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Chapter 1

Potential Impacts of Agricultural Intensification and Climate Change on the Livelihoods of Farmers in Nioro, Senegal, West Africa

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Introduction

Agriculture is the mainstay of the economy of Senegal as in most countries in Sub-Saharan Africa. The Senegalese agricultural sector employs nearly 60% of the active population but contributed only 12.7% to GDP in 2019, a sign of the low productivity of the sector (ANSD, 2020). The major factors constraining productivity are poor soil fertility, overreliance on rainfed agriculture, and low inputs. As a result, Senegal is a food-deficit country in spite of the political stability it enjoys. Coverage rates of its cereal needs through domestic production have varied between 30% and 65% over the past 10 years. The gap is usually filled through imports of rice, wheat, and maize (ANSD, 2016). The incidence of income poverty remains high despite policies that have been implemented over the last decade. The poverty rate has decreased from 55.2% in 2001–2002 to 46.7% in 2011. Poverty is more pronounced in rural areas with an incidence of 57.1% compared to 26.1% in Dakar and 41.2% in other cities (République du Sénégal, 2014).

With most countries of sub-Saharan Africa highly dependent on rainfed agriculture, another environmental stress factor that is projected to impact crop production is climate change (Adiku *et al.*, 2015). Addressing expected agricultural challenges calls for the implementation of sustainable intensification strategies that will enhance crop yields, offset the projected negative impacts of climate change and thereby improve smallholder farmers, livelihoods.

Results from climate change impact studies in the region have been varied, largely in terms of the magnitude of impact, from almost no impact to up to 60% yield losses (Sultan *et al.*, 2013; Faye *et al.*, 2018; Traore *et al.*, 2017). The variability in these results stem from differences in methodologies, timescales, crops studied, and climate scenarios, as well as inherent uncertainties in global climate models (GCMs) used.

This study was conducted in Nioro du Rip, Senegal (Fig. 1), characterized as a semi-arid agro-ecological zone (Adiku *et al.*, 2015). A number of climate change impact studies on agriculture have been done in the sub-region (Sultan *et al.*, 2013; Traore *et al.*, 2017; Freduah *et al.*, 2019). To our knowledge, very limited studies have integrated climate, crops, and socio-economic models to estimate the impact of potential climate change on the livelihoods of smallholder farmers. We applied an innovative approach that uses multiple crop models and an economic model to simulate climate change impacts for multiple farms with data coming from socio-economic surveys of smallholder farmers in the Nioro area. Stakeholders were engaged to discuss and refine current intervention packages and co-develop representative agricultural pathways (RAPs) needed to characterize the future conditions, as well as the potential future adaptation packages.

The specific research questions answered by this study are: (i) what is the sensitivity of current agricultural production systems to climate change (ii) what are the benefits of interventions on current agricultural systems; (iii) what are the impacts of climate change on future agricultural production systems, and (iv) what are the benefits of climate change adaptations?

Description of the investigated farming system

Agriculture in Nioro is dominated by smallholder farmers (with farm sizes ranging from 1 to 2 ha), engaged in cereals (millet, maize, and sorghum) and legume

