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Article

Maize Production Responsiveness to Land Use Change and Climate Trends in Cameroon

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Abstract: Most studies on the responsiveness of maize production to various variables have dwelled on the responsiveness of maize production to variations in precipitation or temperature. This study seeks to verify the response of maize production in Cameroon to both climate trends and land use change. Therefore, for the first time, our study presents findings on the relative influence of both climate and land use change on maize production in Cameroon. The data used in this analysis are essentially time series data spanning the period 1961–2006. The data on quantity of maize produced, area of maize harvested and number of maize seeds planted was taken from (http://faostat.fao.org). The mean maize growing season temperature and precipitation data were collected from the 0.5° × 0.5° gridded collaborative datasets of the UNEP and the School of Geography and Environment at Oxford University and from the global crop calendar dataset. The data were analyzed using the average rate of change, detrended simulations, the multiple linear regression technique, correlation coefficient and the coefficient of determination. The results show that maize production in Cameroon is more likely responsive to land use change (forest area change) than rainfall and temperature. However, for the climatic variables, maize production is more responsive to temperature variations than precipitation. In other words, the greater the land use change (forest area loss) the more likely the long run losses in the current maize production gains while rising temperatures were found to be more suitable for maize production. Even though the 1990s marked the period of recovering rainfall levels in most of the Sahel, large fluctuations were still recorded.

Keywords: maize production; responsiveness; rainfall; temperature; forest area; Cameroon

1. Introduction

Agricultural production is governed by a combination of climate, land use decisions, soil fertility, level of mechanization, and application of high yielding varieties among other factors [1–3]. Technological innovations and changes in agronomic practices have been able to lead to significant increases in corn and soya bean yields [2]. However, recent climate and land use changes may be playing a significant role in the observed maize production trends [1].

The relative impacts of past and future climate and land use changes on maize production in Cameroon remains unclear. This is because warming, for example, might lead to improved yields in some areas while it leads to decreased yields in others; this is exactly the same for precipitation [1,2]. On the other hand, it can be said that, increased deforestation in some parts of the world may enhance yields while in others yields may decline [4,5]. Much work has been undertaken on studying the impacts of climate change on yields at various scales [6–9]. However, a very wide gap exists as there are currently no studies to the best of our knowledge that analyze the relative effects of both climate and land use change on maize production in Cameroon in particular and Africa in general.

Maize was selected for this analysis because it is among the six most widely grown crops (maize, wheat, rice, soybeans, barley, sorghum) in the world [9] and the most affordable (in terms of market price and cost of seeds) and widely grown crop in Africa and Cameroon [10]. In Cameroon, maize (*Zea mays* L.) is not only a staple crop that is consumed as dry fermented dough; it is often also roasted, used as corn porridge and for a large number of other uses. Maize also provides an economic safety net as much of it can be sold directly or converted into corn beer, which is an important contribution to the local economy in many rural areas [11]. This crop is further important because it is mainly grown by small scale subsistence farmers who constitute more than 35% of the rural population. Due to their small scale of production and poverty, these farmers lack the capacity to be able to adjust their farming systems to climate and land use shocks. Therefore, the urgent need to increase maize production is controlled by either climate or land use changes inter alia.

The impacts of climate and land use change on maize production in Cameroon in particular and most of the tropics, sub-tropics and Africa in general will be greatest because many poor people including small scale farmers depend on agriculture and have fewer alternative options beyond agriculture for their survival [12,13]. The influence of climate or land use change on crop production in most of the Sahel is subject to a lot of uncertainty that needs verification at country scale [13,14]. This study therefore aims at verifying the response of maize to both climate and land use change in Cameroon. The results will enable us determine whether it is climate or land use change that is affecting maize production in Cameroon and may pave the way for broader African scale studies.

