar radiation. Also, a similar study was also carried out by Anim-Kwapong and Frimpong, (2005) for three countries in West Africa namely Ghana, Nigeria and Cote D'Ivoire and revealed that a positive correlation exists between cocoa yield, rainfall, and temperature. Adeniyi and Ogunsola (2014), reported that major climatic variables affecting cocoa production were temperature, rainfall and sunshine hour in Osun State, Nigeria. Another study also carried out by Lawal and Emaku (2007) revealed that

Rainfall, temperature and relative humidity have a high correlation with cocoa yield in Ibadan.

In another development, Ofori-Boateng and Insah (2011) also reported that temperature and rainfall have a high correlation with cocoa yield in Nigeria. Oluyole and Sanusi (2009) in their work on overview of the trend of climate change and its effects on cocoa production in Nigeria observed that there was a significant correlation between cocoa yield and rainfall and also humidity. Oguntunde et al. (2014b) also reported a positive correlation between rainfall, temperature and cocoa yield in Ondo state. They established that there is a significant correlation between the yield and the two climatic variables.

V. CONCLUSION

Multiple linear regression and SVM regression models were used for this study. The overall findings revealed that three climate variables have substantial effects on the cocoa yield. The results would provide baseline information that is expected to provide regional- specific climate-cocoa yield interactions that may aid efforts for screening of high breeds of cocoa that could positively respond to future climate fluctuations as well as providing information that may help optimized planting dates and up to date management practices to be carried on cocoa for improved cocoa production in the study area. Research can be extended to other parts of cocoa producing areas of the country to know the relationship between the climatic variables and yield of cocoa in the areas.

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Table 1: Abbreviation and Descriptions of different measured and derived seasonal and annual predictor variable used in this study

S/N	Abbreviation	Description
1	R1	Rainfall totals for season 1
2	R2	Rainfall totals for season 2
3	R3	Rainfall totals for season 3
4	R4	Rainfall totals for season 4
5	R5	Annual rainfall
6	E1	Pan evaporation total for season 1
7	E2	Pan evaporation total for season 2
8	E3	Pan evaporation total for season 3
9	E4	Pan evaporation total for season 4
10	E5	Annual pan evaporation
11	H1	Mean relative humidity for season 1
12	H2	Mean relative humidity for season 2
13	H3	Mean relative humidity for season 3
14	H4	Mean relative humidity for season 4
15	H5	Annual mean relative humidity
16	S1	Mean solar radiation for season 1
17	S2	Mean solar radiation for season 2
18	S3	Mean solar radiation for season 3
19	S4	Mean solar radiation for season 4
20	S5	Annual mean solar radiation
21	T1	Mean temperature for season 1
22	T2	Mean temperature for season 2
23	T3	Mean temperature for season 3
24	T4	Mean temperature for season 4
25	T5	Annual mean temperature
26	W1	Mean wind speed for season 1
27	W2	Mean wind speed for season 2
28	W3	Mean wind speed for season 3
29	W4	Mean wind speed for season 4
30	W5	Annual wind speed

Table: 2 Descriptive and trend statistics of annual cocoa yield and climatic variables

Time Series	Descriptive Statistics		Trend statistics		
	Mean	CV (%)	Test Z	Sign.	Slope
Cocoa Yield (t/ha)	33637.13	39.59	3.71	***	-0.026
Rainfall (mm/yr)	1355	17.63	1.22		0.539
Relative humidity (%)	74.8	2.84	-1.72	+	-0.105
Solar radiation (MJ/m^2/day)	15.14	8.83	-5.38	***	-0.0130
Wind speed (Km/hr)	15.06	23.76	-3.42	***	-0.0254
Pan evaporation (mm/yr)	1396.2	14.63	-3.58	***	-0.122
Mean temperature (°C)	26.69	1.28	0.57		0.003

*** Significant at 0.001, **significant at 0.01, * significant at 0.05, + significant at 0.1

Table 3a: Performance of multiple linear regression models using as predictor variables scores of principal components, annual and seasonal data.