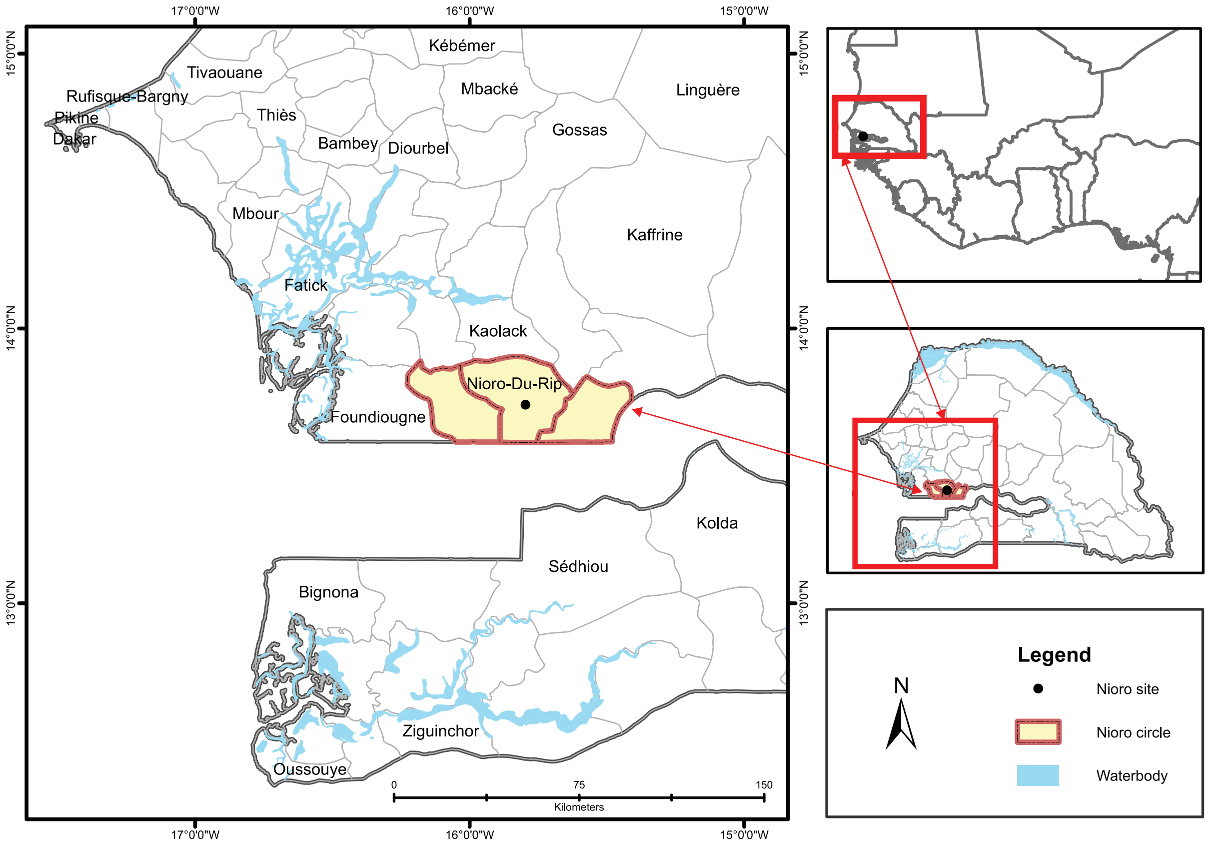


Fig. 1. Location of the study site.

cropping (mostly peanut and cowpea). Nioro falls within Senegal's central peanut basin, established since the early twentieth century as an oil production hotspot by the colonial power. Since the production peak in the early 1970s, peanut remains the dominant cash crop in the area. Livestock also plays a significant role in the functioning of the overall farming system through its dependence on crop residues as feed and provision of manure to the crops. The use of manure for cereal farming is limited to the homestead. Farming is characterized by low inputs, dependence on rainfed water resources, and poor soils. Agriculture in the study area is dominated by millet, peanuts, sorghum and cowpea often grown in an annual cereal-legumes rotation. Maize is also cultivated, typically closer to homesteads, but to a lesser extent. The duration of Fallow is on the decline due to population pressure and increasing land scarcity. Few farmers apply mineral fertilizers as they lack ready access to credit and agro-inputs. As a result, average yields of cereals and legumes are low.

In Senegal, where rainfed agriculture dominates, agro-climatic risks are notably linked to failed sowings, untimely cessation of the growing season, and water stress in the post-flowering and grain-filling stages (mostly terminal drought). Annual rainfall in Nioro ranged between 418 and 1035 mm with a mean of 725 mm over the 30-year baseline period (1981–2019). The growing season begins in May and extends through to September/October; there are six to seven months of dry season every year. Observed climate trends show a sharp increase in maximum temperature and slight increases in minimum temperature and annual rainfall amount. The minimum and maximum temperatures over this period are 19.2°C and 40.4°C, respectively. The annual rainfall amount is characterized by high inter-annual variability that influences crop productivity and farmer livelihoods. The increase in minimum temperature tends to decrease the diurnal temperature range, which is known to have significant impacts on crop development and agricultural productivity (Ly *et al.*, 2013).

Key Decisions and Stakeholder Interactions

Stakeholder engagement

Measuring the impact of climate change on future production systems requires knowledge of the plausible trajectories of agriculture in the coming decades and associated changes to current systems. To identify these changes, we engaged different stakeholders at different scales in an iterative process. A meeting was organized by experts from the Initiative Prospective Agricole et Rurale (IPAR) to kick-start the RAPs development process. The session was initiated by a presentation of preliminary and contextual information related to the AgMIP research questions and definition of key concepts: representative concentration pathways (RCPs), shared socio-economic pathways (SSPs), and RAPs, and a discussion of SSP narratives. Also discussed were the potential intervention packages needed to improve crop productivity under the current climate.

A second meeting was held in Nioro du Rip to develop two RAPs, a Sustainable Development pathway (SDP) and Fossil Fuel Development (FFD) pathway. The second session was centred on discussion of identifying RAP elements and the direction and magnitude in which each one of them will change under each RAP. Participants included experts in agriculture, livestock, horticulture, extension specialists, farm leaders, NGO representatives, and elected officials. During the meeting, we developed the SDP RAP and the FFD RAP based on the AgMIP protocols (see Appendix 1 in this Volume).