2. Methods

2.1. Data Acquisition

Time series maize production data (quantity of maize produced in tons) for Cameroon for the period 1961–2006 were taken from the Food and Agricultural Organization of the United Nations (FAO) website (http://faostat.fao.org) [15]. Other land use related time series variables spanning the period 1961–2006 that were collected from the same website above were: area of maize harvested (hectares), quantity of maize seeds planted (tons) and forest area (hectares) (See Table S1 for detailed information). Forest area change was used as the main proxy for land use change in this study. Therefore, in the context of this study, increase forest area loss is synonymous to increase land use change. However, since the FAO could not provide all yearly variations in forest area, we based our analysis on the estimates for 2010 and 1990 and from these, we were able to estimate the missing data for the rest of the years based on a 220 k ha of forest area lost each year to estimate the missing data; it is for this reason that forest area assumes a linear trend. Similarly, Lambin *et al.* [16] used estimates of changes in cropland, agricultural intensification, tropical deforestation, pasture land expansion and urbanization as different land use change proxies.

The average annual time series or historical rainfall (P) and temperature (t_{mean}) data during the maize growing seasons in Cameroon spanning 1961–2006 were generated from the 0.5° × 0.5° gridded collaborative datasets of the UNEP and the School of Geography and Environment at Oxford University [17,18]. To obtain the mean growing season P and t_{mean} for the maize growing season, the P and t_{mean} data were averaged over the maize growing months for each 5′ × 5′ grid for Cameroon from the global crop calendar dataset (http://www.sage.wisc.edu/download/sacks/crop_calendar.html) [19]. In Cameroon, the critical maize growing season is uni-modal in the northern regions of the country and bi-modal in the southern regions of the country. In the north, maize production is uni-modal as it is grown and harvested between the months of September and January while in the south maize production is bi-modal as it is grown and harvested twice a year; first between the months of May and September and secondly between the months of September and January. Since three quarters of the maize produced in Cameroon is grown in the southern part of the country, this study considered a bi-modal maize production cycle.

2.2. Data Analysis

The data analysis began with an exploration of the average rate of change of the quantity of maize produced against P and forest area. The equation used to compute this was as follows:

$$\text{ARC} = \frac{(y_2 - y_1)}{(x_2 - x_1)} \tag{1}$$

where ARC is the average rate of change of maize production with rainfall and forest area, Y_2 and Y_1 are the final and initial maize production records, and X_2 and X_1 are the final and initial rainfall and forest area time series records.

The trends in all the six variables under consideration as well as their corresponding 12 period moving averages or detrended simulations were estimated to analyze the responsiveness of maize production to climatic variables such as rainfall and temperature and a land use variable such as forest area (Figure 1a–e).

The 12 period moving averages approach was used to detrend all the six variables for the following reasons: (1) The data has no huge outliers; (2) The moving averages tend to capture the linear trend and; (3) The 12 period moving averages captures the seasonal effects that corresponds to a yearly cycle. This was followed by the fitting of a multiple linear regression model to verify the responsiveness of maize production to climate and land use change. The equation used to fit the model was as follows:

$$Y_{QM} = \alpha_0 + \alpha_1 X_{Fa} + \alpha_2 X_{QS} + \alpha_3 X_{AH} + \alpha_4 X_P + \alpha_5 X_T \tag{2}$$

where Y_{QM} is the quantity of maize produced (dependent variable), $\alpha_1 X_{Fa}$ are the coefficient and forest area, $\alpha_2 X_{QS}$ are the coefficient and quantity of maize seeds planted, $\alpha_3 X_{AH}$ are the coefficient and area of maize harvested, $\alpha_4 X_P$ are the coefficient and the mean annual growing season rainfall, and $\alpha_5 X_T$ are the coefficient and mean annual growing season temperature (independent variables).

The correlation coefficients and coefficients of determination between the quantities of maize produced on the one hand and the mean maize growing season temperature, rainfall, forest area change, quantity of seeds planted and area of maize harvested were also computed and used to consolidate and validate the outputs of the linear regression analysis. Also, to validate the results, the following hypotheses were stated:

Null hypothesis (H_0): maize production is not more responsive to precipitation and temperature than to land use change.

Alternate hypothesis (H_1): maize production is more responsive to precipitation and temperature than to land use change.

