Climate Change and Land Degradation in the Savana Region of Togo: What are the Available Useful Adaptation Options?

Mikémina Pilo[#]
University of Kara, Togo
Email: pilomikemina15@gmail.com
Nicolas Gerber
Center for Development Research, University of Bonn
ngerber@uni-bonn.de
Tobias Wünscher
Center for Development Research, University of Bonn
tobias.wuenscher@uni-bonn.de
[#] corresponding author

Abstract

West African farmers are among those most likely to suffer from land degradation in terms of productivity lost as the consequence of climate change, partly due to the agro-climatic characteristics of the regional system and to their limited scope for coping with shocks. Climate change adaptation has thus been touted as a necessary path for rural poverty reduction and development in the region. Yet, do farm households taking steps to adapt to climate change experience a higher income? To answer this question in the context of crop and livestock income in the Savana region of Togo we build a bio-economic model based on farm household model theory. Using survey data collected from a representative sample of 450 farm households in the agricultural year 2013/2014, we identify farm-household types through cluster analysis and apply them in the simulation model. From the results, we conclude that at their current costs, soil and water conservation techniques and irrigation can provide higher income even under climate change. The policy message we draw from this study is to encourage Soil and Water Conservation techniques and sustainable irrigation as sound strategies for higher income under climate change in the region. These are "no regret options" with a positive impact on livelihoods while preserving the resource base.

Keywords: adaptation, bio-economic model, Savana region of Togo

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1. Introduction

The agricultural sector still plays a central role in Sub-Saharan African (SSA) countries' economic development. It supports the welfare of most of the residents directly or indirectly. However, recent agricultural performance trends of the region are discouraging. Indeed, the agricultural productivity growth in SSA region has been lower compared to the rest of the world (Willy and Holm-Müller, 2013) and some authors have suggested that the region is falling further away from the agricultural productivity frontier, thus contradicting the convergence hypothesis (Wurlod and Eaton, 2015). This situation may, among other things, be a signal of low land productivity in agriculture. The latter can be partly attributed to the low investment in agricultural sector, high rates of land fragmentation, intensive tillage of land, nutrient mining and extraction of crop residues to feed livestock, and climate variability and change (e.g., high average temperature, scarce and erratic rainfall) which characterized agricultural activities of the region (Di Falco et al, 2011; Willy and Holm-Müller, 2013, OCDE, 2015). Climate change and variability are major challenges to SSA agriculture today because they not only increase production costs and the risk of crop failure, but also put at risk the stability of the whole agricultural production chain (Wheeler and von Braun, 2013). Scientific evidence on climate change suggests that even with a strong mitigation policy the observed lower and stagnant agricultural performance of the SSA region will persist or even get worse if the sector does not find ways to adapt to climate change (IPCC, 2007) under a business-as-usual scenario for agricultural sector.

Land degradation in terms of productivity reduction due to climate change is well documented by scientific research (Rosenzweig et al. 2014; Calzadilla et al. 2014; Parry et al. 2005; Rosenzweig and Parry 1994; Cline 2007; IPCC, 2007; Seo and Mendelsohn, 2008; Calzadilla et al, 2013) and well known by the general publicClimate change brings with it changes in rainfall patterns, increases the frequency and severity of extreme events and raises average temperatures. Clearly, this has adverse impacts on agriculture in developing countries in general and SSA countries in particular, which are theoretically and empirically well documented (Parry et al. 2005; Rosenzweig and Parry 1994; Cline 2007; IPCC, 2007; Seo and Mendelsohn, 2008; Calzadilla et al, 2013). These studies converge in predicting considerable loss in yields from crops and livestock. In the worst case, agricultural productivity can be reduced by 90% by 2020 (Boko et al, 2007). These uncomfortable prospects highlight the crucial role adaptation has to play in the progress towards a world without hunger. Adaptation practices have the potential to reduce yield loss from weather changes. Many authors support the notion that rural communities can successfully deal with the adverse impacts of climate change thanks to the implementation of adaptation practices (Frankhauser and Burton, 2011; Wheeler et al, 2009). This belief triggered many efforts all over the world to promote adaptation strategies through projects and programmes such as the Africa Adaptation Programme (AAP), Infoclim in Senegal, Project to Support Agricultural Development in Togo (PADAT), Pacific Adaptation to Climate Change (PACC) for thirteen pacific countries, Asia Pacific Adaptation Network (APAN).

