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Climate Change Impact on Smallholder Farmers in the White Volta Basin of the Upper East Region of Ghana

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Abstract

In this paper we use the TOA-MD model to test climate change impacts and adaptation strategies with socioeconomic, survey data from the upper White Volta Basin of Ghana. Combining simulated and expected crop and livestock yields under three different climate scenarios, the economic impact of climate change to 2050 is analysed. We find that livelihood outcome variables like income and poverty levels as well as adoption rates are sensitive to the different climate scenarios. Most particularly, introducing an intensive and extended (I&E) irrigation technology as a climate change adaptation strategy offsets some negative climate change impacts and improves income but not poverty rates in the area. The results are useful in providing spatiotemporally-specific policy recommendations on the potential impacts of climate change and the economic outcomes associated with different adaptation strategies.

Key words: adaptation, climate change, Ghana, White Volta basin

1. Introduction

Climate change is projected to intensify the challenges already faced by Sub-Saharan Africa's (SSA) smallholder farmers. Changes in rainfall levels and distribution, rising temperatures and variations in soil carbon utilization by crops due to climate change etc are expected to negatively influence the growing conditions and the potential yields of many crops in SSA. The decline in output and yields will in turn aggravate the food security status and poverty incidence of smallholders whose livelihood is solely dependent on agriculture.

In arid and semi-arid tropical regions of the world like the Savannah and Sahel zones of West Africa, agriculture is largely rain-fed, and farmers commonly plant local crop varieties with little resilience to the immediate effects of climate variability - drought, flooding and high temperatures.

Though few in number, the increasing concern about climate change is attracting a considerable number of climate impact assessments across SSA e.g. Hijmans, 2003; Jones and Thornton, 2003; Thornton et al, 2009a and 2009b; Claessens *et al*, 2011 etc. The general conclusion from these studies is that SSA's crop and livestock yields will decline if there is no adaptation to future climatic conditions.

Most previous studies exclude economic impacts from estimated yield impacts, or use statistical methods that require costly multi-year farm-level surveys, and neither considers the adaptation or the cost of it, nor downscales the results to permit site-specific impact assessments (Claessens et al 2011). Because of these deficiencies, the findings of existing climate impact studies are often not uniform everywhere, and lack farm level-specific relevance and quantitative economic value.

To address some of the empirical weaknesses of previous studies, this study quantifies the potential economic impacts of climate change on technology adoption, gross and net farm revenues, and poverty rates among heterogeneous farm populations in the upper White Volta Basin (WVB) in the upper east region (UER) of Ghana. The objective is to assess how climate change, with and without adaptation, will impact on the above livelihood parameters and how farmers might respond to these impacts via the implementation of adaptation strategies. This study particularly examines how farmers' wellbeing might be affected if future climatic conditions reduce precipitation and increase temperature trends.

The analysis is implemented using the Tradeoffs Analysis for Multi-Dimensional Impact Assessment (TOA-MD) model and socioeconomic survey data obtained from farm households under the Climate change Impacts on West African Agriculture: a Regional Assessment (CIWARA) Project.

2. Study Area and Dataset

The study is undertaken in the Anayari (200km²), Atankwidi (270km²) and Yarigatanga (200km²) sub-catchments of the upper White Volta River Basin in the UER of Ghana (Fig. 1). These occur respectively in the Kasena-Nankana East, Kasena-Nankana West and Bongo districts of the UER in Ghana, and extend northward into Burkina-Faso. Average rainfall in the WVB ranges from 645mm to 1250mm per annum, which is distributed from May to October/November yearly. Mean rainy season temperature averages about 28.6°C.

