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The Impact of Climate Change on Crop Production in West Africa: An Assessment for the Oueme River Basin in Benin

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Abstract Climate change studies for West Africa tend to predict a reduced potential for farming that will affect the food security situation of an already impoverished population. However, these studies largely ignore farmers' adaptations and market adjustments that mitigate predicted negative effects. The paper attempts to fill some of this gap through a spatially explicit evaluation of the impact of climate change on farm income in the Oueme River Basin (ORB), Benin. The ORB is in many respects representative for the middle belt of West Africa where the predominantly sparse occupation leaves potential for migration from more densely populated areas. We apply a number of structural, spatially explicit relationships estimated for the whole territory of Benin to simulate conditions in the ORB proper that are similar to those currently prevailing in the drier North, and the more humid South. Our scenario results factor out for the main crops cultivated the constituent effects on yields, area, and revenue per ton. We find that under average climate change conditions the current low yields are not reduced, provided that cropping patterns are adjusted, while price increases partly compensate for the remaining adverse effects on farmer income. Consequently, without any policy intervention, farm incomes remain relatively stable, albeit at low levels and with increased occurrence of crop failures after extreme droughts. Scenario simulations show that there are also beneficial aspects that can, with adequate interventions, even turn losses into gains. Main channel for improvement would be the reduction

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of fallow, which is particularly promising because it requires few adjustments in prevailing farming practices, exploits the potential of uncultivated land and improves the water use efficiency. It also enables the Basin's capacity to absorb future migrant flows from more severely affected neighboring Sahelian areas.

Keywords Agricultural production · Adaptation · Price effects · Food security · Scenario analysis

1 Introduction

In a report to the Committee on World Food Security the Food and Agricultural Organization of the United Nations stated that climate change will reduce the available land for farming in developing countries and increase the number of the world's hungry (FAO 2005). The impact is expected to be most severe in Sub-Saharan Africa (SSA), where countries are least able to adapt and to compensate for negative effects through increased food imports, thus seriously limiting the prospect for reaching the MDGs by 2015.

Alarming as these conclusions might be, the reports mentioned their limitations at some length in that they did not account for socio-economic mechanisms (e.g. Krysanova et al. 2010) and policy interventions (DeCanio 2003), and justify this by pointing to inherent uncertainties. The literature distinguishes three approaches to model the socio-economic impact on climate change: Agro-Ecological Zones (AEZ) techniques, agro-economic models and cross-sectional methods.

AEZ studies (e.g. Parry et al. 2004; Fischer et al. 2002; Adams et al. 1998) use crop models that have been calibrated under controlled laboratory and field conditions and rely on rule-based procedures to account for agro-ecological characteristics (soil constraints, temperature and agro-climatic constraints). Farming practices are kept constant to ensure that model results are assigned to the biophysical variables under study (temperature, precipitation or carbon dioxide). The models find it difficult to account for low input levels prevailing in developing countries and tend to diverge widely from yield levels as observed in the field. Furthermore, AEZ ignore adjustment mechanisms of farmers that anticipate changing climatic conditions and, therefore, tends to overrate the expected losses (Downing et al. 1997; Adams et al. 1995 and Solow et al. 1998; Patt and Schröter 2008). Agro-economic studies (e.g. Mendelsohn and Dinar 2003; Kumar and Parikh 2001) use similar crop models as in the AEZ studies but largely ignore the agro-ecological zone characteristics. These studies incorporate farmer adjustments on an ad hoc basis (Mendelsohn and Dinar 1999), but outcomes are based on changing coefficients rather than on actual farm practices. Cross-sectional models address some of the above mentioned shortcomings as they measure farm performances across climatic zones (Benhin 2008; Mendelsohn 2000; Mendelsohn and Dinar 2003; Sanghi 1998; Sanghi et al. 1998; Kurukulasuriya and Mendelsohn 2006), thereby automatically incorporating farmer adaptation strategies (Mendelsohn et al. 1994; Mendelsohn et al. 1996; Mendelsohn and Dinar 1999). However, their limitation is that they do not control for the spatial and temporal variability of biophysical variables that to a large extent explain the variation in farm incomes in the data (Mendelsohn 2000; Kurukulasuriya and Rosenthal 2003).

We also note that most of the above discussed approaches disregard market effects in climate change studies (Deschenes and Greenstone 2004); sometimes because price subsidy and world market effects are taken to dominate (Lorenzoni et al. 2001), but mostly because price effects are simply taken to be minor (Cline 1996; Kurukulasuriya and Rosenthal 2003). We would argue that the price effects at national and local level can be important even for small economies, particularly because of the high costs of trade and transport connecting farmers to the rest of the world, and that they can go a long way in mitigating the impact of climate change on farmers' income.

We conclude that current approaches (e.g. Ison et al. 2011) ignore important mechanisms that compensate the negative effect of climate change.

In our research we aim to address the above mentioned concerns by strengthening the empirical basis of the simulation tools, particularly with respect to their temporal and spatial detail (Gibbons and Ramsden 2008), so as to improve on the representation of cropping conditions, farmers' adaptation and market effects (Stern 2006). We specify a simulation tool and report on simulation exercises for the Oueme River Basin (ORB) in Central Benin. The research is a co-operative venture between economists, Beninese policy analysts and hydrologists. Its intended contributions are as follows. First, rather than operating with calibrated process based models, we estimate structural, spatially explicit relationships for the whole territory of Benin. Next, we apply these to scenario simulations for the ORB, factoring out for the main crops cultivated the three components yield, area, and revenue per ton,

As argued by Adger et al. (2003) and Sperling (2003), we specify these relationships so as to accommodate basic elements of adaptation, primarily, adjustment of cropping pattern (Nyong et al. 2007; Wang et al. 2011), reduction of fallow periods (Smit and Mark 2002), enhanced irrigation, and provision of agricultural inputs such as improved seeds, and the use fertilizers and pesticides. We take soil moisture and agricultural inputs to operate in parallel, and at each site the most constraining of the pair is binding. Regarding area adaptation, adjustment of the cropping pattern enables farmers to adjust to the new soil moisture conditions, while expansion of the total area cultivated makes it possible for farmers to migrate to less affected regions. Finally, prices may adjust in response to changed scarcity on the market at national level, as well as to changed net selling positions at commune level. Also, unlike Parry et al. (2004), we generate spatially differentiated impacts on prices.

To obtain data for these structural relations, we base our projections for the Basin on relationships estimated for the Beninese territory as a whole. This is useful because climate change will, expectedly, create conditions in the Basin that are similar to those currently prevailing in the parts of Benin that surround it, particularly in the drier North, and the more humid South. We will conduct model simulations with these relationships under various scenarios representing different assumptions on climate change and policy interventions, with irrigation, improved provision of inputs, and area expansion as policy levers.

As a second contribution our study relies on a detailed spatial and temporal assessment of climate change impacts that allow reaching down to the administrative level of the commune,[1] while maintaining sufficient detail to account for the variability within the territory of each commune. To allow for this, our study uses a hydrological model of the ORB (Rivertwin 2007a), that calculates soil moisture balances with a daily time steps for a fine resolution (3×3 km grid) so as to provide a precise assessment of the length of the growing period (LGP). The hydrological model makes use of the ECHAM4 climate change model. Using results from four other GCMs, we apply external shocks to the ECHAM4-results to allow for a wider range of soil moisture conditions..

Data and model are kept in a fully integrated Decision Support Tool (DST) that comprises all calculations from basic data down to the tabulation of results and presentation

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[1] A commune (municipality) refers to the second level an administrative entity in Benin. A department, one administrative level higher, consists of several communes.

of GIS maps of the ORB, thereby facilitating the communication between scientists, stakeholder and decision makers, as well as future maintenance of the tool (Letcher et al. 2006).