Farmers have always and will continue to adapt to the changing climate. However, it is unclear whether they are able to identify practices and options that are appropriate to respond to climate change as the required adjustments may fall beyond their range of experience (Seo and Mendelsohn, 2007). The implication of this is the possibility of maladaptation resulting in transitional losses of unknown duration (Di Falco et al, 2011). By maladaptation we mean any practice which is more harmful than helpful, by contrast to an adaptation, which is more helpful than harmful. That is, adaptation practices, if not appropriately implemented, can increase vulnerability to climate change. Thus, it is wrong to think that adaption is an easy process. It is difficult to build resilience to climate change.

Determining the productive implications of adaptation to climate change is therefore crucial. It helps understand how the set of strategies implemented by the farmers (e.g., Irrigation, low fertilizer use, soil conservation techniques, etc.) in response to changes in environmental conditions affect farm income from cropping and livestock. Consequently, the objective of the paper is to assess whether the farm households that actually did implement adaptation strategies are getting benefits in terms of an increase in farm income. This is central if adaptation strategies need to be put in place. Although there is an overwhelming number of studies dealing with adaptation, quantitative estimates of adaptation and its impacts are only starting to emerge (e.g. Seo and Mendelsohn, 2007; Di Falco et al., 2011; Zhang and Zhao, 2015; Shah and Dulal, 2015).

The remainder of the paper is structured as follows: Section 2 presents data and materials while section 3 develops the bio-economic model. In section 4 we walk the reader through the simulations of the identified adaptation strategies and discuss the empirical results in section 5. The paper concludes with section 6.

2. Data and materials

2.1 Data

The data used in this study come mainly from a cross-sectional, representative farm household survey in the Savana region of Togo during the agricultural year 2013/2014 on 450 households (Pilo, 2015). The survey collected information on farmers' perception of current and future states of rainfall, adaptation strategies developed by farmers, household assets and livestock. Additional data were gathered from literature and interviews with extension service managers that operate in the region.

2.2 Materials and Methods

3. The regional Mathematical Programming Model to simulating adaptation impacts

It would be unreasonable to say that farmers are risk neutral. Most agricultural producers in Africa are risk averse, particularly smallholders (Antle, 1987; Binswanger, 1981). They face a variety of yield, price and resource risks that make incomes unstable. All these risks can be classified into production and price risks (Hardaker et al, 1997). Most empirical measures of decision under risk are based on the expected utility (EU) approach (Berg 2003; Buschena and Zilberman 1994; Hardaker 2000)

However, much criticism is addressed to the EU model. The main issues are that a growing number of empirical observations report violations of some of its axiomatic foundations and a divergence of observed decisions from what is predicted by the EU approach (Atwood et al. 1988; Buschena and Zilberman 1994; Hazell and Norton 1986).

For these reasons, our analysis is based on Telser's safety first (SF) model, a downside risk approach. The general structure of Telser's safety first model is the following:

$$\text{Max: } E(Z) = E_Y'X$$

$$\text{S.t : } \begin{cases} AX < b \\ \\ \text{Prob } (Z < g) < \alpha \end{cases}$$

In the above specification, $E(Z)$ represents the total expected gross margin, AX a set of resource constraints, b resource endowments, (Z) is income level, (g) is exogenously determined minimum level of income a household must earn to meet obligations of high priority, and (α) is the acceptable limit on the probability of failing to meet that minimum level of income.

Telser's SF approach accounting for the rainfall risk, adaptation to climate change and the subsistence level of farming in the Savana region of Togo is empirically specified as follows.