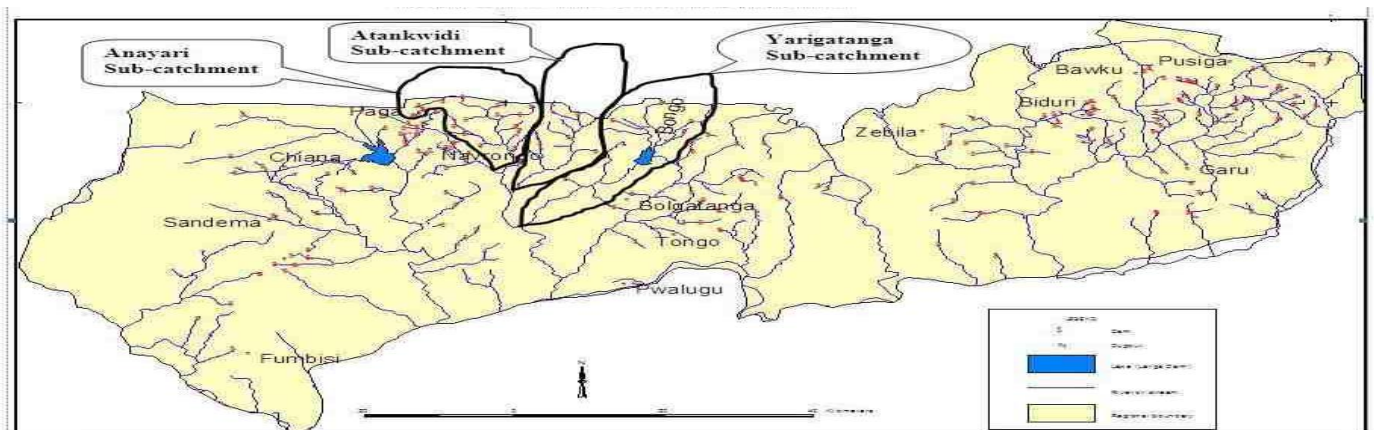


Fig. 1: A map showing the Anayari, Atankwidi and Yarigatanga sub-catchments of the upper WVB. Source: Laubel et al, 2012.

Rain-fed, semi-subsistence agriculture comprising “compound farms” of millet and sorghum systems with mixtures of cowpea, maize, and vegetables located near the homestead; and “bush

farms” located some distance away from the village with rice, groundnuts and other monocrops, and the rearing of livestock is the most predominant source of livelihood in the study area. The average poverty line income in Ghana is about GHC330.00, circa \$170.0 per annum.

The analysis is conducted on a total of 300 farm households sample across the three sub- catchment areas. The data included variables like farm size, household size, land use and farm management activities, off-farm income etc obtained from farms with millet, sorghum, maize, rice and livestock enterprises. A summary of the key variables used to estimate the TOA-MD model parameters is presented in Table 1.

Table 1: Key descriptive statistics of base system variables used in TOA-MD analysis

Two sub-systems of farms are considered under this study. Farms belonging to the first sub-system hereafter called system 1 are purely rain-fed farms that lack access to irrigation; while

<i>Parameter/Strata</i>	<i>1. Farms without Irrigation</i>			<i>2. Farms without Irrigation</i>		
	<i>Mean</i>	<i>Stand. Dev.</i>	<i>CV (%)</i>	<i>Mean</i>	<i>Stand. Dev.</i>	<i>CV (%)</i>
<i>Farm Characteristic</i>						
Household size	8.63	4.46	51.62	8.87	4.33	48.75
Farm size	2.78	1.97	70.79	2.93	2.34	79.70
Herd size (UBT)	14.74	18.36	124.57	30.54	39.60	129.68
Off-Farm Income	1034.53	1887.52	182.45	1816.70	3850.69	211.96
Maize						
Yield/farm (kg)	328.44	243.23	74.05	646.99	1239.50	191.58
Var. Cost/farm (GHC)	226.54	163.23	72.05	313.31	380.80	121.44
Net Rev./farm(GHC)	74.65	268.14	359.22	241.55	660.51	273.44
Price (GHC/kg)	0.96	0.27	28.63	0.92	0.32	39.91
Millet						
Yield/farm (kg)	152.88	209.41	136.97	266.33	256.91	96.46
Var. Cost/farm (GHC)	226.54	119.40	78.43	155.49	119.74	77.00
Net Rev./farm(GHC)	74.65	225.62	381.84	173.96	350.08	201.24
Price (GHC/kg)	1.29	0.56	43.01	1.10	0.21	19.12
Sorghum						
Yield/farm (kg)	230.65	309.19	134.05	482.46	764.39	158.44
Var. Cost/farm (GHC)	106.05	86.41	81.48	122.76	99.55	81.09
Net Rev./farm(GHC)	109.27	247.61	226.63	375.54	787.08	209.58
Price (GHC/kg)	0.91	0.26	29.85	1.01	0.14	14.88
Rice						
Yield/farm (kg)	312.65	355.61	113.75	609.09	570.37	93.64
Var. Cost/farm (GHC)	185.29	168.76	91.06	306.86	208.79	68.04
Net Rev./farm(GHC)	161.03	466.99	290.00	348.04	579.62	166.54
Price (GHC/kg)	1.20	0.51	42.61	1.09	0.35	39.91
Livestock						
Var. Cost (GHC)	144.79	267.86	185.00	252.01	411.34	163.22
Net Rev./farm(GHC)	554.25	974.60	175.84	538.15	1576.07	292.87