A stakeholder engagement meeting was also organized to share results for Nioro. The CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS) platform provided support through information and invitation to its members. About 40 stakeholders attended the event, including government technical services staff and policy makers. The entire engagement with stakeholders is illustrated in Fig. 2.

A high-level policy dialogue with parliamentarians and policy makers of the Senegalese agricultural sector was then held to discuss the agricultural pathways underlined in the SDP RAP and the FFD RAP. The theme of the dialogue was "Climate Change and Senegalese Agricultural Pathways: Implications for Public Policy". Another high-level stakeholder engagement was organized in Dakar to share and discuss results from the AgMIP Phase II regional integrated assessment (RIA). Stakeholders included government representatives, civil society organizations, international organizations (FAO, IFPRI), the National Committee on Climate Change (COMNACC), members of Parliament, representatives of farmers' organizations, think tanks, and research organizations.

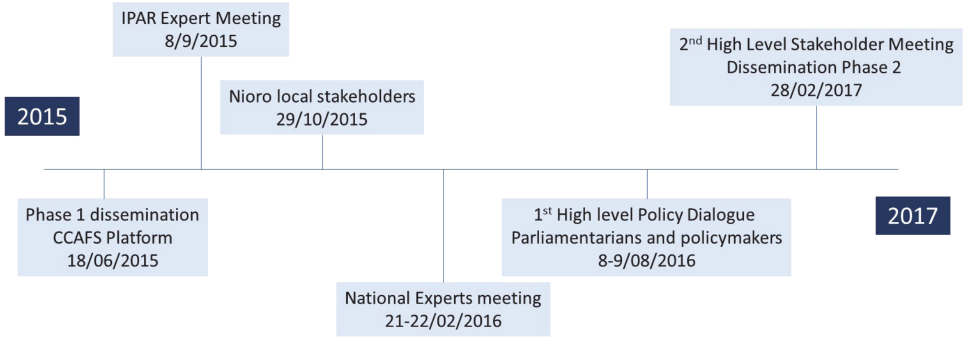


Fig. 2. Timeline of stakeholder meetings.

Representative Agricultural Pathway (RAP) narratives

For our study, two contrasting agricultural development pathways were considered; Sustainable Development Pathway (SDP) (RAP 4) and Fossil Fuel Development (FFD) Pathway (RAP 5).

RAP 4: Sustainable development — taking the green road

Inclusive approaches in public policies are implemented alongside significant development of community initiatives and greater accountability of grassroots organizations. **Good agro-ecological practices are mainstreamed** leading to **a gradual improvement of soil fertility, in particular with better integration of crop-livestock production systems**. The use of water storage technologies and better management induce **increased availability and access to water**.

Decentralization policies are fully implemented in a context of **improved human and social capital**. Development of **infrastructure**, greater access to **Information and Communication Technology (ICT)**, and the process of **urbanization** put some **stress on labour availability**, in particular for on-farm activities. Social and economic processes generate **household segmentation**[1] along with greater labour demand for off-farm income.

RAP 5: Fossil fuel development

Population growth and rapid urbanization lead policy makers to further develop infrastructure and rapidly raise agricultural productivity. **The agricultural sector is a policy priority** and must respond quickly to increased demand particularly from urban dwellers. **Input subsidies, development of road networks, and the revitalization of the peanut basin** are key interventions. These policies and interventions are fulfilled without proper application of good and environmentally friendly agricultural practices, thus contributing to **soil degradation and unsustainable use of water resources**. Herd size and livestock productivity rise as a result of improved political support to the sector, better health protection programs, greater urban demand, and the determination of pastoralists to seize these market opportunities.

The development of the digital economy, mechanization of agriculture, and a strong energy demand exert a powerful influence on rural activities. **Household size decreases along with fragmented farms**.[2] Stronger and better road networks increase employment opportunities outside agriculture.

[1] For instance, households break up into several smaller entities often with the disappearance of the patriarch.
[2] Farm size decreases mainly due to the redistribution of land to the siblings through inheritance.

Adaptation packages

Intervention packages constitute practices that can be implemented under current climate to intensify the production system. Adaptation packages are practices which when adopted under climate change conditions will reduce the negative impact of climate change. The intervention and adaptation packages were co-generated with stakeholders for improving productivity under current climate and future climate, respectively.