The ORB, although relatively small in area, is with respect to the impact of climate change exemplary for most of the West African Middle Belt, witness the similar length of growing period, soil type composition and population density (UNEP/GRID 2000) in Fig. 1. The ORB is also representative for the outcomes from the various Global Climate Change Models (GCM) that consistently predict (Fischer et al. 2002) a gradual increase of water scarcity from South to North (Sultan et al. 2005; Desanker and Magadza 2001). Moreover, the West African Middle Belt Middle is in general sparsely settled (Gleave and White 1969; Jaiyeoba 1997; Jaiyeoba 1998) and constitute an attractive candidate to absorb migrant fluxes from the Northern Sahelian zones that are threatened by encroaching deserts (Gonzalez 2001; Prospero and Lamb 2003) and the densely populated coastal areas where agricultural production capacity is endangered by nutrient mining (Bationo et al. 2007; IUCN 2004; Carsky and Toukourou 2005; Vanlauwe et al. 2001). Under climate change, this situation is most likely to worsen, with accelerated desertification in the North and more frequent occurrence of torrential rains and floods in the South. Climate change predictions are less extreme in the Middle Belt proper (Thornton et al. 2006) which can be considered as a key asset for future development of the agricultural sector in the region. However, this raises important issues in land management, particularly because the low population density often appears to be associated with high fallow requirements to maintain soil fertility (de Ridder et al. 2004) and new settlers are bound to meet resistance from incumbent farmers. This study will, therefore, evaluate the impact of climate change conditions under various intensive agronomic and irrigation development scenarios (Brumbelow and Georgakakos 2007) that should alleviate these tensions. We intend thereby to go a step further than Höllermann et al. (2010) who simulated water supply

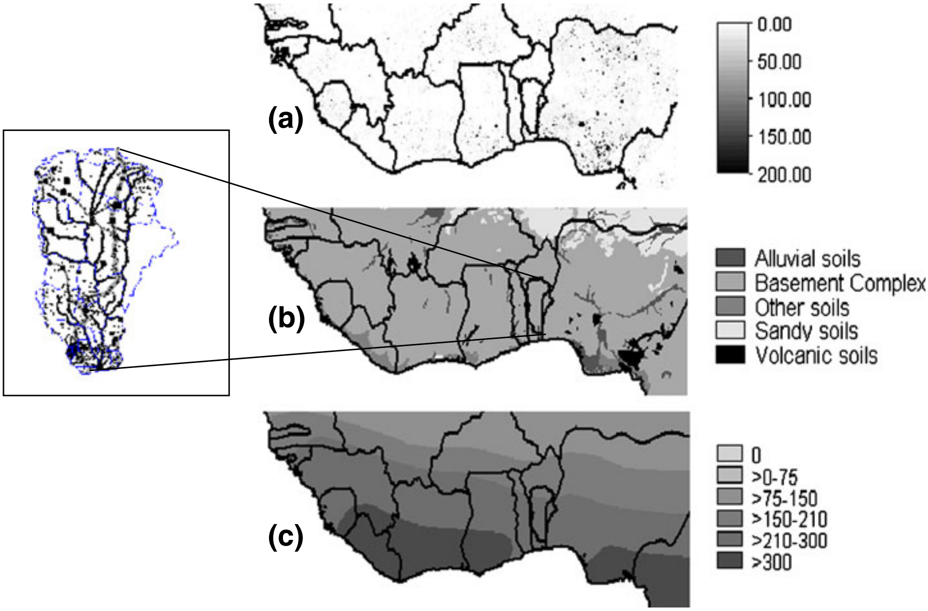

Fig. 1 Population (**a**), soil (**b**) and LGP (**c**) in West Africa. Insert map: infrastructure (*black lines*), Oueme River (*grey line*) and settlements (*dots*) in the Beninese ORB

under various climate change scenarios for a sub-catchment in Benin without accounting for farmer adaptations and changes in market prices.

1.1 Overview

The remainder of the paper is organized as follows. Section 2 presents a sketch of the ORB and describes the data sets used for our study. Section 3 discusses the various functions that make up the model and how they were estimated. Section 4 presents the scenarios and policy interventions, the results of which are reported in section 5. Section 6 concludes.

2 The Data Base and Its Compilation

2.1 The Oueme River Basin

About two million people currently inhabit the ORB, 60% of them employed in agriculture. Urban population is mainly concentrated in the rapidly growing agglomeration of Parakou (150,000) and smaller cities such as Djegbe in the South (1,000), the Manigri arrondissement in the East (15,000), and Patargo (13,000) and Donga (12,000) in the North East. Many rural villages are located along the main North-to-South highways, benefiting from the transport possibilities to bring their cotton to the large factories in the Southern part of the Basin and to sell their home made produce such as charcoal and cassava flour.

Two roads connect North and South. One is The North-East transport road that connects the Coast with Burkina Faso and is intensively used for transport. The other, towards the North-east, leads to the two national game parks adjacent to the Basin that are actively being promoted for tourism. Table 1, with the land use distribution in the ORB, shows that agriculture covers only just over one third of the area.

The agricultural land is in fact a ‘mosaic with agriculture’, a composite of cultivated areas, fallow and other vegetation for which the limits of the resolution (30 m) of the satellite images, LANDSAT ETM Plus (Igue et al. 2006a, b),[2] cannot reach a more precise delineation. Of these mosaics only about 7,615 km^2, or 43% is actually under cultivation. The savannah and rangeland area are used for the herding of livestock, around 684 thousand heads of cattle, 467 thousand of goats and 268 thousand of sheep mainly in the Northern communes. The average livestock density is only 0.27 Tropical Livestock Unit (TLU)[3] per hectare (e.g. de Leeuw and Milligam 1984) and in the middle and southern part of the basin this figure is much lower, leaving potentially ample room for expansion of livestock production, provided that tsetse- infested areas can be avoided. Forest land serves for logging, hunting, gathering and the preparation of charcoal that is sold to the villages and cities.

The annual rainfall in the ORB increases along the North–south axis, from 800 to 1400 mm per year, with rainy seasons in the North lasting from April to September and in the Southern part from March till November. Rainfall in the South is stable year round, while patterns in the North are more erratic, causing seasonal water shortages for crop and livestock production. Water scarcity also finds expression in population density and

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[2] LANDSAT scenes were processed with ERDAS version 8.3.1. Using an unsupervised classification, 26 land use classes were defined

[3] To compare grazing demand or environmental pressure of different species in common units, animals body weights were converted into TLU equivalents.

Table 1 Land use in the ORB

Land use	Area (in km^2)	Percentage of total area
Forest	11208	21.74
Savannah	21008	40.76
Mosaic with agriculture	17611	34.17
Plantations	1394	2.71
Water bodies	21	0.04
Rangeland	21	0.04
Bare land	4	0.01
Urban and built-up areas	276	0.54

cultivation intensity, which are low in the Northern, drier part of the Basin, where seasonal crops such as maize and sorghum dominate, and where migrating livestock from Northern Benin and neighboring countries comes for grazing. Population density and cultivation intensity rise gradually from North to South. In the South, tubers become the major crop, while livestock is almost absent due to prevalence of diseases. Cultivation of cotton is an important activity for the farmers throughout the Basin and supported by large scale cotton factories. Along the Oueme river, population density also rises towards the South. The Oueme River has a relatively low baseflow from January until September but discharge rates dramatically increase during the winter months when floods threaten the Southern part of the actual river basin. The river is mainly used as a drain and sometimes for deviations that store the water in buffers for urban water plants. The Ilauko dam, with a capacity of 23,500 m3, is the largest water storage reservoir in the basin and is used for irrigation of a sugarcane plantation. FAO’s AQUASTAT data base indicates that approximately 2% of the total available groundwater has economic use.

2.2 Data Sources and Their Use

The study could access a large number of detailed data sets, comprising primary (e.g. village surveys), secondary (e.g. household surveys, commune statistics), and processed (e.g. satellite image) data as well as outputs from various modeling exercises (e.g. soil moisture availability). The data sets with their attributes, resolution and sources are listed in Table 2. All data processing follows a standard procedure of geo-referencing at point, grid or commune level in a GIS (ILWIS version 3.3; ITC-ILWIS 2001) and subsequent export to a SAS-environment for further processing. The data are finally organized into a consolidated data base that is used for statistical estimation and model simulation, using dedicated programs to analyze and visualize the results.

The ORB is represented on a 3×3 km grid map (5,727 cells) with 36 Beninese communes, 22 of which share their area with adjacent basins. The Nigerian and Togolese parts of the basin are considered as additional administrative entities at the commune level. The household survey data from the International Food Policy Research Institute (IFPRI 2004), (obtained from the Programme d’ Analyse de la Politique Agricole (PAPA), Porto Novo, Benin), has approximately 1,000 observations distributed among some 100 georeferenced locations in Benin, with over 80% of these observations located outside the ORB. The 26 land uses that were interpreted from the satellite image at a resolution of 300X300m are combined into 6 major land use groups (crop land, savannah\rangeland, plantation, forest, bare land, urban). Next, the areas of these land use groups are aggregated to 3×3 km grid cell, and further represented as a distribution of land use by grid cell.

Table 2 Data used, resolution and source

Area	Attribute	Resolution	Source
ORB	Identifier	grid 3 km	Project output
	Identifier	grid 300 m	Project output
	ORB delineation	polygon	Project output
	HBV model results (water balance)	grid 3 km	Rivertwin 2007a
	Land use map	grid 300 m	Igue et al. 2006a, b
Benin & ORB	Urban/Rural area map	30 arcsec	Igue et al. 2006a, b
	Climate change scenarios	30 arcsec	Rivertwin 2007b
	Population map	30 arcsec	UNEP/GRID 2000
	Administrative map	polygon	FAO 2006
	Soil suitability	grid 0.5°	FAO/IIASA 2000
	Length of Growing Period (1960–1996)	grid 0.5°	FAO/IIASA 2000
Benin	Crop production (crop, area, production yield)	polygon	Rivertwin 2007c
	Household Survey (agricultural income, land, labor, inputs)	point data	IFPRI 2004

The study concentrates on the evaluation of 10 dominant crops in the ORB that cover more than 95% of cultivated area and 96% of produced value. As mentioned in the introduction, the approach is to establish the dependence of crop yields and area shares on water availability for the entire country and to apply this relationship to simulate the effect of changes in soil moisture conditions for the ORB under climate change on crop income. Prices are obtained from a commune-level data set. Finally, in the absence of production statistics for the Nigerian and Togolese parts of the ORB, the data from adjacent communes in Benin are used to simulate crop yields, crop area shares and prices in these areas.