3. Results

3.1. Trend analysis and Detrended Data Simulations of the Variables under Consideration

It can be observed from the trend analysis and differencing analysis (detrended data analysis) that for both the original data and the detrended simulations over the period 1961–2006, the quantity of maize seeds planted, the quantity of maize produced, the area of maize harvested and mean annual temperature are all rising (Figure 1a–c,e). On the other hand, the trends in rainfall are generally highly fluctuating and recovering during the post 1990s than during the pre 1990s (Figure 1d). Whatever the case, the data reveals a generally declining rainfall trends during the post 1990s. Forest area also assumes a declining linear trend explained by the assumption of a fixed annual rate of forest area loss set at 220 k ha per year [20–22] (Figure 1f). The detrended simulations are generally consistent with the trends of the original data.

The specific average rate of change in maize production over time is about 889 k tons every 45 years or 19 k tons per year. Furthermore, the rate of change in the quantity of maize produced is about 889 k tons at temperature levels of 0.03 °C. The average rate of change in the quantity of maize produced with respect to changes in rainfall is 889 k tons per −14.66 mm of rainfall; this implies a rate of −60 k tons in the quantity of maize produced for every mm of rainfall. Finally, an average rate of change in the quantity of maize produced of 889 k tons is associated with −9 k ha of forest area loss.

From these trends, it can be observed that three variables stand out; these are: the quantity of maize produced, temperature, and forest area with R squares of 0.66, 0.58 and 1 respectively. This can be interpreted to mean that a greater proportion of the variations in the quantity of maize produced, temperature and forest area changes can be accounted for by the linear relationship between each of these variables overtime time.