3.1 Specification of the objective function

Maximize: $$E(Z) = \left(\sum_j \overline{C_j} X_j^P - iX^J\right) + \left(\sum_k \overline{C_k} X_k^P - iX^K\right) - \sum_{l=1}^{12} P_w' X_l^F - \sum_{i=1}^{12}(1+i)P_w X_t^l + \sum_{t=1}^{12} P_w X_t^o + \sum_{liv=1}^{4}\sum_{l=1}^{12} P_{liv} X^L - \sum_{liv=1}^{4}\sum_{l=1}^{12} P_W X_l^{liv} \quad (4)$$

Where $\overline{C_j}$ = expected gross margin of traditional crop production activity j,
$\overline{C_k}$ = expected gross margin of cash crop production activity k,
X_j^P = j[th] traditional crop production activity measured in hectare,
X_k^P = k[th] cash crop production activity measured in hectare,
X^{liv}= liv[th] livestock production activity . liv= { goats, sheep and caws}
P_w = Wage rate in franc CFA per Man-Day (MD),

P_w' = reservation wage rate which accounts for household leisure demand. It has been set in the range of 50% of P_w for wealthier farmers and 0% of P_w for poor farmers in the study of Dessalegn (2005) in the Upper East Region of Ghana. This means that poor farmers' leisure time is negligible. Given the similarities between our study area and that region, we used the same reservation wage rate.

X_t^o= t[th] month off-farm activity in Man-Days,

i = interest rate, a rate which accounts for the cost of capital and the transaction costs in the credit market. It usually differs between farmers depending on the farmer's wealth. For instance, in the case of Dessalegn (2005) study in Ghana, it was set in the range of 50% for poor farmers and 25% for wealthier farmers,

X_t^l = t[th] month hired labour hiring activity (in MD),
X_t^F = t[th] month family labour used for crop farming (in MD),
X_t^L = t[th] month labour used for livestock farming (in MD),
X^J = borrowing activity related to traditional crop production in Franc CFA,
X^K = borrowing activity related to cash crop production in Franc CFA,

$$\overline{C_j} = E(gm_j),\ \overline{C_k} = E(gm_k)$$
$$gm_j = Y_{jqs} * P_j - X^J,\ gm_k = Y_{kqs} * P_k - X^K$$
$$E(gm_j) = \sum_{s=G,N,B,F,D} P_s Y_{js} * P_j - X^J, \qquad E(gm_k) = \sum_{s=G,N,B,F,D} P_s Y_{js} * P_j - X^K$$

Where gm_j, gm_k are gross margin per hectare of traditional crop j and cash crop k respectively, which are gross return in rainfall state s, less capital cost per hectare. The capital cost includes cash cost on fertilizer, seed, tractor/bullock. And Y_{js} and Y_{ks} is the yield level of traditional crop j and cash crop k respectively in state of rainfall s. The rainfall conditions are grouped into five states namely: G=good, B=bad, N= normal, F= disastrous due to flood and D=disastrous due to drought.

3.2 Specification of the set of constraints

In the following sections, the various constraints to be incorporated in the programming model are discussed.

3.2.1 Land Constraint

The sum of crop allocated surface under each type of land (compound land, irrigated land, bush land, water and soil conservation area) cannot exceed total available surface for the given type. For the sake of analysis, this study identifies four land types that are compound land, non-irrigated bush land, Irrigated land, Water and soil conservation area. For each of these land type we implement a corresponding constraint. For compound land it is specified as:

$$\sum_{j=1} X_{jc}^{P} \leq L_c$$

Where X_{jc}^{P} is production activity of crop j (measured in hectares) on compound plots and Lc is total compound land available. The superscript p indicates that the activity is a production activity on the other hand the suffix c indicates that the production activity is on compound land. The remaining constraints relative to land are presented below.

$$\sum_{j=1} X_{jB}^{P} \leq L_B \qquad \text{Bush Land Constraint,}$$

$$\sum_{j=1} X_{jI}^{P} \leq L_I \qquad \text{Irrigated land constraint}$$

$$\sum_{j=1} X_{js}^{P} \leq L_s \quad \text{Water and soil conservation constraint}$$