For the spatial distribution of actual yields and areas, three data sources were consulted: the commune statistics on crop yields and areas provided by the PAPA, the georeferenced household survey of the IFPRI also with crop yields and areas, and the agro-ecological zoning by FAO/IIASA (2000) that contains a yield map at different input levels based on a crop-growth model. Commune production and cultivated areas are obtained from the PAPA data, and the total agricultural land available from the soil and population maps. At this point two factors have to be accounted for. One is that multiple cropping takes place in some communes for specified crops, the other that fallow is part of the production system and needs to be accounted for. Therefore, on the one hand the occupied agricultural area is computed by commune, and on the other the cultivated land needs, dividing cultivated area by cropping intensity factors. Next, the fallow ratio is computed by commune. This gives a distribution of area over crops, and fallow.

The following step is to estimate the yield by grid cell. For this, the commune output is distributed by crop over the cultivated land at grid level, relying on a constrained scaling procedure (Keyzer 2005) that adjusts grid level output until it meets the commune total, within grid level bounds. These bounds are set so as to offer a range around a reference yield multiplied by the cultivated land at grid level. The reference yields at grid level were obtained through spatial interpolation between sites where household level measurements took place. Specifically, at gridcells that are inhabited and where cultivation takes place, the crop output is calculated by taking the weighted sum of the five nearest grid cells where household observations are available, with weights attributing higher importance to cells that are nearby and have larger cultivated areas.

3 Function Specification and Estimation

The model developed in this study evaluates the impact of climate change on farm income by analyzing its effects on yields, area, and net revenue for the main crops cultivated. It consists of a set of structural relationships that are built up in five stages, with the following sequence. First, future soil moisture conditions, expressed as the Length of Growing Period (LGP, measuring an uninterrupted period within the annual cycle during which moisture availability is conducive to crop growth), are evaluated using the results of a hydrological model (Rivertwin 2007a) with daily time steps that calculates water balances on a 3×3 km grid. Next, and second, the impact of water availability changes on crop yields is represented via a biophysical relationship between LGP and potential crop yield. The following, third, step relates the LGP to actual yields, using potential yields as upper bounds, while maintaining prevailing practices regarding fallow and multiple cropping. Subsequently, fourth, the (fallow inclusive) crop area shares are related to LGP in the base year, and this relation is applied to simulate farmers' future adaptation to new water availability conditions. Finally, fifth, market effects of commodity scarcity are accounted for by two mechanisms, one relating the variation of prices across the Basin to the locally prevailing supply–demand imbalance, the other, by adapting prices to total supply in the Basin on the basis of an assumed price flexibility that varies among crops and is higher for a crop that is more local and has a lower price elasticity of demand. All estimations are based on data for the year 2003.

Regarding notation, let the set of crops be denoted by I, with elements i and the set of grid cells by G, with elements g. In fact, G refers to the full territory of Benin, as well as to the Togolese and Nigerian fringes of the ORB. Each grid cell belongs to a commune, indexed by d, which in turn belongs to one of the provinces, indexed by p**.** In addition, the subsets G^o of G for survey points are defined, indexed by s, and G^b of G, indexed by b for the grid cells of the ORB.

3.1 From Climate Change via HBV Model to Length of Growing Period

The HBV[4] model (Bergström 1995) is a semi-distributed hydrological model that is applied in large scale catchment areas. It is used to generate for each 3×3 km grid cell within the ORB, at daily time steps and for homogeneous units of land use and soil type within each cell, the items of a water balance, comprising precipitation, soil moisture conditions, evapotranspiration and runoff (Rivertwin 2007a). These variables are used to calculate the LGP as the size of the largest window of contiguous days within a year that have soil moisture greater than half of evapotranspiration. In this calculation interruptions of 15 days at most are ignored in periods with adequate levels of soil moisture. LGP calculations cover the period 1980–2030 using climatic data from historical time series (1980–2003) and from the simulations of the Global Climate Change model ECHAM (2003–32030) (Rivertwin 2007b). Figure 2 shows the LGP calculations for the reference year 2003.

The impact of climatic change is evaluated under average LGP conditions as well as under extreme droughts when LGP falls below critical levels and become restrictive for crop cultivation. To calculate the probability of extreme events, it is assumed that the grid-specific LGP can be characterized by its mean and coefficient of variations (CV) obtained from the climate change model runs. However, unexpectedly it was found, that the CVs from climate change simulations of the HBV-model over the period 2000–2030 were lower

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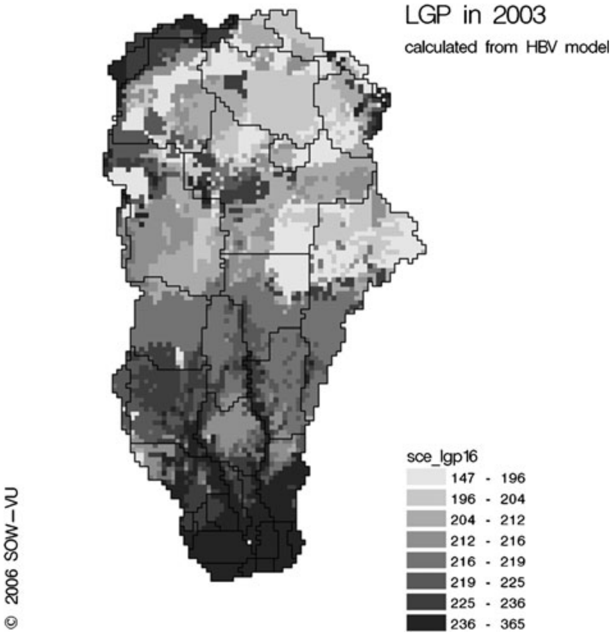
[4] HBV stands for 'Hydrologiska Byråns Vattenbalansavdelning', a hydrological model developed by Bergström (1995).

Fig. 2 LGP in days for the year 2003



than those of the historical time series 1980–2003, which are themselves lower than for the period 1970–2003 that would comprise the seventies when extensive drought periods distressed West Africa. These low-CV values are also at odds with results from other climate change studies that all predict more erratic rainfall for West Africa. Therefore, it was decided to adopt the CV from a recent continental study that shows a gradual increase towards higher latitudes (Thornton et al. 2006).

3.2 From Water to Potential Yields

The crop-specific impact of water availability on potential yield is represented by its biophysical relationship with LGP. The estimated (fifth degree polynomial) function is based on data from the Agro-ecological zones study that used a water and soil constrained crop growth model, the details of which are explained in FAO/IIASA (1993). The results of this study were scaled to the SLISYS model output that was used in the Rivertwin project to model crop yields (Gaiser et al. 2006). The estimated polynomial follows the FAO-potentials closely ($r^2>0.95$) for the 10 crops under study. Figure 3 shows a graph of the response from the theoretically determined potential yields and the estimated functional form against LGP for soybeans. The LGP constrained potential yields are further adjusted for the prevailing soil constraints, resulting in agro-ecological potential yields.