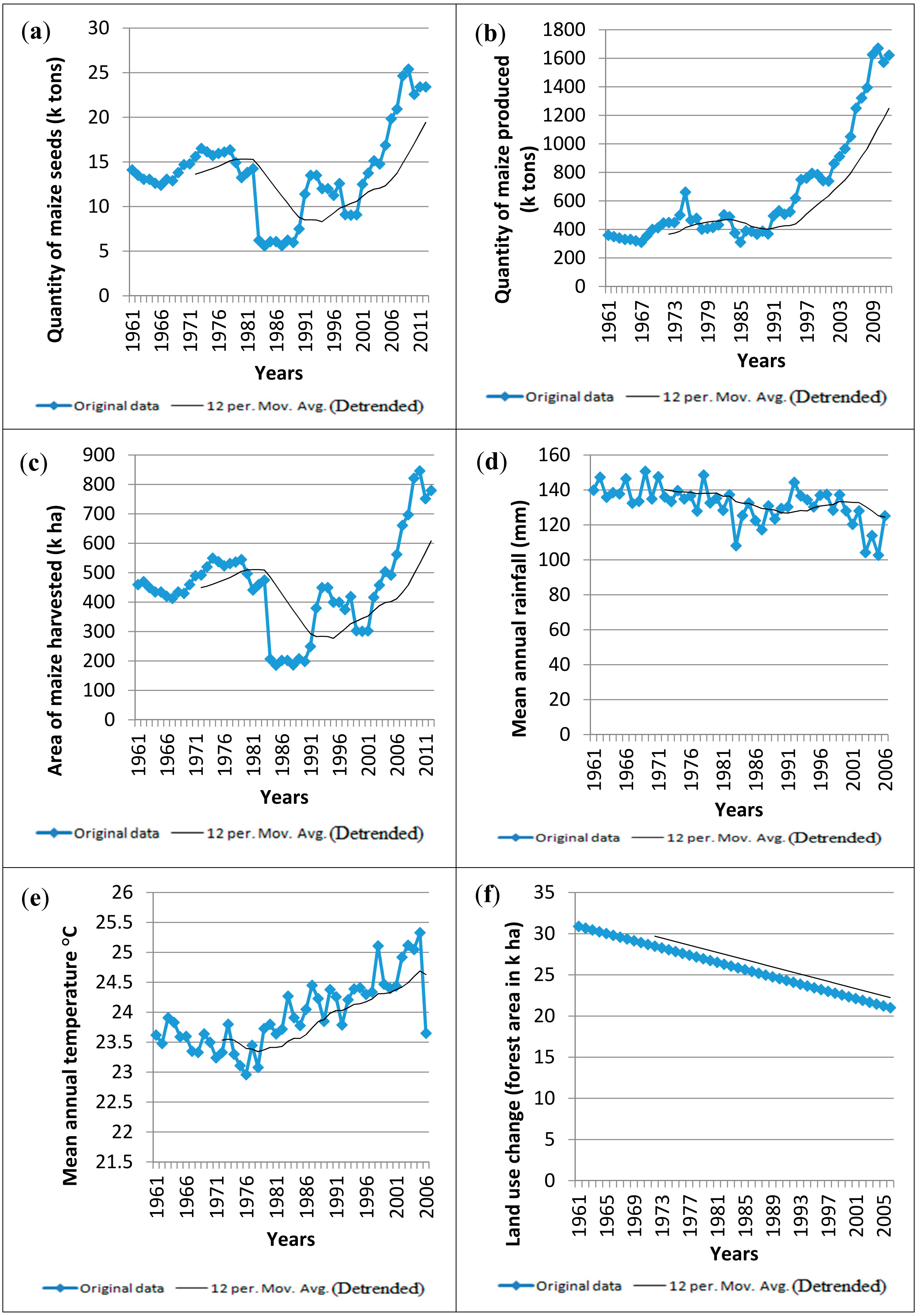

Figure 1. Trends over time of original and detrended: (**a**) Quantity of maize seeds; (**b**) Quantity of maize produced; (**c**) Area of maize harvested; (**d**) Average annual rainfall; (**e**) Average anual temperature; and (**f**) Land use change.

3.2. Assessing the Responsiveness of Maize Production to Rainfall, Temperature and Forest Area Change

It has been observed that the quantity of maize produced is more likely to be responsive to land use change here represented by forest area change. This is because both forest area and maize production have an R^2 of 0.62 or 62% implying that 62% of the variations in maize production can be explained by the linear relationship between maize production and forest area (Figure 2e). This R^2 value is the highest of all the variables under consideration and means there is more reliability in the relationship between forest area and maize production than in the relationship between maize production and rainfall. To further support this result, correlation analysis between maize production and forest area produced a strong negative correlation of −0.78 (Table 1). This means that forest area loss is associated with increase maize production in the short run but in the long run, the current gains in maize production reported on Figure 1b will be undermined if the current rates of deforestation persist. The above is true as in the short run, the availability of land will mean more deforestation and more maize production but in the long run, when the prospects of further land expansion would have diminished, such expansion will not be possible.

Table 1. Correlation matrix of all the variables under study.

Variables	Area of Maize Harvested	Quantity of Maize Produced	Quantity of Seeds Produced	Mean Annual Rainfall (mm)	Mean Annual Temperature °C	Land Use Change (Forest Area in k ha)
Area of maize harvested	1					
Quantity of maize produced	0.22	1				
Quantity of seeds produced	0.86	0.32	1			
Mean annual growing season rainfall (mm)	0.18	**−0.48**	0.22	1		
Mean annual growing season temperature (°C)	−0.31	**0.59**	−0.30	**−0.65**	1	
Land use change (forest area in k ha)	0.26	**−0.78**	0.16	0.58	**−0.76**	1

Therefore, the more the land use change or the more forest area is lost, the higher the amount of maize produced in the short run and the lower the amount of maize produced in the long run. Parallel regression analysis of all the climatic (rainfall and temperature) and land use (forest area) variables shows that forest area change has a *t*-value of −7.37 (Table 2) which is the highest among all the other independent variables. This again means that forest area is more likely to affect maize production more than all the other variables in the series. The overall tendency is that the more the loss in forest area the more the amount of maize produced in the short run when more agricultural expansion through deforestation is possible and the less the quantity of maize produced in the long run when the availability of land for further agricultural expansion would have reduced. On Table 2, the regression coefficient of forest area of −56.38 goes a long way to support the view that in the long run, the impact of forest area loss on maize production will be negative.

Table 2. Regression analysis outputs.

	Coefficients	Standard Error	*t*-Stat	*p*-Value
Area of maize harvested (ha)	0.37	0.25	1.44	0.15
Quantity of maize seeds (tons)	20.63	8.17	2.52	5.72
Rainfall (mm)	−1497.11	1721.03	−0.86	0.38
Temperature (°C)	47,710.87	41,147.57	1.15	0.25
Land use change (Forest area in k ha)	−56.38	7.64	−7.37	0.01

Multiple R square 0.92, R square 0.85, Adjusted R squared 0.83.