Intervention packages under current climate

We tested two intervention packages: (i) Management intervention and (ii) Management intervention plus improved (genetically) varieties. Management intervention involved increasing plant population. For maize, this increased from 4 plants m^{-2} to 5.5 plants m^{-2} coupled with 30 kg N ha^{-1} fertilizer applied in addition to what each farmer applied in the survey year. For millet, plant population was increased from 2 plants m^{-2} to 3 plants m^{-2} coupled with 15 kg N ha^{-1} per farmer. The inorganic fertilizers were applied in 3 instead of 2 splits. For peanut, plant population density was increased from 10 to 20 plants m^{-2}. On the policy/socioeconomic side, government subsidized fertilizer costs to farmers for maize and millet from 50 to 70%. There was also additional cost of fertilizer applied to millet and maize along with the labor cost associated.

The second intervention package was driven by improved seeds with high genetic potential in addition to the improved management practices (included in Intervention Package 1). For the cereals (maize and millet), the photothermal time from emergence to end juvenile stage was reduced by 20% and the difference added to the photothermal time from flowering to maturity. The maximum kernel number G2 (in maize) and scaler for partitioning of assimilated to the panicle head (in millet) were increased by 20%. In peanut, the maximum fraction of daily growth that is partitioned to seed + shell (XFRT) was increased by 20%. In addition to the policy/socioeconomic parameters in package 1, this package included costs of seed per ha for all three crops.

Adaptation package under future climate

The adaptation strategy used to withstand weather conditions under climate change scenarios was a virtual heat-tolerant variety of each of the three crops. This adaptation allows for higher tolerance to increased temperature. For maize and millet, the time from flowering to maturity was increased by 10% to make up for reduction in phenology due to temperature stress. For peanut, the time between first seed (R5) and physiological maturity was increased. Additionally, the planting window under current climate was narrowed for the future climate.

Data and Methods of Study

Climate

Agro-climatic characteristics of West African agriculture

Nioro, Senegal is situated in an arid agro-ecological zone and has an average annual rainfall of 741 mm. Mean annual minimum and maximum temperatures are 20°C and 35°C, respectively. The rainfall season is unimodal, with the onset of the rains occurring in agricultural areas from May to July and ending in September–October. The temporal distribution of temperature is typically bimodal with one maximum in April–May and another one in October. Climate risks and hazards affect crop production in most parts of the region where rainfed agriculture dominates. Agro-climatic risks are notably linked to false starts of sowing, untimely cessation of the growing season, and water stress in the post-flowering and grain-filling stages. The seasonal distribution of rainfall could be affected by a warming climate, with expected increase in rainfall variability and frequency of extreme events impacting agricultural productivity.

The agro-climatic characteristics are then used to evaluate the sensitivity of crop productivity and to find the most suitable climate index to explain crop yields in the different years.

Figure 3 shows the dynamics in the onset and cessation dates of rains over a 30-year period in Nioro. In some cases, a later rain cessation date led to an expanded growing season with positive benefits to the crops. However, the same amount of rainfall can be spread out over a longer time with long dry spells occurring during the reproductive stage of crops. This occurred in 2007, which was characterized in the farmer survey as a bad year in terms of rainfall variability. The 2007 rainy season started on June 18, which is not too late compared to climatology (June 23). The rainy season ended towards October 28, 2007 vs. October 26 on average. In 2007, there was a long dry spell of 13 days just after the onset of the cropping period, which might have negatively impacted the seedlings at their early development stage. Towards the end of the cropping period, 17 days of dry spell occurred again, which also had negative impacts on the crop at the critical reproductive stage.

Projected change in rainfall and temperature

The selection of five GCMs per site, according to the AgMIP protocol, characterizes different projected climates for the region (Ruane and McDermid, 2017).

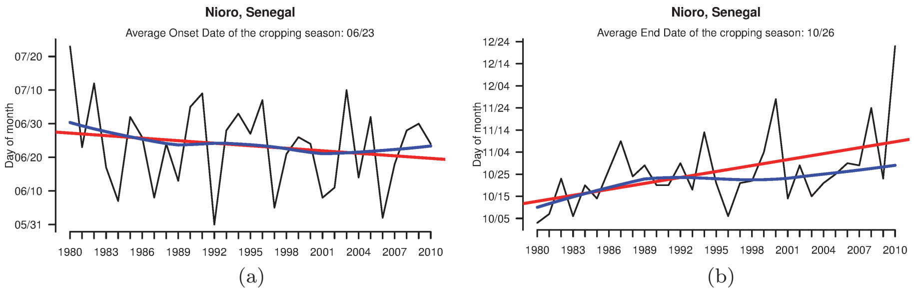


Fig. 3. Evolution of the onset date (a) and the cessation date (b) in the cropping season at the Nioro (Senegal) site from 1980 to 2010. The red line is the linear trend in the full time series while the blue line is the smoothed function that fits the evolution of the datasets. The criteria were developed for the West Africa region based on the annual climate outlook forum (PRESASS in French) and adapted from Sivakumar (1990).