Time series	Model	Predictor(s)	R^2
PCA data	1	PC1	0.0059
	2	PC1, PC2	0.0548
	3	PC1,PC2,PC3	0.2484
	4	PC1,PC2,PC3,PC4	0.2581
Annual data	1	R5,H5,S5,W5,E5,T5	0.3325
	2	R5,S5,W5,E5,T5	0.3273
	3	R5,S5,W5,T5	0.2111
	4	R5,S5,T5	0.2078
	5	S5,T5	0.0239
Seasonal	1	R1,R2,R3,R4,H1,H2,H3,H4,S1,S2,S3,S4,W1,W2,W3,W4,E1,E2,E3,E4,T1,T2,T3,T4	0.8097
	2	R1,R2,R3,R4,H1,H2,H3,H4,S1,S2,S3,W1,W2,W3,W4,E1,E2,E3,E4,T1,T2,T3,T4	0.7477
	3	R1,R2,R3,R4,H1,H2,H3,H4,S1,S2,S3,W1,W2,W3,E1,E2,E3,E4,T1,T2,T3,T4	0.7339
	4	R1,R2,R4,H1,H2,H3,H4,S1,S2,S3,W1,W2,W3,E1,E2,E3,E4,T1,T2,T3,T4	0.6031
	5	R1,R2,R4,H1,H2,H3,H4,S1,S2,S3,W1,W3,E1,E2,E3,E4,T1,T2,T3,T4	0.5967
	6	R1,R2,H1,H2,H3,H4,S1,S2,S3,W1,W3,E1,E2,E3,E4,T1,T2,T3,T4	0.5706
	7	R1,R2,H1,H2,H3,H4,S1,S2,S3,W1,W3,E1,E2,E4,T1,T2,T3,T4	0.5499
	8	R1,R2,H1,H2,H3,H4,S1,S2,S3,W1,W3,E1,E2,E4,T1,T2,T3	0.508
	9	R1,R2,H1,H2,H3,H4,S1,S2,W1,W3,E1,E2,E4,T1,T2,T3	0.4679
	10	R1,R2,H1,H2,H3,H4,S1,S2,W1,E1,E2,E4,T1,T2,T3	0.4571
	11	R1,R2,H1,H2,H3,H4,S1,S2,E1,E2,E4,T1,T2,T3	0.4508

Table 3b: Performance of support vector machine using as predictor variables scores of principal components, annual and seasonal data.