In the case of the relationship between the quantity of maize produced and rainfall, it is observed that an R^2 of 0.23 is obtained (Figure 2c). This means that only about 23% of the variations in maize production can be explained by the linear relationship between quantity of maize produced and rainfall. This therefore means that the relationship between rainfall and maize production is not only weaker but also less reliable than the relationship between maize production and forest area. Also, a negative relationship shown by a correlation of −0.48 (Table 1) means the less the amount of rainfall, the higher the quantity of maize produced. This correlation, though also negative is also weaker when compared to the relationship between maize production and forest area. This is consistent because in reality maize production is rising and such a rise should be associated with rising rainfall which would rather depict a positive correlation, unlike implied in the correlation of −0.48. The corresponding t value is relatively low as it stands at about 0.86 (Table 2). In relation to this, it can be said that maize production is less responsive to rainfall in Cameroon. Generally, it is expected that when rainfall is declining, food production should also decline but in the case of Cameroon declining rainfall is associated to rising maize production.

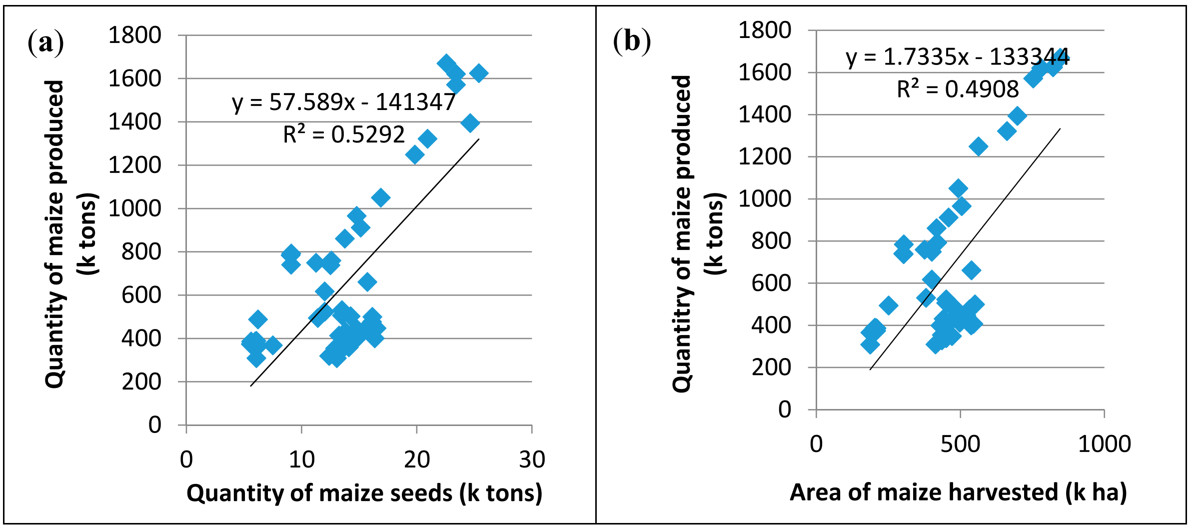

Figure 2. *Cont.*

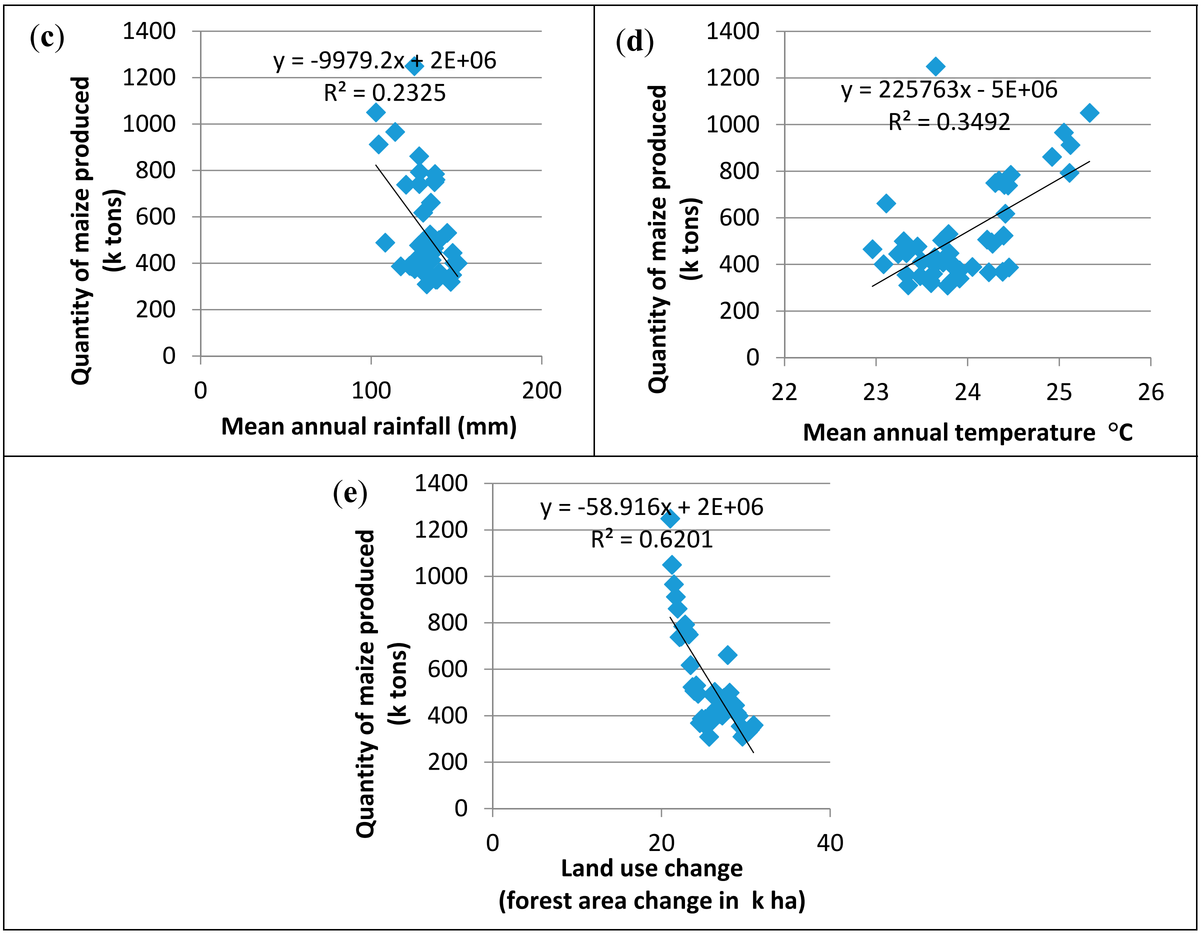