farms in the other sub-system hereafter called system 2 are those with access to irrigation facilities. The assumption is that farms with access to irrigation will be better-off under reduced precipitation and increased temperature following changed climate. Irrigation will be an important adaptation strategy and determinant of the economic outcomes for these farms under climate change since Irrigation mutes the negative impact of reduced precipitation.

Particularly intensified and expanded (I&E) use of ground water irrigation will be a practical, least-cost strategy for climate change adaptation (Laube et al, 2012) because irrigated farms are less vulnerable to climate change. We assume no ‘carbon fertilisation’ which though has a critical effect on crop growth and yields, is not a common practice by most WVB farms.

3. Methodology: The TOA-MD Model

The theoretical framework of the TOA-MD model (Antle, 2011a) assumes that farmers, as economically rational people, choose from a set of farm systems that yield positive expected net returns. In this climate analysis, the economic outcomes associated with each of the two systems - base system (system 1) and an adapted system (system 2), are simulated and compared for three different climate scenarios. It is expected that changes in climatic conditions will affect the economic outcomes of the system 1 causing some farmers to adopt system 2 where they will employ improved technology under the changed climate. Some farms however continue to operate under system 1 following climate change. By so doing, both adopters and non-adopters of system 2 and thus the entire population of farms may gain or lose in terms of changes in their income and poverty levels.

In the TOA-MD model, a farmer at a site s using a production system h earns per-hectare returns equivalent to $v_t = v_t(s, h)$ each season/period. Let: System 1 = Farmers with base technology and base climate, and System 2 = Farmers with adapted technology under changed climate. Now if $\omega = v_1 - v_2$ measures the difference in income between systems 1 and 2; then $\omega = v_1 - v_2 > 0$, means climate change leads to a gain for farms that continue to use the base technology, but if $\omega = v_1 - v_2 < 0$, then climate change implies a loss for the farms that continue to use the base technology.

When the production system changes for instance from j to k following climate change, the expected economic returns (gain or loss) as a result of this change is given by:

$$\omega(p, s, j, k) = V(p, s, j) - V(p, s, k) \quad (1)$$

Where a positive $\omega(p, s, j, k)$ denotes the loss associated with changing from system j to k while a negative $\omega(p, s, j, k)$ denotes a gain from changing from system j to k .

If we let $\varphi(\omega \setminus p, j, k)$ be the spatial distribution of gains or losses in the population of s farms, the percentage of farms with $\omega(p, s, j, k) < a$ is:

$$r(a, p, j, k) = 100 \int_{-\infty}^a \varphi(\omega \setminus p, j, k) d\omega \quad (2)$$

Where a is returns/ha.