Table 1. Selected GCMs for Nioro, Senegal according to the AgMIP protocol.

Emission Scenario	Level of Emissions	Cool/Wet	Hot/Wet	Middle	Cool/Dry	Hot/Dry
RCP 8.5	High	GFDL-ESM2	GISS-E2-H	BNU-ESM	CESM1-BGC	CMCC-CM
RCP 4.5	Medium	GFDL-ESM2	GISS-E2-H	bcc-csm1-1	MRI-CGCM3	IPSL-CM5B-LR

A scatterplot combining temperature and precipitation change relative to the 30-year baseline is plotted to determine, in terms of tendency, models being hot/dry, hot/wet, cool/wet, cool/dry, and/or in the middle of the different projections for RCP 4.5 and RCP 8.5. Once the GCMs were selected, some additional analysis were conducted to ensure that the models also capture the main West African climate features that might help to better interpret variability or model-specific bias. For detailed interpretation of the validity in selecting the GCMs, see Ruane and McDermid (2017). The list of GCMs selected for this study is given in Table 1.

Future climate scenarios

A significance test was done to assess the projected change in rainfall and temperature at the study site using the AgMIP criterion (Ruane and McDermid, 2017). Figure 4 shows monthly ΔT and ΔP for the cool/wet, cool/dry, middle, hot/wet, and hot/dry scenarios (e.g., average temperatures for the baseline and each of the five GCMs at the study location). The results show that the five selected GCMs predict a significant change in monthly total rainfall especially during the rainiest months. In general, all 29 GCMs tend to simulate higher rainfall with a large variance, specifically during the rainiest months. Most of the studies on the impact of climate on West African crops have shown that total annual or seasonal rainfall amounts do not

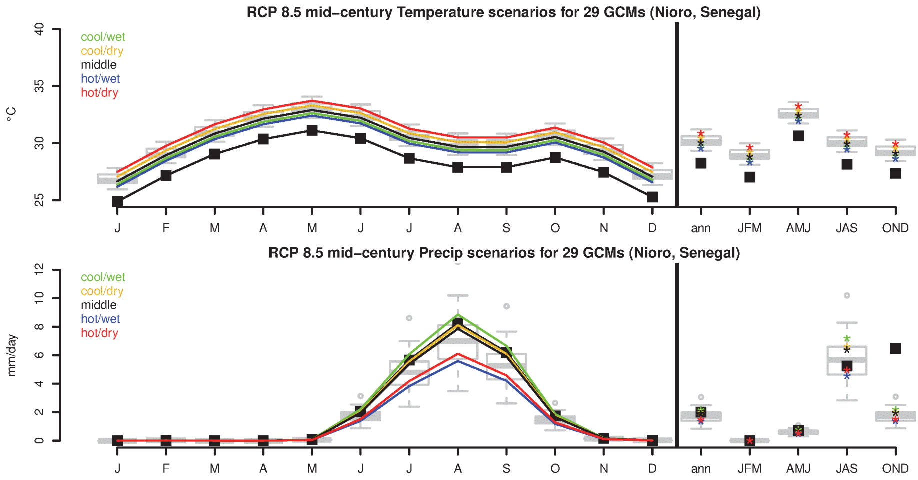


Fig. 4. Projected changes in the average monthly mean rainfall in Nioro, Senegal of 29 GCMs. The black curve with squares represents the average values for the 30-year baseline period (1981–2010) and the colors represent the five *representative GCMs selected following* the AgMIP protocol.

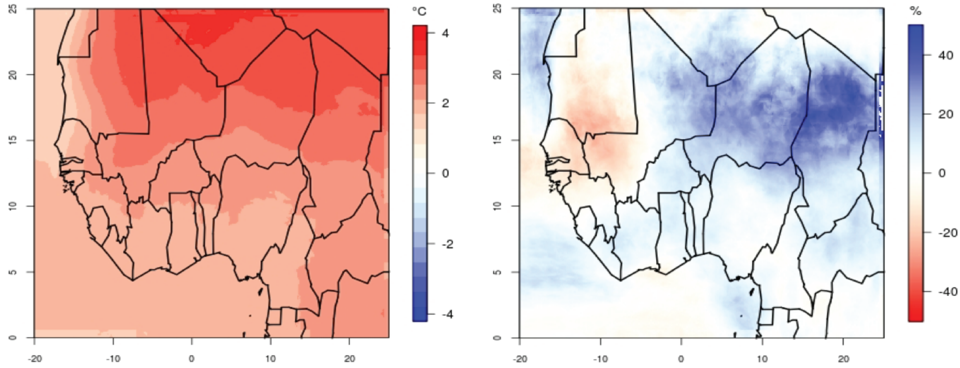


Fig. 5. Expected average change (from 29 GCMs) in JJAS temperature and precipitation in West Africa (RCP 8.5) — Mid Century time slice (2040–2069).

explain a large part of their variability. Instead, one needs to define more accurate rainfall parameters that describe the seasonal and intra-seasonal variability of the monsoon.