Figure 2. Scatter plots between (**a**) Quantity of maize produced and quantity of seeds planted; (**b**) Quantity of maize produced and area of maize harvested; (**c**) Quantity of maize produced and mean annual rainfall; (**d**) Quantity of maize produced and mean annual temperature and (**e**) Quantity of maize produced and land use change.

Concerning the relationship between temperature and maize production, an R^2 of 0.34% or 34% (Figure 2d) between quantity of maize produced and temperature is obtained. The associated correlation coefficient is positive at 0.59% or 59% (Table 1) while the corresponding *t*-value is 1.14 (Table 2). This positive correlation implies that the higher the temperature, the higher the quantity of maize produced. Based on the fact that the R and R^2 for the latter relationship are higher than those for the relationship between maize production and rainfall, it can be said that maize production is more vulnerable to temperature than rainfall.

4. Discussion

From the results, we observe that declining forest area is associated to increasing maize production. This implies a possible inverse relationship. In the long run, the current gains in maize production reported on Figure 1b will be undermined if the current rates of deforestation persist. Therefore, the more the land use change or the more forest area is lost, the higher the amount of maize produced in the short run and the lower the amount of maize produced in the long run. Theoretically, this is feasible because when there is an increase in the rate of decline in forest area, the area in question becomes vulnerable to all types of erosion and low soil nutrient storage which in tend reduces productivity.