3.1 Climate Change Projections

The analysis explores three principal scenarios - the CSIRO, NCAR and the I&E. The first two climate model runs, the national centre for atmospheric research (NCAR) and the commonwealth scientific and industrial research organization (CSIRO) models, are used to simulate the potential effects of climate change on crop yields using the A2 inputs of the IPCC's 4th assessment report (IFPRI, 2009). Both models project higher temperatures, high evaporation, increased precipitation and reduced crop yields without CO₂ fertilisation for SSA by 2050 (fig. 2). The intensive and expanded (I &E) model, based on the assumption that irrigation water from aquifers within the WVB is used as an adaptation strategy to bring yields levels up to 95% of their baseline values, is tested as an adaptation strategy under a third scenario. In all three scenarios, we test a recommended 10% reduction in yield of livestock caused by declines in feed intake and availability.

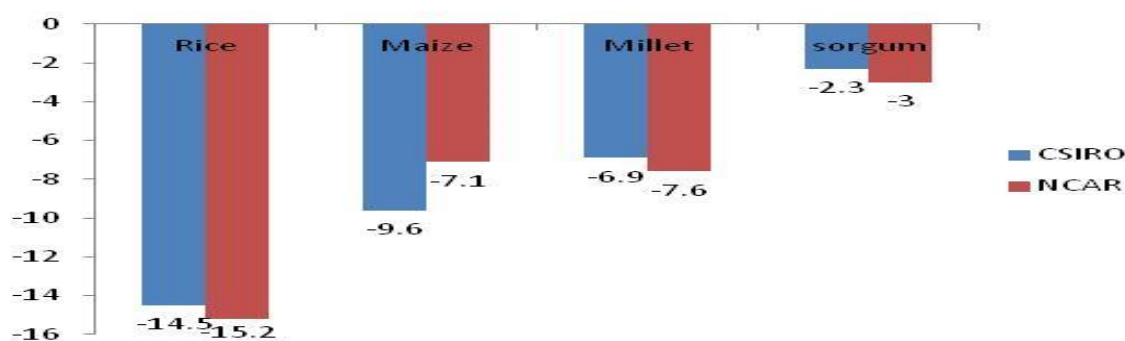


Fig. 2: Mean yield change of major crops for the CSIRO and NCAR A2 Scenarios

Source: Authors' plots from IFPRI (2009) projections.

4. Results

The results based on the three scenarios are presented in Table 2. They show the effects of different climate scenarios on adoption rates for new technologies (economic feasibility of adaptation strategies), and on potential income gains and losses, and poverty rates as a result of farm households switching from system 1 to 2 under climate change. The results are disaggregated across the two strata of farms – those with and those without access to irrigation; and aggregated for the entire farm population.

First, the results on the adoption rates for system 2 show in all three scenarios that farms with access to irrigation have higher adoption rates than farms without irrigation access. The adoption rates for the entire population of farms are 27%, 22% and 35% respectively for the CSIRO, NCAR and I&E irrigation scenarios respectively. Therefore, availability of water for intensive and expanded irrigation following climate change is expected to have a profound effect on the rate of adoption of improved technology under climate change.

Next, net farm incomes are shown to be sensitive to climate change. The results of the percent gains, losses and thus net losses by farms with and without irrigation access as a percentage of net mean farm income mirror those of the adoption rates. As may be seen across all three scenarios, farms with irrigation access gain more but lose less due to climate change. The aggregate net losses are 14%, 21% and 26% under the I&E, CSIRO and NCAR scenarios respectively. This means, irrigation reduces the percentage of average, net farm income losses for the entire population of farms from 26% under the NCAR scenario to 14% under the I&E scenario. As noted above, irrigation buffers farms from the negative effects of reduced precipitation on farm productivity.

Table 2: Climate simulation results across scenarios in the upper WVb in Ghana (A2: 2050)

<i>Scenario/Stratum</i>	Adoption Rate (%)	Gains (%)	Losses (%)	Net Loss (%)
CSIRO				
Farms without Irrigation	25.00	11.91	35.74	23.83
Farms with Irrigation	30.49	14.59	33.26	18.67
All Farms	27.1	13.24	34.51	21.27
NCAR				
Farms without Irrigation	20.04	9.44	37.65	28.21
Farms with Irrigation	24.94	11.76	35.39	23.63
All Farms	21.94	10.59	36.53	25.94
I&E Irrigation				
Farms without Irrigation	33.45	16.23	32.28	16.05
Farms with Irrigation	36.35	17.64	30.89	13.25
All Farms	34.57	16.93	31.59	14.66

Notes: Gains, losses and net losses are expressed as a percentage of mean agricultural income in the base system.