The expected average change in temperature and precipitation during the main months of the rainy season (from June to September) relative to the baseline period 1981–2010 was evaluated from 29 GCMs. Overall in the region, according to the RCP 8.5 scenario, temperatures are expected to increase in the future by 2°C. For precipitation, the changes are variable: a decrease by about 20% is expected in the western part of the region, while an increase of about 30% is expected inland and towards the eastern part of the region (Fig. 5).

Crops

Crop yields and crop management information on millet, maize, and peanut were collected from the World Bank household survey data (WLD, 2008), which served as input data for the crop models. A total of 225 households were covered: 219 cultivated peanut, 221 cultivated millet, and 98 cultivated maize. Data collected include observed yields and crop management (sowing date, time, and amount of fertilizer/manure applied). Data on cultivar information were obtained from literature (MacCarthy *et al.*, 2009, 2010; Akponikpè *et al.*, 2010; Naab *et al.*, 2004; Dzotsi *et al.*, 2003). Weather data used were those described in the climate section. Simulation of crop yields was done using two of the most commonly used crop models in the sub region; DSSAT (Hoogenboom *et al.*, 2019) and APSIM (Keating *et al.*, 2003).

Economics

The socio-economic data for Nioro comprise a sample of 225 farm households from the World Bank RuralStruc Household Survey data 2007–2008. These farm households were partitioned into four strata based on maize and livestock production: (i) non-maize with livestock; (ii) non-maize without livestock; (iii) maize with livestock; and (iv) maize without livestock. Table 2 presents the descriptive statistics of the socio-economic data by strata.

To conduct the economic analysis, we used the TOA-MD model (Antle and Valdivia, 2014) to assess the impacts of climate change and adaptation on farmers' livelihoods (e.g., vulnerability, farm income, poverty rates, etc.).

Integrated Assessment Results

Core Question 1: What is the sensitivity of current agricultural production systems to climate change?

Maize

Simulated average yields under current climate were 934 and 617 kg ha^{-1} for DSSAT and APSIM, respectively. Maize yields simulated under RCP 4.5 for the five GCMs ranged from 682 to 803 kg ha^{-1} using DSSAT and from 593 to 654 kg ha^{-1} using APSIM. These resulted in yield reductions of between 7% and 27% for DSSAT; relative to the baseline; yield reductions for APSIM were 3 and 6% for two GCMs, while the other three GCMs projected yield increases of between 3 and 11% under RCP 4.5. With RCP 8.5, grain yields ranged between 553 and 828 kg ha^{-1} for DSSAT and from 588 to 646 kg ha^{-1} for APSIM. These resulted in yield changes of between −33% and −9% for DSSAT, relative to the baseline, while APSIM

Table 2. Summary statistics by strata.

Socio-economic Indicators	Unit	N	Mean	Std	CV	Minimum	Maximum
Strata 1 — No maize with livestock							
Household size	Persons	41	11.63	6.16	52.94	4	39
Farm size	Ha	41	8.29	4.53	54.60	2	21.02
Herd size	UBT	41	2.17	5.80	267.65	0	37.1
Off-farm income	XOF	41	543451	844930	155.47	0	4650000
Strata 2 — No maize & no livestock							
Household size	Persons	91	11.27	4.53	40.18	3	30
Farm size	Ha	91	7.96	5.98	75.16	1	35.98
Herd size[a]	UBT	66	1.00	0.89	88.69	0.15	3.95
Off-farm income	XOF	91	520806	638394	122.58	0	378000
Strata 3 — Maize with livestock							
Household size	Persons	45	13.09	6.00	45.86	3	26
Farm size	Ha	45	9.60	4.82	50.25	3	23.5
Herd size	UBT	45	6.86	11.16	162.60	0	47.7
Off-farm income	XOF	45	730418	701888	96.09	0	2399000
Strata 4 — Maize & no livestock							
Household size	Persons	48	13.10	6.71	51.19	3	30
Farm size	Ha	48	9.60	4.61	48.00	1.5	26.1
Herd size	UBT	40	2.42	2.92	120.52	0.15	14.3
Off-farm income	XOF	48	490854	529565	107.89	0	2665000

Note: [a]For Strata 2 and 4, herd size is not zero but there is no production of milk or meat or live animals.