3.2.2 Labour Constraint

Labour is the most important factor of production constraining agricultural and livestock production in the study area. There is a relatively working labour market so the model assumes that farm households can both hire-in and hire-out labour. Households make labour allocation decision both during the rainy and dry seasons mainly between crop and livestock farming. Traditionally, during the rainy season labour is allocated between rainfed agriculture production and livestock rearing, while during the dry season the allocation is made across livestock rearing, temporary irrigation, leisure, and off-farm activities. Thus the labour constraint can be represented as:

$$L_R^F + L_D^F + L^o - L_R^H - L_D^H - L_R^L - L_D^L \leq \overline{L} \qquad \text{Household annual labour constraint,}$$

$$L_R^F - L_R^H - L_R^L \leq L_1 \qquad \text{Rainy season labour constraint,}$$

$$L_D^F + L_D^o + l - L_D^H + L_D^L \leq L_2 \qquad \text{Dry season labour constraint,}$$

Where the super- and subscripts R stands for rainy season and D for dry season, F for farm labour, H for hired labour, O for off farm labour and L for livestock labour, while l is leisure and $\overline{L}$ total household labour endowments over the year respectively. L_1, L_2 represent rainy season and dry season specific labour endowments. Because of the seasonality of most farming activities, supply of labour may be more critical at some time of the year than others (Hazell and Norton, 1986). Disaggregating the labour allocation schedule into shorter time intervals increases the precision and incorporates details about the activities (Hazel and Norton, 1986). Thus, labour allocation is disaggregated into monthly labour in this research since the data structure allows us.

3.2.3 Fertilizer and Credit Constraints

The fertilizer type commonly used in the study area is a combination of Nitrogen, Phosphorus and Potassium nutrients (NPK) and Urea. Due to the risk associated with rainfall variability farmers apply fertilizer mainly on cash crops. All fertilizer used is purchased from the market. The fertilizer constraints on these fields can be specified as:

$$\sum_{j=1} a_{fj} X_j^P - X_f \leq 0 \qquad \text{Fertilizer balance,}$$

Where a_{fj} = Kg. Of fertilizer f required to produce a hectare of jth crop activity and X_f= Amount of fertilizer purchased in Kgs.

$$\sum_{j=1} a_{jk} X_j^P + \sum_{t=1} P_w X_t^j - X^k - \sum_{t=1} P_w X^o \leq K \quad \text{Credit constraint,}$$

$$X^k \leq \overline{K} \qquad \text{Credit market constraint,}$$

Where:

a_{jk} = the amount of direct cash cost required to produce a hectare of the jth crop activity, X^k = the amount of borrowed fund, K = total available own fund in CFA and $\overline{K}$= amount of cash available from credit market (rationing in the credit market). The rationing constraint accounts for the fact that under the existing market condition, households can access to only limited amount of cash. The rationing system in the credit market can be clearly observed in agricultural input markets where farmers get fixed amount of in kind input credit.

3.2.4 Consumption Constraint: Estimating Engel curves

Households in the study area consume a whole set of food and non-food items. The major consumables are cereals such as Millet, Groundnut, beans and Rice. On the other hand households solely depend on the market for the purchase of some consumable items such as sugar, salt, root and tuber crops and non-food items such as kerosene.

Consumption estimates usually use Calories to measure the quantity of food consumed, this approach has advantage in aggregating different food types and also when there is policy interest to know the nutritional implication of the consumption decisions. In our case the main modelling interest is to incorporate the impact of consumption decision on overall household resource allocation decision, for which units like Kg are more useful than Calorie units, since farmers think in terms of Kg, not in Mega joules. Therefore, in order to keep consistency and ease of integration into the matrix the quantitative terms (in Kg) of consumption are retained. The empirical specification of the Engel curves is specified by the below equation.

$$KG_p = b_0 + b_1\, TOTINC + b_2\, HHSIZE + e_p$$

KG_P = is Kg of crop P consumed, which includes Maize, Soya, Beans and Rice, TOTINC = is total household expenditure in CFA, HHSIZE= is household size measured in the number of household members (not weighted by age or gender, for lack of data) , and b's are parameters to be estimated while e is the error term.