| Time series	Model	#Predictor(s)	R^2
PCA data	1	PC1	0.24953
	2	PC1,PC2	0.188526
	3	PC1,PC2,PC3	0..49350
	4	PC1,PC2,PC3,PC4	0..53424
	5	PC1,PC2,PC3,PC4,PC5	0..54314
Annual data	1	R5,H5, S5, W5,E5,T5	0.56978
	2	R5,S5,W5,E5,T5	0.58393
	3	R5,S5,W5,E5	0.51814
	4	R5,S5,T5	0.52289
	5	S5,T5	0.37069
Seasonal	1	R1,R2,R3,R4,H1,H2,H3,H4,S1,S2,S3,S4,W1,W2,W3,W4,E1,E2,E3,E4,T1,T2,T3,T4	0.6659
	2	R1,R2,R3,R4,H1,H2,H3,H4,S1,S2,S3,W1,W2,W3,W4,E1,E2,E3,E4,T1,T2,T3,T4	0.5703
	3	R1,R2,R3,R4,H1,H2,H3,H4,S1,S2,S3,W1,W2,W3,E1,E2,E3,E4,T1,T2,T3,T4	0.5659
	4	R1,R2,R4,H1,H2,H3,H4,S1,S2,S3,W1,W2,W3,E1,E2,E3,E4,T1,T2,T3,T4	0.5403
	5	R1,R2,R4,H1,H2,H3,H4,S1,S2,S3,W1,W3,E1,E2,E3,E4,T1,T2,T3,T4	0.5450
	6	R1,R2,H1,H2,H3,H4,S1,S2,S3,W1,W3,E1,E2,E3,E4,T1,T2,T3,T4	0.5092
	7	R1,R2,H1,H2,H3,H4,S1,S2,S3,W1,W3,E1,E2,E4,T1,T2,T3,T4	0.5094
	8	R1,R2,H1,H2,H3,H4,S1,S2,S3,W1,W3,E1,E2,E4,T1,T2,T3	0.5120
	9	R1,R2,H1,H2,H3,H4,S1,S2,W1,W3,E1,E2,E4,T1,T2,T3	0.4550
	10	R1,R2,H1,H2,H3,H4,S1,S2,W1,E1,E2,E4,T1,T2,T3	0.4725
	11	R1,R2,H1,H2,H3,H4,S1,S2,E1,E2,E4,T1,T2,T3	0.5044
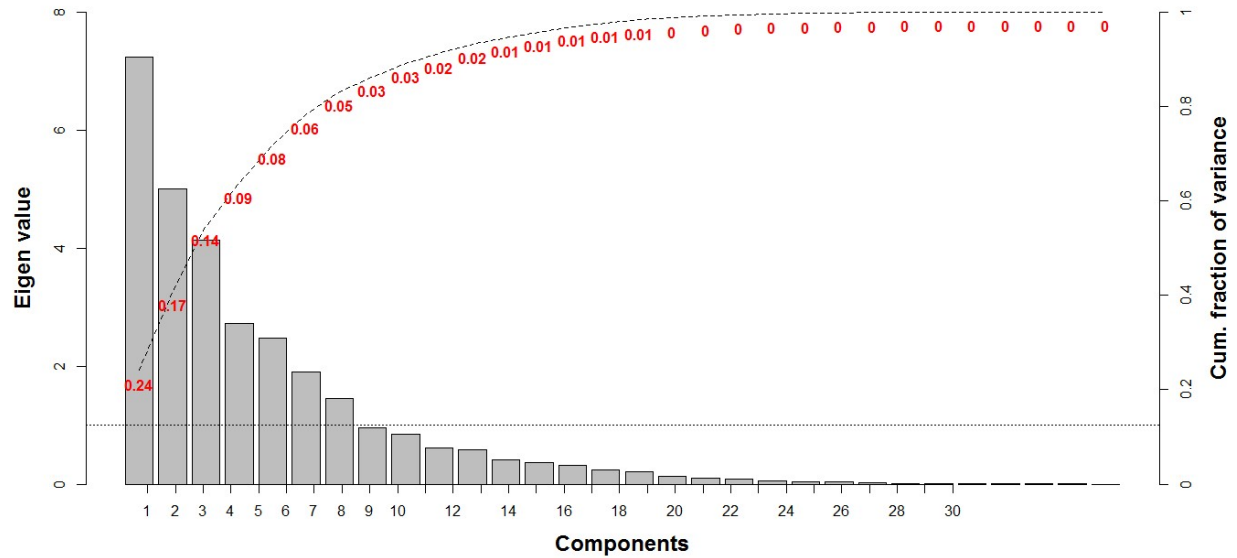
Figure 1: Loading of observed annual and seasonal climatic variables on the first principal component
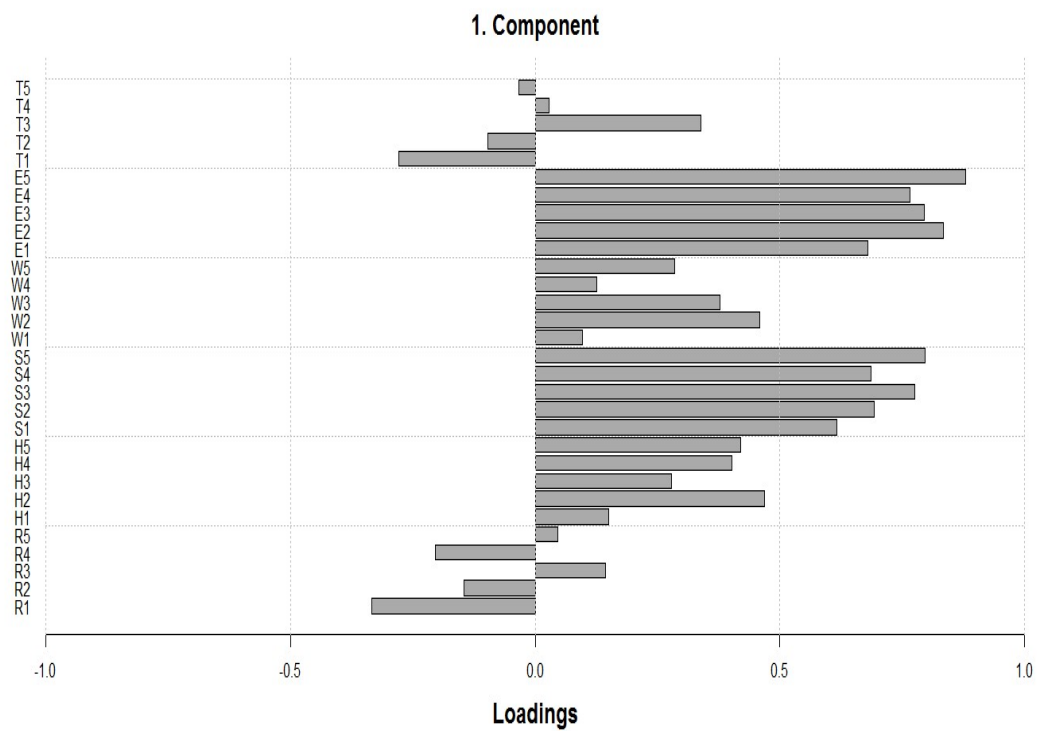