3.3 From Potential to Realized Yields

Plotting the agro-ecological potential and observed yields (per hectare harvested, hence excluding fallow) against LGP shows that observed yields are low and stable throughout the LGP range and far below the potential. Figure 4 gives a typical example for Maize, where red dots representing potential yields follow the expected water constraint pattern, while observed yields show no effect under alternative levels of water availability. This

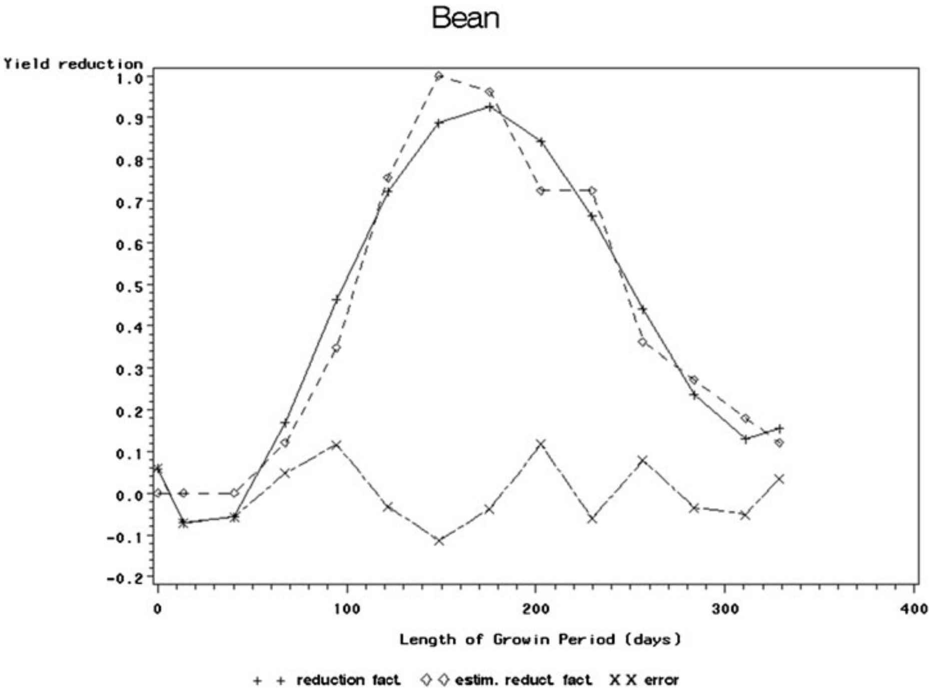


Fig. 3 Yield response (observed and estimated) to LGP for Soya Beans

agrees with Gaiser et al. (2006), who found that under average climatic conditions nutrients rather than water are the limiting factors for crop production in the ORB. Therefore, it was decided to establish a relationship between yield and LGP using the potential yield as upper bound only. It would be desirable to include agrochemical inputs as well but since these are hardly being applied within the ORB at present, an agronomic coefficient has to be used to represent possible relaxation of the prevailing input constraint. The relationship between yield and LGP is estimated by cross section. Since climate change will lead to conditions within the ORB that are similar to those currently prevailing around it, particularly in the drier North and the more humid South, the projections for the Basin are based on estimation for the Beninese territory as a whole, distinguishing three components, as follows.

3.3.1 Yield Functions, Estimated at Commune Level

For the crop specific relationship between actual yield y_i^g and LGP, we summed crop specific grid information across communes and accommodated the information in the following formula:

$$y_i^d = \alpha_{i1} \frac{\sum_{g \in G^d} a_i^g / (LPG^g)^2}{\sum_{g \in G^d} a_i^g} + \alpha_{i2} + \varepsilon_i^d, \tag{1}$$

where α_{i1} and α_{i2} are the parameters to be estimated, a_i^g is the area of crop i at grid g and, ε_i^d an error term at commune level. Estimation is done by area-weighted least squares, with crop-specific a priori restrictions on signs. Resulting crop-specific parameters are shown in Table 8 of the Appendix. The table shows that several parameters were insignificant at the 0.01 level

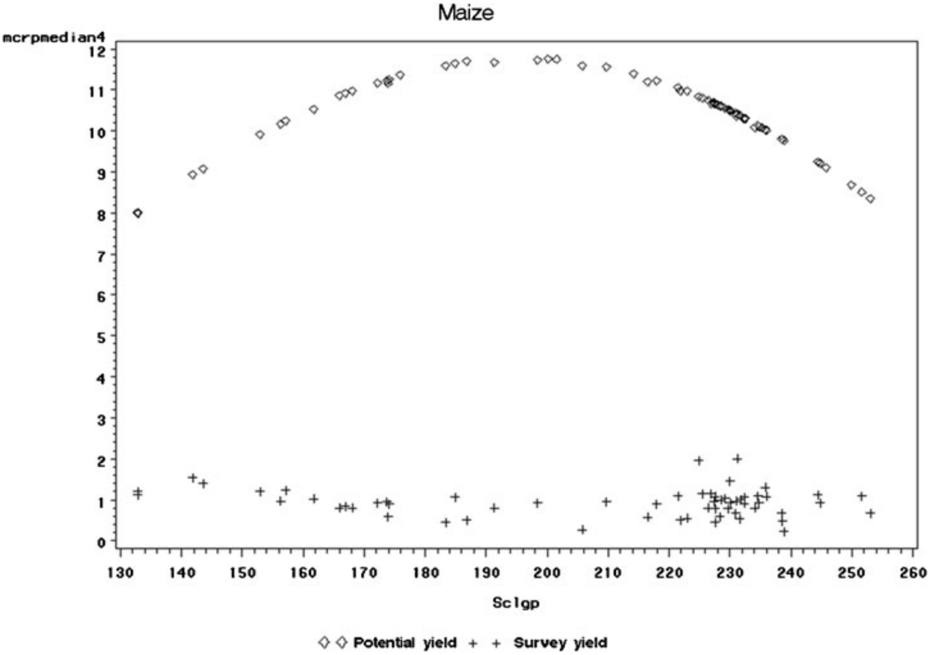


Fig. 4 Potential (diamond) and observed (plus) maize yield (t/ha) vs LGP

with low fits but the a priori bounds on signs were ineffective, except for the minor crops soybeans and sweet potato only. Moreover, fixed effects (commune-specific error terms, see (b) below) are maintained in simulation. The estimated functions will be used to describe the variation in yield under climate change conditions with respect to the base year.

3.3.2 Determine Fixed Effect at Commune Level $\left(\varepsilon_i^d\right)$

The deviation of the estimated yields from the observed value of the commune yield level is defined by:

$$\varepsilon_i^d = y_i^{d*} - y_i^d, \tag{2}$$

3.3.3 Apply Estimated Function with Fixed Effects for Prediction

As the yield functions underlying (1) are at grid level, assuming commune-level fixed effects, (2) and bounding yields between 0 and the yield potential $\overline{y}_i^d$, grid level yield can be computed as:

$$y_i^g = \max\Big(\rho_{ig}^f \max\Big(\Big(\min\Big(\alpha_{i1}/(LPG^g)^2 + \alpha_{i2}\Big), \overline{y}_i^d\Big), 0\Big) + \varepsilon_i^{d_g}, 0\Big), \tag{3}$$

where ρ_{ig}^f is the exogenous intensification factor initially set at unity. This factor is raised under policy simulations when input constraints are lifted to three intensity levels that were reported by the IPNIS - Integrated Plant Nutrition Information System[5] (FAO) for the

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[5] http://www.fao.org/landandwater/agll/ipnis/index.asp

prevailing Agro-ecological zones in Benin. In extreme years, the LGPs may fall below the range shown in the FAO table (FAO/IIASA 1993) and in this case crop yields are penalized through a reduction factor which is equal to the relative deviation of water constrained potential yield from its maximum $\overline{y}_i^g$under optimal LGP conditions.

3.4 From LGP to Crop Areas

The long term structural relationship that we formalize here refers to the adaptation of farmers to climate, and is established in a reduced form with climatic conditions as driving variable. A relationship is postulated between area share and LGP, to be estimated by cross section, and, similar to yield-LGP relationship (1). Also here we base our projections for the Basin on estimation for the Beninese territory as a whole so as to capture the variability under climatic change conditions for the ORB, distinguishing four components, as follows.

3.4.1 Area Share Functions, Estimated at Commune Level

Area share functions are specified at the grid-level and estimated after summation, at commune level.

$$k_i^d = \max\left(\beta_{1i} + \beta_{2i}\frac{\sum_{g\in G_d} LPG^g\theta_i^g}{\sum_{g\in G_d}\theta_i^g} + \beta_{3i}\frac{\sum_{g\in G_d}\left(LPG^g\right)^2\theta_i^g}{\sum_{g\in G_d}\theta_i^g}, 0\right), \tag{4}$$

where $k_i^d$is the fallow inclusive area ratio of crop i, with respect to a reference crop maize, β_{i1}, β_{i1}, .. are the parameters to be estimated; θ_i^g is the area cultivated as observed, where it is assumed that the numeraire crop (maize) has positive area at all g. The resulting crop-specific parameters are shown in Table 8 of the Appendix. Not all parameters were significant at the 0.01 level, yet, a priori bounds on signs were ineffective and the commune-specific error terms (see (b) below) are maintained in the simulation.

3.4.2 Determine Fixed Effect at Commune Level $\left(\varepsilon_i^d\right)$

The deviation of the estimated from the observed value of the relative area at commune level is:

$$\varepsilon_i^d = \frac{a_i^d}{a_{i*}^d} - k_i^d, \tag{5}$$

which has non-zero denominator because the numeraire crop is cultivated everywhere.

3.4.3 Apply Estimated Function with Fixed Effects for Prediction

The area functions (4) can also be used for prediction at grid level by:

$$\widehat{k}_i^g = \max\left(\delta_i^g \max\left(\beta_{1i} + \beta_{2i}LPG^g + \beta_{3i}\left(LPG^g\right)^2, 0\right) + \delta_i^g\varepsilon_i^{d_g}, 0\right), \tag{6}$$

where $\delta_i^g = 1$ if $\theta_i^g > 0$ and *0* otherwise. The maximum operator prevents negative area ratios and the error term $\left(\varepsilon_i^d\right)$ keeps the area ratios at observed level through location-specific effects.