3.4 Imposing Probabilistic Constraints

The probabilistic constraint in a Telser's SF model is specified as: $pr(Z<g)< \alpha$ Where (Z) is income level, (g) is exogenously determined minimum level of income a household must earn to meet obligations of high priority, pr (.) is the probability of event and (α) is an acceptable limit on the probability of goal failure.

In order to incorporate the probabilistic constraint into a linear programming model one needs to either make assumption on the distribution of income or use distribution free methods. Here, we implemented Atwood 1985 where a Lower Partial Moment (LPM) based constraint allows optimization algorithms to endogenously select the appropriate and least constraining level of (t) given statistical data set. Indeed, Atwood 1985 demonstrated that the sufficiency constraint necessary to impose the probabilistic constraint, ($\Pr(Z < g) \leq \alpha$) is: $t - L^{*}Q(t) \geq g$. Where t is a reference level below which deviations are measured, Q (t) is the LPM.

4. Simulation of the impact of adaptation

4.1 Farm Household Classification

We use appropriate clustering technique to identity special characteristics common to a group households (cluster). The analysis of the characteristics of these clusters reveals that the cluster 2 (with 8 observations) has the highest level of asset value, farm equipment, own fund and operated land; so we refer to it as *wealthier farmers group*. By contrast, the cluster 4 (with 303 observations) has the lowest level of asset value, farm equipment, own fund and operated land; we refer to it as *poorer farmers group*. These two clusters represent the "extreme cases" in our dataset. We undertake simulation analysis first for these two clusters and complement our analysis with simulations for the remaining two "middle" clusters, in order not to lose any information these last two groups can provide. The detailed are not presented here due to pages limitations.

5. Results and discussions

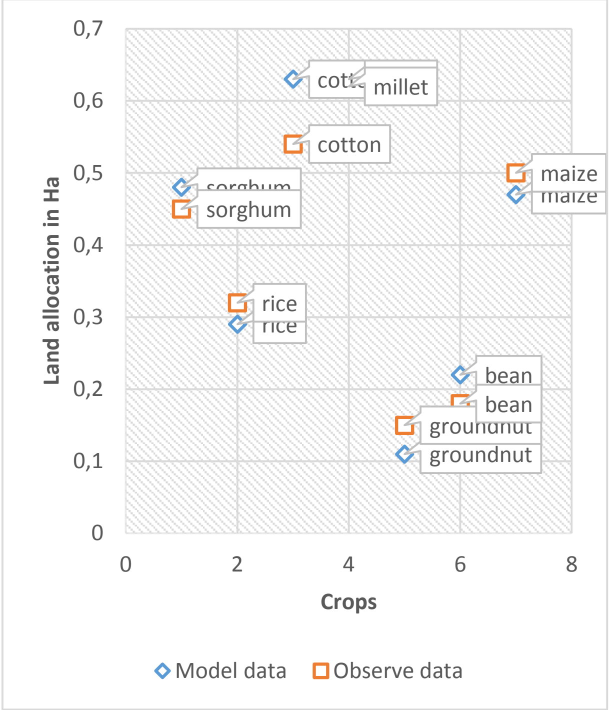
Farmers' perceptions of rainfall risks, reflected in their evaluation of rainfall conditions in the area, were used as a reference to elicit their subjective probabilities. The most important consideration in eliciting subjective probabilities is to organize the questions so as to help the respondents to make judgments that are consistent with their real feelings of uncertainty and as well as with the rules of probability (Dessalegn, 2005). In our survey farmers were asked to evaluate the rainfall conditions of their community for the period from 2003 to 2012 as good, normal, bad, disastrous due to flood or disastrous due to drought. Some of the questions employed in the elicitation exercise were: "Following your characterization of the rainfall conditions in this locality, how many of the years between 2003 and 2012 had good, normal, bad, disastrous due to flood or disastrous due to drought?". In addition, farmers were asked to name a representative year for each rainfall condition between 2003 and 2012 so as to help them have a good focus on the past rainfall events. The results of the elicitation process, indicate that on average good, normal, bad, disastrous due to flood, disastrous due to drought conditions have a probability of 0.29, 0.34 and 0.24, 0.04 and 0.09 respectively.