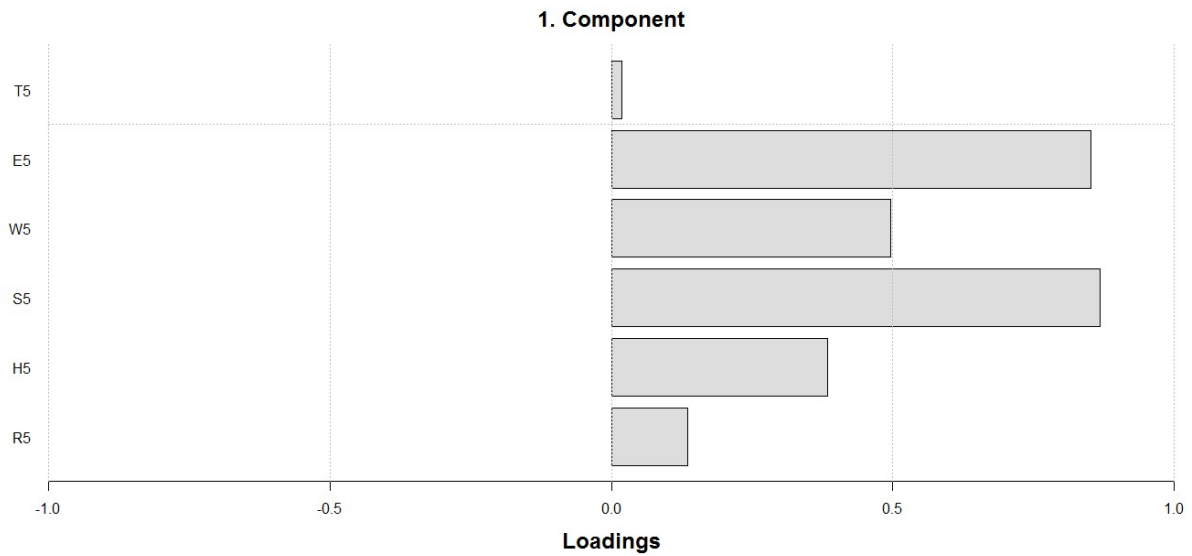Figure 2: PCA loading for annual and seasonal climatic variables

Figure 3: Loadings of observed annual variables on the first principal component
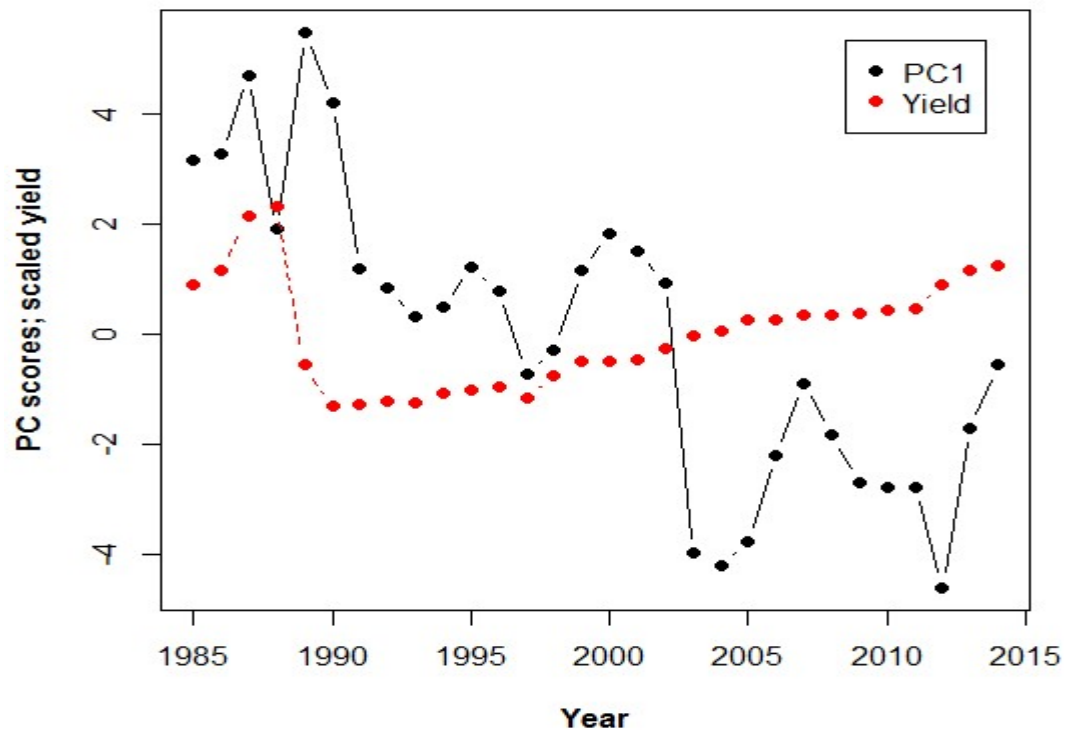