3.4.4 Determine Crop Area at Grid Level

Finally, given the area ratios (4), the cultivated areas themselves can be computed as:

$$\widetilde{a}_{i*}^{g} = (1 - \varphi^{g}) \frac{\overline{a}^{g}}{\sum_{i \in I_g^*} \mu_i^g \widehat{k}_i^g + \mu_{i*}^{g}} \tag{7}$$

where μ_i^g is the inverse of the cropping factor, which refers to the number of times that a crop is cultivated in 1 year in the commune and $\overline{a}^g$ the fallow inclusive agricultural area for each grid cell and $I_g^* = \left\{ i | \delta_g^i = 1, i \neq i* \right\}$, and φ^g the rate of fallow. In the baseline simulation μ_i^g and φ^g are uniform for all agricultural land in a commune.

To exclude the possibility of spatial autocorrelation in the estimated relationships the error terms were tested using Moran's *I*, a weighted correlation coefficient that detects departures from spatial randomness. The test showed that the Moran's I value were close to zero, confirming that spatial autocorrelation was absent.

3.5 From Output to Prices

Because in this region farmers hardly purchase any fertilizers, pesticides or seeds, their income is well estimated by taking the product price × yield × area. Two price effects of LGP-change are distinguished, one at commune level and one at national level. The commune effect is due to a changed net selling position of farmers resulting from the impacts on yield and area. To represent it, market price is taken to be a function of the self-sufficiency ratio (supply over demand). The national effect is, on its part, attributable to overall scarcity and dependent on overall output, and will be more intense for bulky crops that are hardly traded internationally, such as roots and tubers, and for crops with low demand elasticity. The commune effect is estimated via a cross sectional estimation over communes for the year 2003 with price as function of the self-sufficiency ratio. Data on supply are derived from the above described commune statistics on crop production. Demand figures are obtained from regional Northern, Central and Southern consumption patterns derived from Ghana (Alderman and Higgins 1992) that were corrected for the national data of FAO Food Balance Sheets, thereby assuming consumption patterns in Benin to vary according to same three zones (Table 3).

Only price effects for crops that have domestic trade are estimated (bean, cassava, maize, potato, soya and yams) omitting those whose price is largely determined by foreign trade. Using a linear functional form we estimate for each crop,:

$$p_i^d = \alpha + \beta r_i^d, \tag{8}$$

where p_i^d refer to prices, r_i^d represents production/consumption ratios and α and β are parameters to be estimated (Appendix, Table 10). The estimated function is applied in the model as:

$$\widetilde{p}_i^d = \max\left(\left(\alpha + \beta r_i^d \right), 0 \right), \tag{9}$$

to obtain a fixed effect: $\eta_i^d = p_i^d - \widetilde{p}_i^d$. This fixed effect is used in the model to correct for commune specific conditions:

$$\widehat{p}_i^d = \max\left(\left(\alpha + \beta r_i^d \right), 0 \right) + \eta_i^d. \tag{10}$$

Table 3 Regional consumption patterns (in kg/caput) for 10 crops in Benin, year 2003

Crop	South	Centre	North
Bean	7.737	7.737	7.737
Cassava	170.895	164.169	101.81
Cotton	0.658	0.658	0.658
Maize	44.641	41.065	67.596
Peanuts	15.798	15.798	15.798
Potato	8.963	8.963	8.963
Rice	33.574	31.895	34.413
Sorghum	0.561	0.421	69.472
Soya	1.392	1.392	1.392
Yams	89.437	109.069	237.771

FAO Food Balance Sheets; Alderman and Higgins (1992); own calculations

Finally, overall scarcity of products at national level is accounted for by a priori specified price elasticities of demand (PAPA 2006. private communications). Combined, commune-level and national effects lead to a change in price per crop for each commune.

The DST that accommodates the basic data sets and estimated structural relationships of this study is now operational at the ‘Programme d’ Analyse de la Politique Agricole’ of the ‘Institut National de Recherche Agronomique du Benin’ in Porto Novo.

4 Scenario Formulation

In the previous section, a set of structural relations is developed to evaluate the impact of climate change on farmers’ per capita income at given soil moisture conditions, land use and levels of application of farm inputs. These are used to specify scenarios as packages of exogenous variables under climate change conditions. Each package stands for a set of interventions under climate change that aim to foster development in the ORB by (a) alleviating water constraints; this can be envisaged as being implemented through measures in the sphere of irrigation, water conservation and adapted tillage techniques, (b) better use of yield potential, where practical options would be an intensified application of agrochemicals to traditional cultivars, essentially to support a reduction of fallow, and of improved technology packages with hybrid seeds and modest doses of fertilizer, pesticides and herbicides and, finally, (c) expansion of the agricultural area, essentially through intensified settlement of farmers into the ORB rather than by mechanization. These scenarios are, specifically, implemented in the model by exogenous adjustments of:

a. LGP in the potential-to-actual yield relationship (1): alleviating water constraint;
b. factor ρ_{ig}^{f} in potential-to-actual yield relationship (1) of each crop *i*: alleviating input constraint;
c. reducing fallow rate φ^{g} and increasing the cropping factors μ_{i}^{g}
d. total cultivated area $\overline{a}^{g}$ in area allocation (5): expanding cultivated area.

Simulations are conducted for a period of 15 years under climate change as obtained from the ECHAM4 model (the base climate change scenario). Shocks on the ECHAM4 model will be used to mimic a larger variety of Climate Change options. The outcomes are compared to the results for the historical climatic period. The scenarios simulations to be reported on are listed in Table 4, in two groups: Agronomy-Water (AW) and Climate Change (CC).

Table 4 The scenarios

	Water				Agronomy						Climate change	
	Scenario	Zero[a]	Low[b]	Moderate[c]	Strong[d]	Zero[a]	Low[e]	Mod+fallow[f]	Mod.+intens. [g]	Strong[h]	Variance 1[l]	Variance 2[m]
{	AW1	×				×						
	AW2	×					×					
	AW3	×								×		
	AW4				×	×						
	AW5	×						×				
	AW6	×							×			
{	CC1	×				×					×	
	CC2	×				×						×

[a] Business As Usual

[b] Tillage techniques (+ 10 days)

[c] Water conservation (+ 20 days)

[d] Additional irrigation (+ 50 days)

[e] Adjustments in organic matter (+10%)

[f] Light fertilizer application (+20%) original fallow, increased yields

[g] Light fertilizer application (+20%) shorter fallow period, similar yields

[h] Modest fertilizer and hybrid seeds (+50%)

[i] Land use reference year 2003

[j] Expansion of land use with 50%

[k] Expansion of land use with 100%

[l] Alternative Climate Change Scenario: high variant

[m] Alternative Climate Change Scenario: low variant

The Table shows that rather than running all combinations, an effort was made to identify meaningful packages.

1. *Agronomy-Water.* Scenarios AW1-AW6 study how successful policy interventions could be under climate change conditions. The scenarios allow for adaptations in water and input supply using the land use of the reference year and the base climate change scenario. Specifically, Scenario AW1 is the Business As Usual (BAU) scenario as no interventions are planned, while AW2 and AW3 simulate increasing intensity of input supply while keeping water supply at Zero (base-level) intensity level; the AW4 scenarios raise the water supply at Strong intensity level without lifting input restrictions. Finally, the AW5 and AW6 interventions decrease the fallow period by 20 and 50%, respectively, by applying modest amounts of fertilizer to sustain the yield levels.
2. *Climate Change.* Scenarios Cc1 and Cc2 make use of outcomes from other climate change studies to test sensitivity relative to the ECHAM4 model. This leads to a decrease or increase of LGPs by 10%, respectively. Scenarios are run without any policy intervention and under average climate change conditions.

The next section reports on the results of the simulations, analyzing the effect of changes in yields, area shares and prices on rural per capita income as a measure of mean outcome. Moreover, the mean income shortfall beyond a threshold level is evaluated as a measure of serious risk for the food security situation[6] in the ORB (e.g. Leichenko and O'Brien 2002)

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[6] The threshold income level is based on the purchase of a daily of 2000 kcal, using a standard diet derived from FAO food balance sheets, this corresponds to an income of 0.6 USD per day based on PPP exchange rate

as maintenance of adequate stock supplies is deemed unwarranted after three decades of relatively stable patterns of sufficient rainfall and the low current transport capacity cannot guarantee the timely delivery of food aid in emergency situations. Both income level and income shortfall are expressed in US dollars on the basis of the purchasing power parity (PPP) [7] exchange rate.

The DST is used to evaluate the outcomes of the different scenarios as reported in the next section.