These results are consistent with the results presented by several authors arguing that the problems of food production in most African countries are more linked to land use change than climate change. For example, Olsson and Mryka [23], discussed the greening of the Sahel during the post 1990 period. This study concludes that, it is erroneous to attribute the declines in food production in most of the Sahel after the 1990s to rainfall because this period marked a tremendous recovery of African rainfall. To them, systems of land use change such as forest area loss, agricultural expansion and irrigation are at the center of the current food crises facing Africa in general and the Sahel in particular. Fluctuations in rainfall only go a long way to accentuate the problem. In another related study, Eklundh and Olsson [24] argued that the key problem of food security in the Sahel is anchored mostly on various systems of land use such as forest clearance in favor of agricultural production. These views are also supported by Epule *et al.* [25]; Anyamba and Tucker [26] and Schlenker and Lobell [27] who report that current declines in African agriculture are more associated to the various systems of land use and that changes in rainfall simply worsen the situation. They also emphasize the argument that since the 1990s, rainfall in the Sahel has been rising and this rising rainfall is associated to declining food production in most of Africa, as such, such declines in food production cannot be anchored on rainfall trends. In this current study, the increasing maize yields cannot also be attributed to rainfall which is declining during the maize growing seasons.

The relationship between forest area, climate change and food production is evident as declines in forest area have impacts beyond the land phase of the hydrological cycle in the long run. According to the Charney hypothesis, the available moisture in most of Africa is not available for agriculture due to declining vegetation. Such declines in vegetation are caused by land use processes such as agriculture and over grazing, and this results in increased reflectivity of the landscape or albedo [28–30]. The feedbacks of this will include less heating of the earth, less absorption and less moisture will be released to the atmosphere, less convection will occur and less rainfall and less food production in the long run [30]. So, it can be seen that the likely problematic variables is forest area; rainfall which is the component of climate simply makes a bad situation worse.

Rainfall has been rising in the Sahel during the post 1990s. However, as concerns the maize production season rainfall levels in Cameroon, the post 1990 period witnessed variable and declining rainfall as seen on Figure 1d. As such, the declining rainfall cannot be used to explain the trends in maize production because declining rainfall will mean declining maize production, yet, maize production seems to be rising. Since rainfall is not associated with rising maize production, it is obvious that some other variable(s) are impacting maize production more than rainfall. The dissociation between rainfall and food production has been analyzed by [25,26] in the argument that in most parts of Africa, higher post 1990s rainfall levels have not been associated with declining food production because other variables such as land use change seem to play a greater role in the food security calculus of the continent. Aufflammer [6] and Lobell *et al.* [8] argue that there still exist many uncertainties regarding the role of climate change on food production in Africa, a view that actually supports the hypothesis that other factors such as forest area change should be watched with care.

On the other hand, the positive correlation between the quantity of maize produced and temperature shows that increase in the quantity of maize produced is associated with increased temperatures. The interesting issue here is that maize production is more responsive to forest area change and less responsive to rainfall and temperature. However, maize production is also more responsive to temperature than rainfall because the *t*-value and correlation coefficient of temperature against maize production are higher than those for rainfall and maize production. The argument that maize production is more responsive to temperature than rainfall is consistent with previous studies. For example, Shi and Tao [10] and Schlenker and Lobell [27] tend to supports the results of this current study as they argue that changes in temperature had stronger effects on maize production than changes in precipitation. These studies were based on predictions for the entire African continent. However, the debate that temperature increase also increases maize production should be interpreted with caution. For example, the results of Lobell *et al.* [8,31] have contradicted this current study in that they used historical maize trials in Africa and daily weather data to suggest that there is a non linear relationship between warming and maize production in Africa. To these authors, each degree day spent above 30 °C reduced final maize production by 1% under optimum rainfall conditions and 1.7% under drought conditions.

Also, the results concerning the influence of climate on maize production have been contrasted with studies carried out in China. These studies have analyzed the effects of climate change on cropland using heat waves and water resources in establishing that climate change impacts cropland [32], that climate disasters affect wheat production and cropland [33,34]. These results are different from what currently obtains in most of the Sahel and Cameroon and they go a long way to establish how the influence of climate and land use variables varies with time and from one part of the world to another. In an earlier study carried out at a global scale, Lobell and Field [9] observed that for wheat, maize and barley, there is a clearly negative response of global yields to increased temperatures. In the context of this current study, the positive response of maize production to rising temperature should be considered in terms of optimum temperatures that are suitable for germination, transpiration and photosynthesis and beyond and below which maize production might decline.