Figure 4: Time series of scores for first principal component and yield of cocoa (arranged to scale for better comparison)
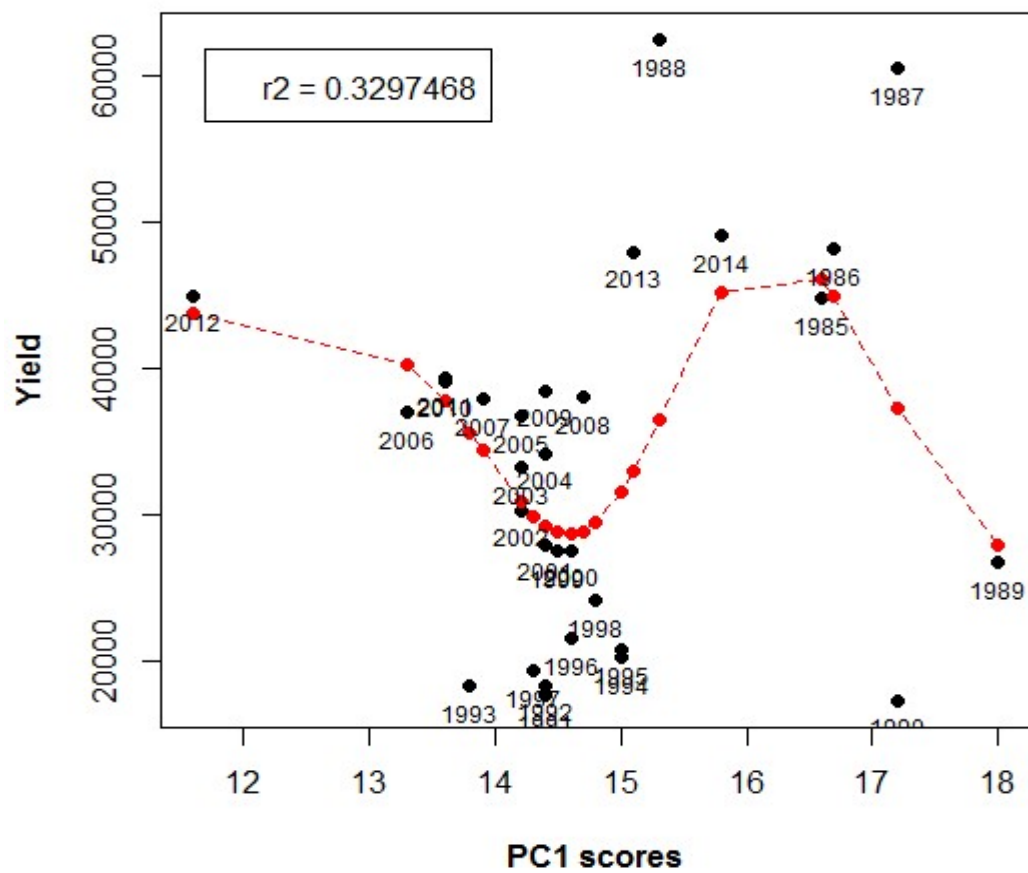
Figure 5: Scores of the first principal component versus cocoa yield. Black symbols are observed; red symbols are SVM regression function.