5 Results

The present section reports on the results of the scenario simulations. It starts with a detailed description of impacts and adaptation mechanisms as they come to bear in the Business as Usual (AW1) scenario. Next, follows the comparison of results from the different scenario variants.

To highlight the contribution of the three basic model components, yield, cultivated area and price, they will be activated in sequence, starting with the impact of climate change on crop yields, while keeping area shares and prices fixed at base year (2003) level in line with the traditional climate change impact studies that focus on yield impacts. Next, the area adaptation is allowed to enter, while maintaining the baseline prices. Finally, price adjustment comes in.

Yield Effect Under Climate Change In general, the LGP decreases throughout the ORB except for parts of the North, Mid-East and South, while more pronounced decreases are found in the Central South and North East. Using function (3), Fig. 5 shows for base year areas and prices, the impact of climate change on mean farm income (Map b) as compared to mean farm income for the same prices and areas but with the climate of the historical period (Map a). Dramatic income losses are found in the North East and Central part of the ORB where crop incomes were modest in the historical period. Less affected are the richer regions in the East and poorer regions in the West and South, while poorer regions in the North-West and South modestly benefit from the climate change. A comparison of the average crop revenues for the 10 crops under evaluation for the historical climate and under climatic change show the expected responses. Cotton, Groundnut and Sorghum benefit from the lower LGP's under climate change, while the drought prone tuber crops, Cassava and Yam, and cereals, Maize and Rice, are negatively affected. A modest decline occurs for the pulse crops, Soya and Beans, and, for Sweet Potato.

These are mean outcomes over 15 years sampled from the historical period and the future, respectively, in conformity with the common protocol of the Rivertwin project. Also Important are the shortfalls that measure changes in farmers' risk resulting from increased climatic variability. Figure 6 compares these shortfalls between future and historical period and shows that shortfalls rise both in absolute terms and in spatial extent. It is also noted that the frequency of occurrence of shortfalls, calculated as the number of sites where a shortfall occurs over the (15) years, increases from 23,000 over the historical period to 27,000 under climate change conditions.

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[7] A purchasing power parity (PPP) exchange rate equalizes the purchasing power of different currencies in their home countries for a given basket of goods

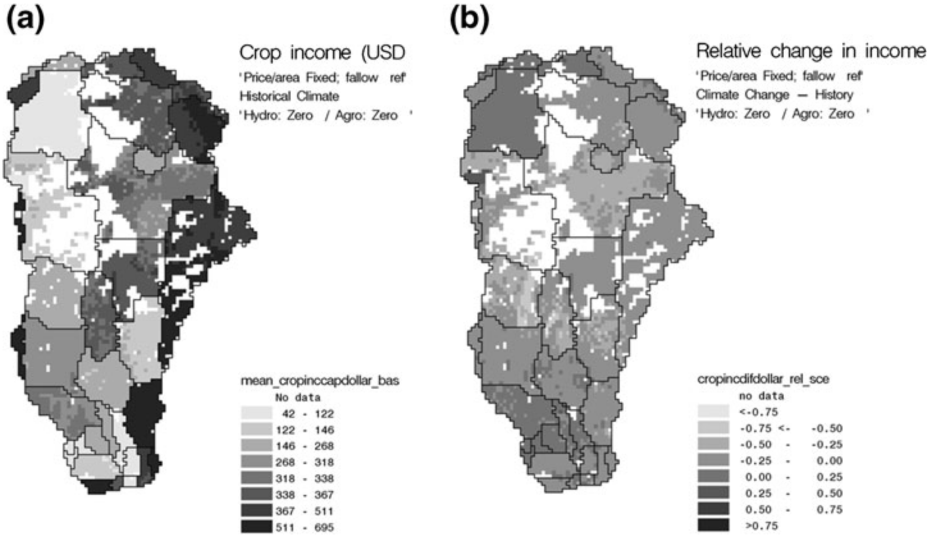

Fig. 5 **a** Crop income in USD per caput under historical climate and **b** relative changes in income under climate change

Adaptation of Cropping Patterns Next, still keeping only the prices constant in the base year, the adaptation in area shares (6) to changed LGP is allowed (6), with outcomes as shown in the bar chart of Fig. 7, while yields change as before. The chart indicates that Maize, Cassava and Yam become less dominant to the benefit of Cotton, Groundnut and Sorghum, while changes are less pronounced for Beans, Soya, Sweet Potato and Rice in absolute as well as in relative terms.

These adaptations in the cropping pattern make it possible for farmers to improve their per hectare revenues by 1 to 5%. Cash crops Cotton and Groundnut become more important

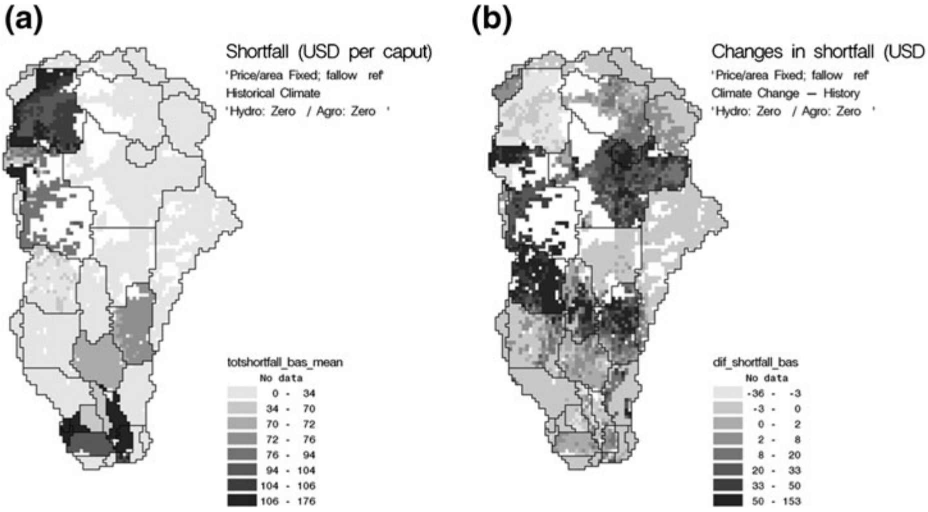

Fig. 6 Shortfall in USD per caput: **a** historical climate and **b** climate change

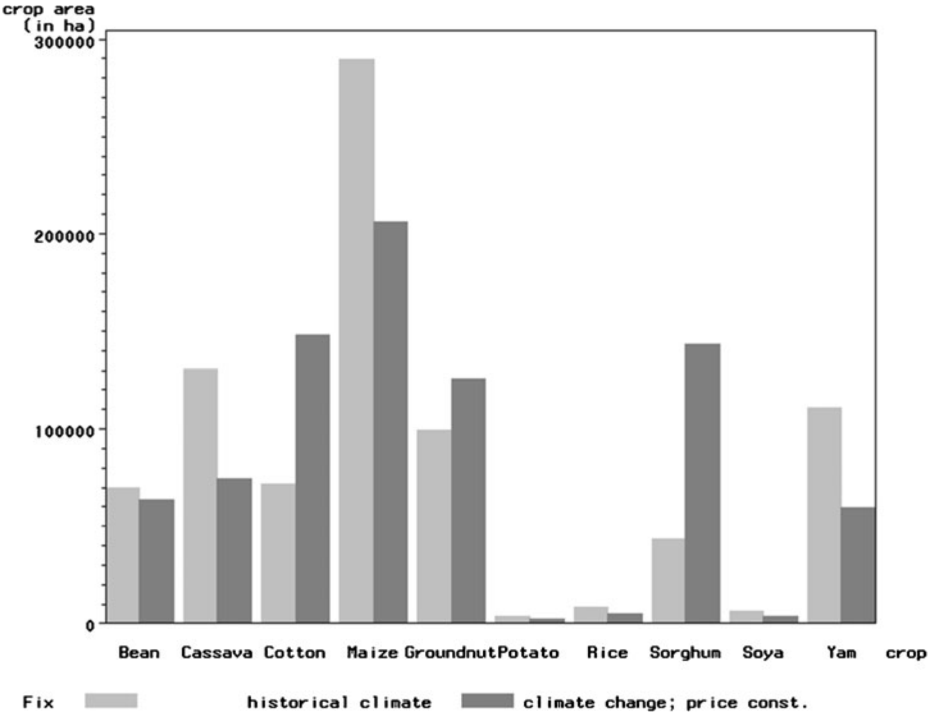

Fig. 7 Adaptation of cropping pattern

as they benefit from drier conditions. Sorghum acts as substitute for Maize and Cassava because of its higher drought resistance. For the other crops, the effect of area reduction dominates possible gains in crop revenues per hectare. The resilience of Sorghum, and more generally, its better adaptation to changing water availability is also reflected in a reduced income shortfall from 46 to 34 USD per caput, with a frequency of occurrence dropping from 28,000 to 20,000.