In addition, some of the possible reasons for the rise in temperature are evident from this study. As observed on Table 1, rising temperatures may be a result of reduced rainfall. This is supported by a correlation of about −0.65 between temperature and rainfall. Furthermore, a decline in forest area may also cause temperatures to rise as seen in an inverse correlation of −0.76 between temperature and forest area (Table 1). Also, there is a clear link between increase temperatures and increase maize production. Increase temperature reduces rainfall and introduces drier conditions such as droughts and the feedbacks from all these linkages could lead to increase tree mortality and further reduced rainfall and increase atmospheric carbon dioxide. The repercussion this has on increase food production is that the increase atmospheric carbon dioxide has an aerial fertilization effect as it triggers crop productivity and enhances crop moisture management and efficiency through reduced transpiration [35]. Based on these results and discussion, the null hypothesis (H_0) which states, "Maize production is not more responsive to precipitation and temperature than land use change" is valid. The statistical methods used in this study are consistent with the time series models described in the paper on statistical methods on the contribution of climate to crop yields presented in a paper by Shi *et al.* [36]. Roudier *et al.* [37]; Bele *et al.* [38] and Carins *et al.* [39] also present state of the art evidence that climate change negatively influences crop production and forests for various stations in West Africa and Cameroon. These studies are consistent to this current study in the sense that maize production in Cameroon is more responsive to temperature changes than rainfall. However, a contrast could be drawn if we consider the fact that the Rouder *et al.* [37] study could mean declining rainfall is associated to declining food production. In this current study, declining or highly variable rainfall is instead associated to rising maize production. This study only looks at the relationship between rainfall, temperature and forest area change.

It is therefore possible that other variables may be playing a role in impacting the behavior of maize production. As such, caution should be taken in considering these results only in the context of the variables used. Carins *et al.* [39] argue that plant breeding, crop management or agronomic improvements may trigger remarkable progress on crop yields even in the midst of declining rainfall. Therefore, it is possible that the increasing maize production may be accounted for by the surge in the use of fertilizers, high yielding seed varieties, increase access to farm inputs such hoes, cutlasses and pesticides and the proliferation of extension workers. It has even been argued that the availability and accessibility to farm inputs has been partly responsible for arable production increase in most of Africa due to remittances from migrant urban workers to their rural families [35,40]. Increasing farm sizes through deforestation which is a proxy for land use change often leads to the creation of more land for farming and consequently increases production. In most of Africa in general and Cameroon in particular, farmers still depend a lot on farmland expansion to increase yields [41]. However, being that land is a fixed asset, in the long run when land will no longer be available for further expansion, production is likely going to stagnate and later decline as the prospects of further agricultural land expansion through forest clearance depreciates [39]. Also, increase forest area loss would mean more carbon dioxide in the atmosphere and an increase aerial fertilization effect which will enhance crop water management, reduce transpiration and increase yield [35].

5. Conclusions

This study has analyzed and assessed the responsiveness of the quantity of maize produced to climate and land use change in Cameroon. The results suggest that land use change seen through the main proxy, forest area change, is more responsible for possible dynamics of maize production than precipitation and temperature. Among the climatic factors, temperature is seen to be more associated with rising maize production while declining precipitation is more correlated with increasing maize production.

With these results, a basis is provided for adaptation strategies to be tailored with emphasis on the levels of forest area change. It is suggested that similar studies be performed at larger scales such as for the entire African continent and at smaller scales to verify population perceptions in various maize growing regions of Cameroon. Also, studies that focus on the implications of various management schemes such as irrigation and reforestation will help in the optimization of the negative impacts of forest area loss on maize production. Caution should be observed in viewing these results as several other variables related to agronomic and technological improvements may be responsible for production increases in the midst of declining rainfall; however, evaluating the influence of some climatic and land use variables on maize production goes a long way in giving us an insight into the behavior of the selected variables.

Supplementary Materials

Supplementary materials can be accessed at: http://www.mdpi.com/2071-1050/7/1/384/s1.

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Author Contributions

Terence Epule Epule collected the data, analyzed the data and wrote this manuscript. Christopher Robin Bryant edited and supervised the study.

Conflicts of Interest

The authors declare no conflict of interest.

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