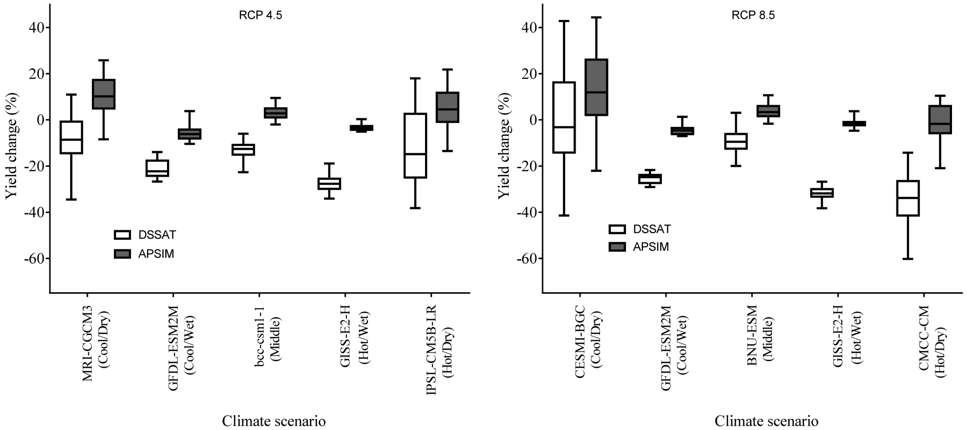


Fig. 6. Climate change impact on maize productivity simulated by two crop models, DSSAT and APSIM, under current management systems in Nioro, Senegal.

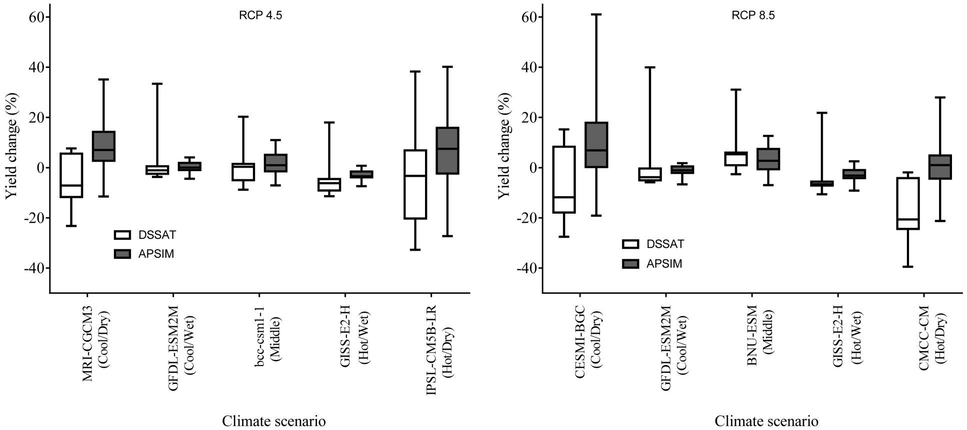


Fig. 7. Climate change impact on millet grain productivity simulated by two crop models, DSSAT and APSIM, under current management systems in Nioro, Senegal.

simulated yield changes of −5% and −2% for two GCMs and yield increments of between 4% to 14% for the remaining three GCMs. Thus, projections by APSIM were generally less negative compared to those of DSSAT (Fig. 6), mainly because of the differences in temperature threshold used by the two crop models. Additionally, while APSIM responds to water and nutrient stress by extending the crop duration to physiological maturity, maize phenology in DSSAT is not sensitive to these stresses. Thus, the growth durations of the crops varied under the two models.

Millet

Simulated average yield of millet in Nioro under current climate was 586 kg ha^{-1}. Yields for future climate scenarios ranged from 526 to 593 kg ha^{-1} for DSSAT under RCP 4.5 and from 468 to 611 kg ha^{-1} under RCP 8.5. These represent yield changes of between −6% and +1% for RCP 4.5 and between −16% and +5% for RCP 8.5. Average yield simulated by APSIM under current climate was 446 kg ha^{-1}, while the GCM-simulated yields ranged from 431 to 466 kg ha^{-1} under RCP 4.5 and from 430 to 461 kg ha^{-1} under RCP 8.5. Thus, millet yields changed from between −3% and +9% under RCP 4.5 and between −3% and −1% for the two wet scenarios and between +1% and +11% for the remaining three scenarios under RCP 8.5. Simulated variations in climate change impact among farms by both crop models were higher in the wet climate scenarios, while the dry scenarios had lower variation among farms. As with maize, the magnitude and direction of yield changes were not always the same for the two crop models (Fig. 7). Additionally, the magnitudes of impact on millet were less than that for maize, confirming millet as more robust to climate change (Faye *et al.*, 2018).