In addition to the effects on income, we also estimate poverty rates (% of the farm population living on less than s \$1.00/day) due to climate change under the 3 scenarios at the disaggregated and aggregated levels (Fig. 3a and b).

Fig. 3b: Poverty rates of farms under system 2 (% of farms with < \$1.00/day)

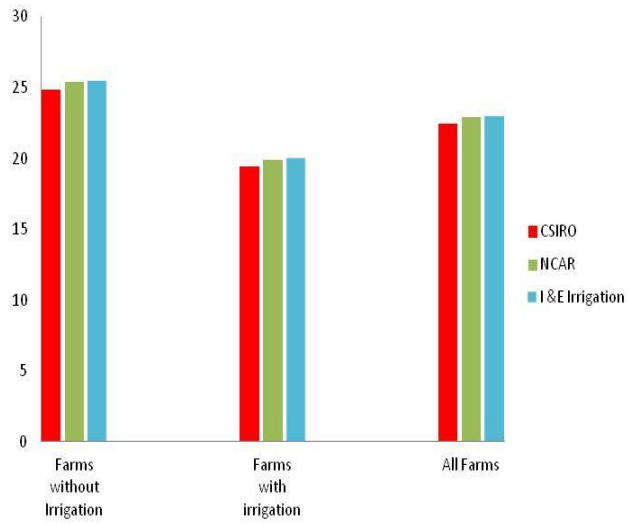
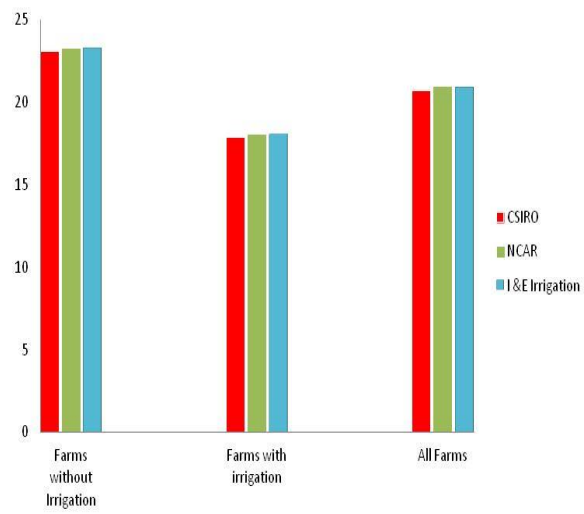


Fig. 3a: Poverty rates of farms under system 1 (% of farms with < \$1.00/day)



As expected, the different climate scenarios produce different poverty impacts on the farms. The results show that overall poverty rates under system 1, the base system are lower than those under system 2, the adapted system. Surprisingly, the I&E scenario has a less profound effect on the simulated poverty rates than the CSIRO and NCAR scenarios. It appears that off-farm income will play an important supplementary role in reducing future poverty rates in the WVb under future climate scenarios.

5. Conclusion

By assessing climate impacts at the farm household level, the study reveals that net farm incomes and poverty rates are sensitive to climate change; with irrigated and rain-fed farms having different responses to climate change. Irrigation access appears to benefit the production of rain-fed crops either directly via supplementary irrigation during drought events within the production season and indirectly via increased financial access of farms with irrigation to obtain other yield-improving farm inputs. Since surface water for irrigation is not available everywhere in the study area, it means future climate changes that result in reduced precipitation and high temperatures will negatively affect livelihood outcomes. An important adaptation strategy for farmers and policy makers will be to introduce an I&E technology to offset some of the negative climate change impacts on agricultural productivity, improve net farm incomes and reduce poverty rates in the WVb.

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