5.1 Base Run Scenario

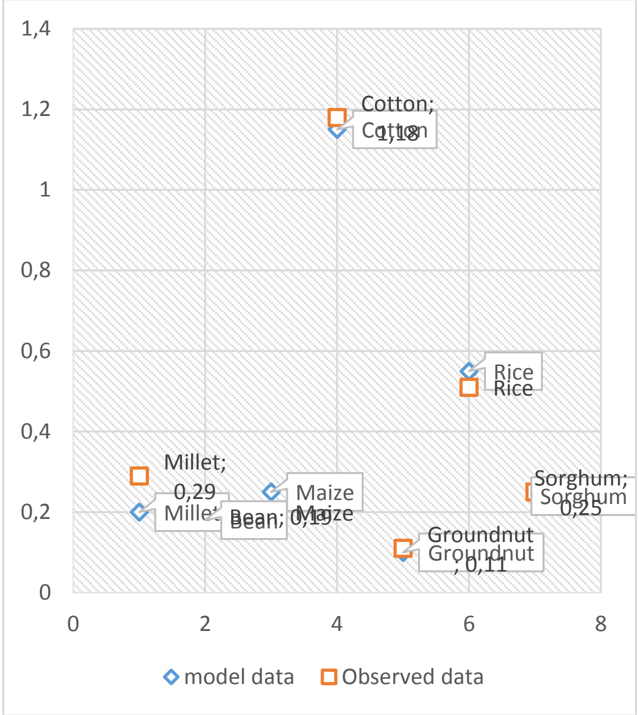
This section tests how well the previous constructed model serves its intended purpose. Naturally, the model cannot replicate each and every empirical observation. However, this is rarely realised because of information gap between the modeller and the decision maker. Thus, the realisable approach consists to value the extent to which certain model outputs, which are of policy and research interests, are depicted. For example Dessalegn (2005) used land use as an indicator variable to validate their model.

Land allocation across different land use types is of much importance in this study, therefore we retain it as our indicator variable. Figure 1 shows how correctly the model predicts the observed data.