Price Effect The last step evaluates the price effect for crops that are mainly traded locally. The bar chart of Fig. 8 shows the aggregate effects on unit revenues. It appears that changes in revenues per ton partly compensates for the revenue losses for crops whose output is falling. The prices for Cotton, Groundnut and Rice remain constant by design as these largely depend on world market prices. The price of Sorghum is kept constant because it is traded widely in the Northern provinces of Benin and imported from neighbouring countries.

Table 5, which summarizes these aggregate results of the various stages, indicates that the last stage (2.c) of price adjustment raises income, and further reduces the shortfall to 32 USD per caput, because prices rise especially in bad years. Of course, this neglects the rise in the cost of living of the farmers concerned, and even more so for the non-farmers who are not considered in our study. Yet, it is concluded that with cropping pattern adaptation and price adjustments both the loss of income and the rise in income shortfall of the future period (2.c) relative to the historical period (1.a) are almost fully compensated for.

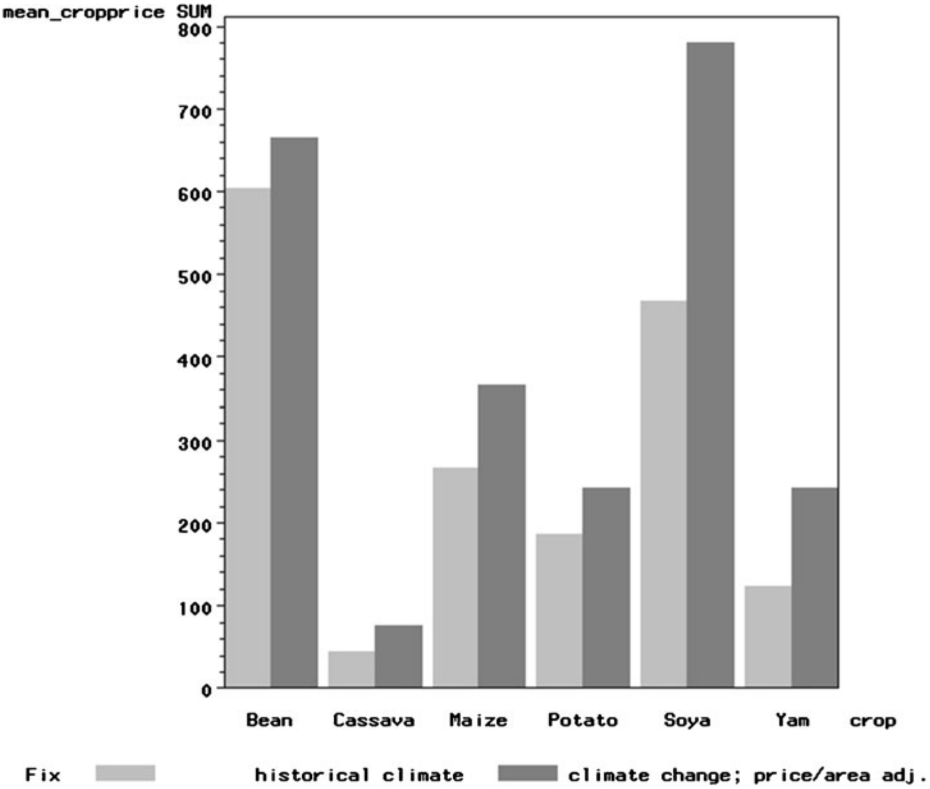

Fig. 8 Revenue per ton crop

6 Policy Interventions

After the analysis of the individual underlying mechanisms we now turn to the policy interventions. For a comparison of the results the BAU (also called AW1)-scenario is used

Table 5 Changes of total crop production, rural income and shortfall under climate change, decomposed for impact on yield, farmers' adjustments and price effects

	Crop revenue in USD	Crop revenue (USD per caput)	Shortfall	
			USD per caput	Total Frequency
1.a Historical climate (prices/area adjusted)	440,837,794	302	40	21,766
1.b Historical climate (price/area fixed)	382,444,707	262	45	24,093
2.a Climate change (price/area fixed)	341,094,546	233	56	29,873
2.b Climate change (price fixed)	362,259,872	248	47	24,123
2.c Climate change (price/area adjusted)	423,210,375	290	40	22,688

with area adjustments and price effects for past (1.a in Table 5) and future (2.c in Table 5), which henceforth also is referred to as ‘reference’.

Scenarios AW1-AW6 AW-scenarios concentrate on the effect of biophysical and hydrological interventions. Table 6 summarizes these results at aggregate level in tabular form. Scenario AW1 (2.c of Table 5) shows losses with respect to the historical period and drops approximately 12% from 441 to a 423 million USD. Figure 9 shows the outcomes of the AW1 and AW2 scenarios in comparison to BAU. The AW1 scenario shows modest income declines as the effects of area adjustments and prices do not fully compensate the yield decline. Increasing the level of agronomic inputs from zero to low shows an overall positive effect as incomes become higher in general, especially in the Southern and North-Western part of the ORB, where the effect is significant.

Higher input application is very beneficial: the Light intervention of scenario AW2 already fully compensates for the negative effect of climate change and results in a 17% increase to 518 million USD, while the Strong intervention of the AW3 scenario further increases total crop revenues with 67% to a 736 million USD. As expected all crops benefit from the increase in inputs. Cotton and Rice are particularly responsive, as they match the more favorable conditions under climate change. Maize and Beans also benefit but to a lesser extent and effects are modest for the other crops. The AW3 scenario increases the income levels further for the entire basin while shortfall drops considerably but as mentioned earlier, this is overoptimistic as it assumes that inputs are provided free of charge to the farmers.

More important is that shortfall indices show a steady decline with higher intensity levels as they drop from 40 (AW1) to 14 (AW3) USD per caput, with a reduction in frequency from 23,000 to only slightly over 4,000, respectively.

Table 6 also confirms that under the assumed irrigation at commune level, hydrological interventions, even at the Strong level, hardly contribute to crop production under the average conditions. This could be expected, on the basis of the important gap between actual and (water constrained) potential in Fig. 7. A remark on the actual specification of this scenario is now in order. It is supposed that the irrigation takes place at say, county level, in areas where the LGP drops below 150 days, irrespective of whether individual crops benefit from it. This is reflected in the crop composition, which shows that on average, cash crops (Cotton and Groundnuts) lose on importance under the AW4 scenario and are replaced by the less favorable tuber crops and cereals. If farmers could adjust water

Table 6 Changes of total crop production, rural income and shortfall for the AW scenarios

AW Scenarios	Crop revenue in USD	Crop revenue (USD per caput)	Shortfall	
			USD per caput	Total Frequency
AW1	423,210,375	290	40	22,688
AW2	518,534,009	355	29	18,408
AW3	735,831,517	504	14	4,128
AW4	425,492,770	291	40	22,409
AW5	548,017,397	375	23	12,557
AW6	727,769,553	498	15	4,653

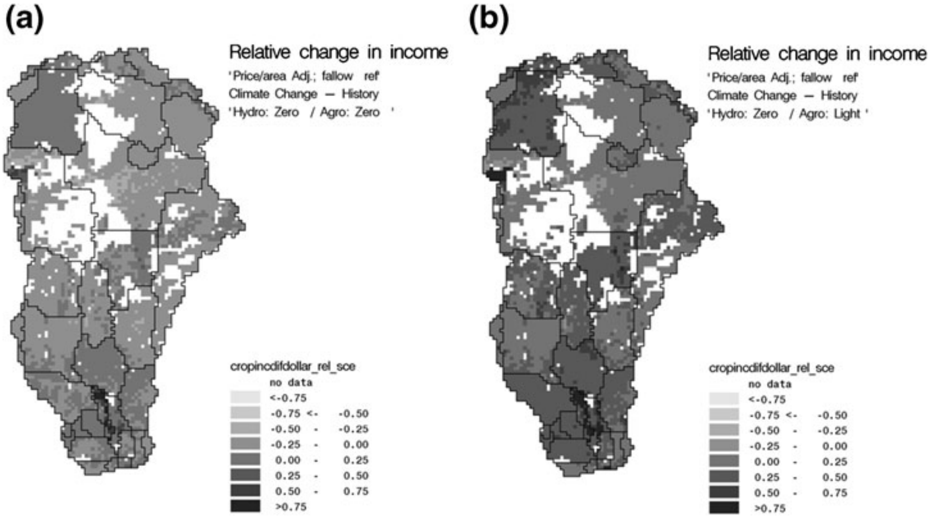

Fig. 9 Relative income changes under climate change for the AW1 (**a**) and AW2 (**b**) scenario

availability on an individual basis, this does not happen and cash crops could maintain their position.