Figure 1: The calibration of the bio-economic model

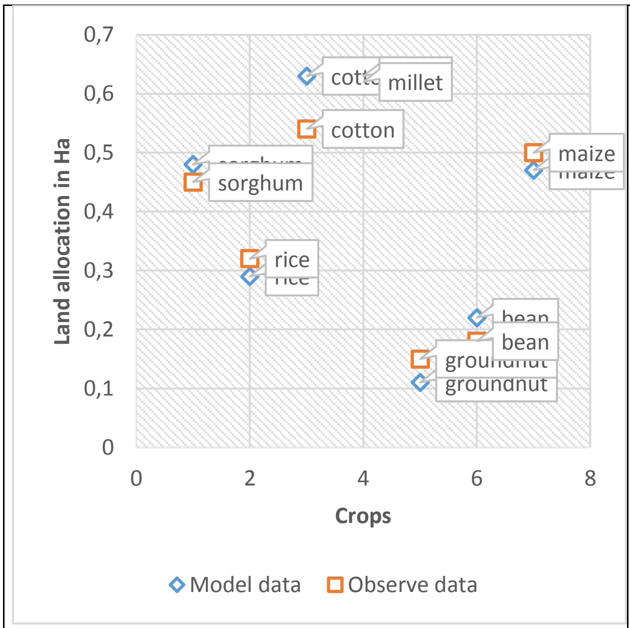


Calibration of the bio-economic model for cluster 1

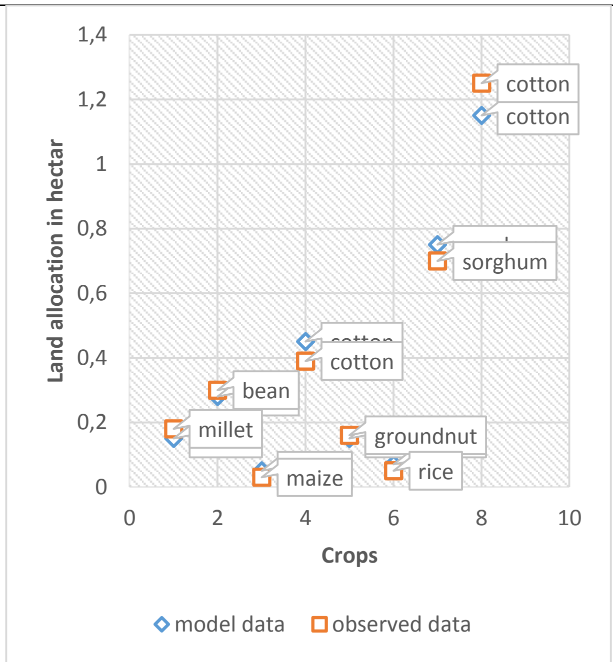


Calibration of the bio-economic model for cluster 2

Source: Authors, 2016 from simulations in GAMS



Calibration of the bio-economic model for cluster 3



Calibration of the bio-economic model for cluster 4

Source: Authors, 2016 from simulations in GAMS

We used in addition to the plotted figures above, the regression technique to assess the association of the model values with observed values. This is captured as bellow:

$$X^M = \beta_0 + \beta_1 X^o$$

X^o is observed land use type, X^M is modelled land use while $\beta_i' s$ are parameters. For a valid model there is a high association between the model results and observed values and the intercept tends to be zero while the slope is one. The table 1 below gives the results of the regression.

	$\boldsymbol{\beta_0}$	$\boldsymbol{\beta_1}$
Values	-0.009827	1.047698
P-Values	0.545	0.000

R-squared = 0.9770

The value of the slope is 1.048 and significant at 1% level while the constant was not significantly different from zero. In addition, the R-square of 0.9770 implies that there is a very good association between modelled and observed land use. Thus, the constructed model can be used for simulation purpose.

5.2 Simulation experiment

A climate change scenario is implemented in the model through the creation of an additional climate file representing possible future climate. This scenario is based on farmers' subjective perception of future climate given the absence of scientific forecast of future climate for the study area. The new climate is an average weather condition of the five states of nature prevailing in Togo, namely: good rainfall condition, normal rainfall condition, bad rainfall condition, disastrous due to flood and disastrous due to drought. This new climate is obtained by asking farmers to state their subjective perception of future rainfall conditions based on their past experience. The exact question was: "Based on your experience, in the ten coming years (2013 to 2023), how many years are you expecting to be Good, Normal and Bad in terms of rainfall, disastrous due flood and disastrous due to drought? The new climate file is substituted to the baseline[1] climate file (S0) to simulate the climate change scenarios (S1). The outcomes of the scenario S1 are then compared to the outcomes from the scenario S0 for the four farmers' groups retained. To assess the impact of adaptation strategies, we introduce successively the retained strategies in the scenario S1. Thus, we first introduce irrigation by converting 25% of the operating area into irrigated area, this scenario is referred to as S2. For soil and Water conservation (SWC) techniques, we supposed these techniques are implemented on 25% of the operated land, this scenario is named scenario S3. For fertilizer reduction, we reduce applied fertilizer quantity by 25%, this is the scenario S4. These figures are guided by the ongoing country policy debates regarding adaptation. The results are presented in the table 2 below.