Interestingly, a 20% reduction in the fallow period in the AW5 scenario already shows a better result of crop revenues than the Light increase in input of scenario AW2. Moreover, the shortfall is also more strongly reduced (23 as opposed to 29 USD per caput while frequency of occurrence reduces 13 as opposed to 18 000). The AW6 (50% reduction of the fallow) has an effect almost as marked as the Strong intervention level of scenario AW3. Finally, the AW5 and AW6 scenarios show that reduction of fallow is very effective. Large increases in income can be realized. Also here, the effect is exaggerated because the reduction requires significant increase in application of agrochemicals to maintain fertility and combat herbs and pests. Figure 10 shows the areas that benefit most from the 20% fallow reduction, particularly the municipalities (communes) Save, Bante and Djidja, where the fallow period is among the highest in the ORB. By the same token, areas where the fallow period is low, in Nigeria and the North Eastern areas, fallow reduction has limited effect.

It is concluded that the impact of climate change can be largely compensated by biophysical interventions and fallow reduction in the major part of the Basin. This corroborates our earlier assertion that low input farming is not necessarily very much affected by climate change and that a large growth potential remains untapped. The scenario of fallow reduction has the additional advantage in that it does not require farmers to increase their yields on the cultivated area and hence enables them to keep most of their practices, except that modest amounts of fertilizers and other agrochemicals will have to be applied. It might, therefore, be more attractive to farmers than intensification through introduction of hybrid seeds and a wide range of agrochemicals (scenarios AW2 and AW3). It is reiterated here that lowering of fallow periods more effectively uses the rainfall, which is largely left to evaporate on land kept fallow.

Be this as it may, it is noted that, irrespective of the intervention, per caput agricultural incomes remain low, varying from 0.8 (A1) to 1.4 USD per caput per day for the AW1 and AW4 scenarios, respectively. This confirms that traditional farming systems will not be able to eradicate poverty, climate change or not.

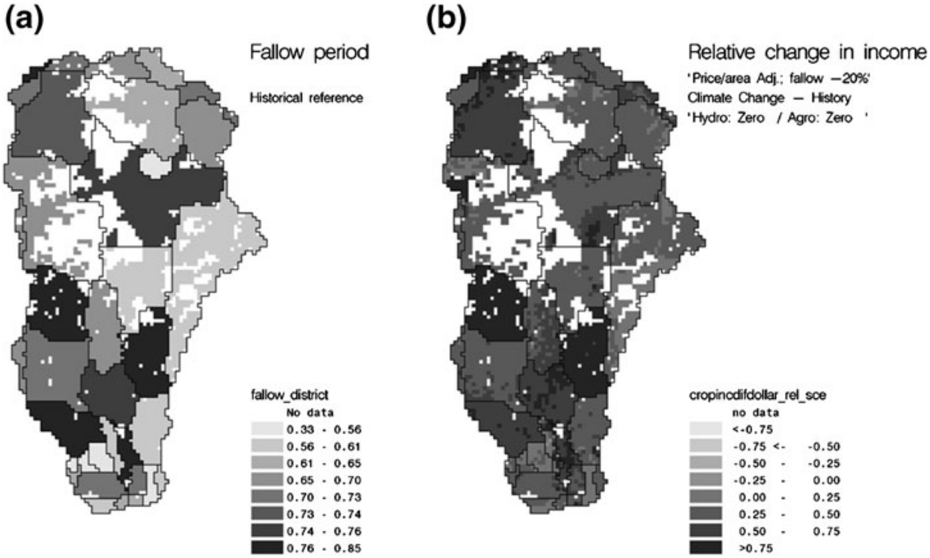

Fig. 10 Fallow period (**a**) and income changes (**b**) with respect to historical reference

7 Climate Change Scenarios

Finally, the findings that test the sensitivity relative to the ECHAM4 model are reported on the Climate Change scenarios Cc1 and Cc2. For this, shocks are applied to the climatic scenarios by an upward and a downward shift in LGP of 10%, with full adjustment of prices and areas. These shocks capture the variation between continental studies that use different GCM's (Thornton et al. 2006). Spatial patterns of relative changes in crop income and shortfall do not differ much from the patterns under scenario AW1. At aggregate level (Table 7) there is a small decline compared to AW1. Income and shortfall under the reduced LGP even shows a rise relative to the AW1 scenario, due to the positive response of Cotton in both yields and area shares. The scenarios with 10% higher LGP show slightly poorer outcomes than under the AW1 scenario. Yet, it is concluded that the results of our simulations do not critically depend on the used GCM.

8 Conclusion

Our main scientific contribution to the climate change research is the strengthening of the empirical basis to represent cropping conditions, farmers' adaptation and market effects

Table 7 Changes of total crop production, rural income and shortfall for the CC scenarios

AW Scenarios	Crop revenue in USD	Crop revenue (USD per caput)	Shortfall	
			USD per caput	Total Frequency
AW1	423,210,375	290	40	22,688
CC1	433,434,671	297	37	21,804
CC2	402,334,204	275	44	22,999

under climate change conditions by estimating structural relationships for the entire Beninese territory so as to simulate future conditions in the ORB proper that currently prevail in the drier North, and more humid South.

The main findings of the study are as follows. First, model simulations conducted for two 15 year periods from the periods 1980–2003 and 2004–2030, respectively, show that reduced rainfall and increased rainfall variability that generally emerge under climate change have very different effects on various crops. For remunerative staples such as Maize and Yam the yields fall on average, with more frequent crop failures under drought conditions, whereas for Cotton, the most rewarding cash crop, and for Groundnut, yield improves on average. Second, in response to these changed conditions, farmers can adapt their cropping pattern, and it appears that expansion of Cotton and Sorghum at the expense of Maize and Yam in many parts of the region compensate to a great extent for the revenue loss due to climate change. Third, once price adjustments in response to changed scarcities of local crops are accounted for the losses are reduced further. Fourth, losses can turn into gains once fallow is reduced through application of modest amounts of fertilizer. This a promising option for agricultural intensification as this requires few adjustments in prevailing farming practices, exploits the potential of uncultivated land and improves the water use efficiency. Indeed, reduction of fallow also has important policy implications as it is key to maintain the Oueme River Basin’s capacity to absorb foreseen migration fluxes, from adjacent areas that are more affected by climate change conditions, notably, the drier North and more humid South. Fifth, beyond reduction of fallow, orientation on cash crops, yield improvement and where possible, intensification of livestock could be the next step that creates opportunities for delivery to more affluent markets in the adjacent regions in Nigeria and the coastal areas of Benin. Sixth, as securing food supply under increasing shortfalls and organization of other public services, like access to clean water (Keyzer et al. 2007), requires coordination at higher levels than the individual. It is ultimately good local governance that largely determines success of settlement policies in the rural areas. Overall, our conclusions are less pessimistic compared to, for example, Höllermann et al. (2010) as we accounted for farmers' adaptation mechanisms and market price adjustments that largely compensate for negative future climate change effects.

Finally, successful development of the Basin cannot rely on agricultural development alone and future growth, in fact, largely depends on success of urbanization (e.g. WDR 2009; Venables 2010). Even though the income position of the rural population can remain stable under climate change and even improve somewhat if the above mentioned fallow reduction and intensification take place, elimination of poverty can only be achieved through large scale introduction of cash crops and expansion of livestock production, using export possibilities to the richer neighboring Nigeria, jointly with expansion of agricultural processing, transport and trade in the urban area.

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Appendix

Table 8 Parameter estimates for the yield-LGP function

Crops	$\alpha 1$	$\alpha 1$
Bean	−1728.37	0.551013*
Cassava	−283756.00	17.353390*
Cotton	22724.05*	
Maize	−19070.70	1.279507*
Groundnut	28644.35*	
Sweet Potato	0.00	3.393013*
Rice	−12553.10	1.811457*
Sorghum	17673.82*	
Soya beans	0.00	0.645163*
Yam	−168164.00*	14.285870*

Significant at the 0.01 level

Table 9 Parameter estimates for the crop area share function

Crops	B1	β2	β3
Bean	1.453082	−0.00735	9.74E-06
Cassava	−2.49922	0.024908	−0.00005
Cotton	11.80437[a]	−0.0845[a]	0.00015[a]
Groundnut	8.661198[a]	−0.06825[a]	0.000136[a]
Sweet Potato	−0.12632	0.001514	−3.44E-06
Rice	0.302652	0.000854	−7.47E-06
Sorghum	19.79401[a]	−0.15866[a]	0.000315[a]
Soya beans	−0.27421	0.002988	−7.05E-06
Yam	−4.82014	0.057509	−0.00014[a]

[a] Significance at the 0.1 level

Table 10 Estimated parameters of the price function

Crop	α	B
Bean	5.58561[a]	−0.0426[a]
Cassava	4.91142[a]	−0.0163[a]
Maize	4.51735[a]	−0.0066
Sweet Potato	4.75900[a]	−0.0189
Soya beans	5.52053[a]	−0.0184[a]
Yam	4.84764[a]	−0.0506[a]

[a] Significance at the 0.01 level

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