[1] The baseline scenario in this study represents simulation outcomes from the calibration procedure

Table 2: Annual average operating profit per hectare

Scenarios (Sn)	Profits/Benefits (US$)		Percentage of variation		Residual Impacts	
	Wealthier farmers (cluster 2), n=8	*Poor farmers (cluster 4), n=303*	*Wealthier farmers (cluster 2)*	*Poor farmers (cluster 4)*	*Wealthier farmers (cluster 2)*	*Poor farmers (cluster 4)*
S0	710.54	582.34	-	-	-	-
S1	451.45	335.23	-36.46%	-42.47%	-36.46%	-42.47%
S2	693.82	487.45	+32.89%	+27.43%	-3.57%	-16.76%
S3	549.08	397.00	+ 12.94%	+ 18.34%	-24.19%	-24.54%
S4	379.86	268.16	-10.78%	12.09%	-46.99%	-54.78
	Cluster 1 (n=90)	Cluster 3 (n=40)	Cluster 1	Cluster 3	Cluster 1	Cluster 3
S0	630.32	588.90	-	-	-	-
S1	355.00	340.23	-43.67%	- 42.22%	-43.67%-	-42.22%
S2	582.17	517.67	+36.04%	+30.13%	-07.64%	-12.09%
S3	486.95	375.76	+20.93%	+06.03%	-22.75%	-36.19%
S4	289.43	269.00	-10.40%	-12.09%	-54.08%	-54.32%

Source: Authors, 2016 from simulations in GAMS

The overall research question of this study is: to which extent do private adaptation strategies mitigate climate change impacts on farm income from crops and livestock? To answer this question, the bio-economic model is solved introducing sequentially the retained strategies. From the results one can note that adaptation strategies in terms of irrigation and SWC techniques do mitigate climate change impact for all the four identified groups although the impacts vary from one group to another. Specifically, if a representative wealthier farm group household converts 25% of its operated land into irrigated area, this will mitigate on average 96.43[2]% of the climate change[3] impacts. However, this will reduce climate change impact by only 83.24%, 92.36% and 87.10% on average if the representative household was from cluster 4 (the poor group), or from clusters 1 or 3 (the middle groups), respectively. These performances fall to 75.81%, 75.46%, 77.25% and 63.81% for cluster 2 (wealthier), cluster 4 (poor), cluster 1 and cluster 3 (middle groups), respectively, if the converted area was devoted to SWC techniques. As one could have predicted, the reduction of applied fertilizer quantity by 25% increases the four groups' vulnerability to climate change[4] (by 10.53% for the wealthier farm group and 12.31% for the poor farm group, for instance). The variation of impacts observed between groups is more likely the result of differences in households' managerial skills and farms' specific characteristics. Clearly, irrigation practice appears to be the superior strategy for the four groups. It should be the first target for any policy aiming to reduce climate change adverse impacts on farm households' income. SWC

[2] To estimate the percentage of irrigation mitigation we used the formulae $[\frac{S_2-S_0}{S_1-S_0}] * 100$, for SWC techniques $[\frac{S_3-S_0}{S_1-S_0}] * 100$ and for fertilizer reduction $[\frac{S_4-S_0}{S_1-S_0}] * 100.$ In these calculations only the number in the column Profits/Benefits are considered.
[3] See section 5.2 for more clarification on what we mean by climate change in the context of our model.
[4] By vulnerability to climate change we refer to the degree to which these groups are impacted by climate change.

techniques should not be ignored in the pursuit of this aim since irrigation practices could merely be impossible for some farms.

6. Conclusion

Achieving food security under the climate change context is a crucial challenge mainly for countries the agricultural performances of which rely heavily on rain-fed agriculture like in Togo. To inverse this discouraging prospect, agriculture needs to adapt to the changing climate. However, quantitative analysis of the impacts of adaptation strategies is rare. We contribute to filling this research gap by simulating climate change adaptation options and assessing their impact on farm income from crops and livestock in the Savana region of Togo. Contrary to most of the previous studies on the topic, a farm modelling approach was used. The findings revealed that irrigation and soil and water conservation techniques can be used to deal with the adverse impacts of climate change on farm households' income. However, fertilizer reduction, an adaptation strategy used by farmers in the study area, decreased income for all analysed farmer types. Policy makers should consider the promotion of irrigation and soil and water conservation techniques to stimulate climate change adaptation. Given the high cost of irrigation, which considerably limits its adoption at individual level, the above mentioned stakeholders should focus on community-based irrigation approaches to allow farm households to benefit from economies of scale.

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