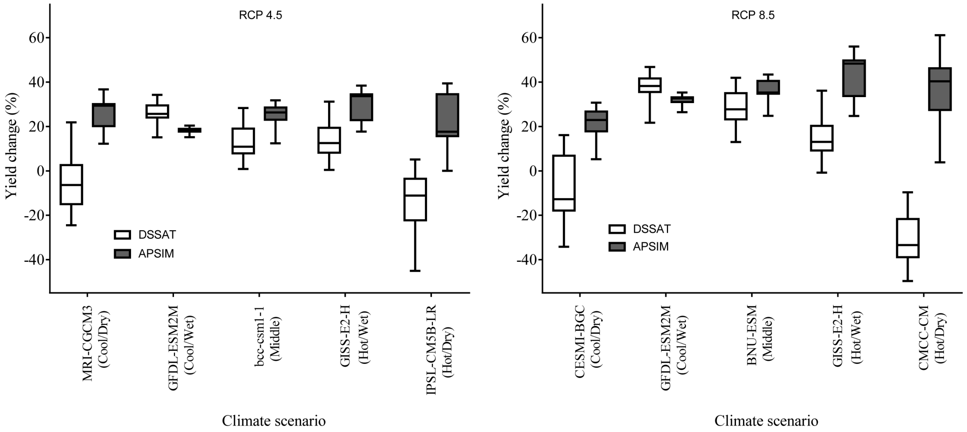


Fig. 8. Simulated climate change impact on peanut grain yield by two crop models, DSSAT and APSIM, under current production systems in Nioro, Senegal.

Peanut

Simulated average yields of peanut at Nioro under current climate were 665 and 645 kg ha^{-1} for DSSAT and APSIM, respectively. For DSSAT, simulated average yields across GCMs ranged between 568 and 829 kg ha^{-1} under RCP 4.5 and between 437 and 905 kg ha^{-1} under RCP 8.5. Percentage yield changes ranged from −11% to +26% under RCP 4.5 and from −7% to +39% for RCP 8.5, relative to the baseline. With APSIM, simulated average yields ranged from 762 to 826 kg ha^{-1} under RCP 4.5 and from 772 to 908 kg ha^{-1} under RCP 8.5. Thus, future average GCM-simulated yields increased by between 18% and 30% under RCP 4.5 and between 22% and 44% under RCP 8.5.

Simulated peanut yield changes were generally positive (Fig. 8). Unlike the maize and millet cereals, peanut is a C3 plant and hence, has a higher response to CO_2 fertilization. Additionally, its yield is not limited by N stress and thus they benefited from CO_2 fertilization. Furthermore, about 40% of yield increases in peanut for Nioro can be attributed to higher projected rainfall compared to the current climate.

Household vulnerability to climate change

Vulnerability is defined here as the proportion of farms that are at a risk of losing income from climate change. The TOA-MD results show that the percentage of vulnerable farms varies between 24% and 59% across GCMs, RCPs, and crop models. Under DSSAT, the dry scenarios displayed the highest vulnerability to

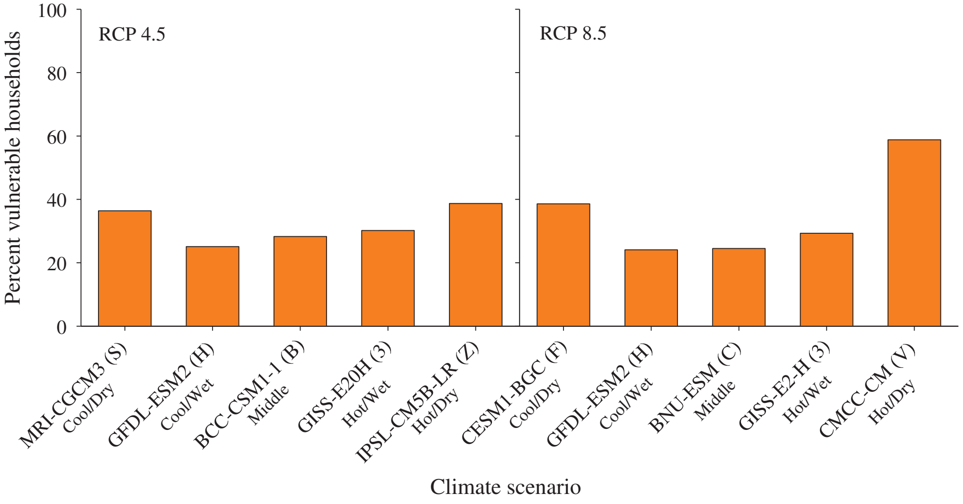


Fig. 9. Percentage of farm households vulnerable to climate change estimated with the TOA-MD regional economic model based on a crop model (DSSAT) simulation under RCPs 4.5 and 8.5.

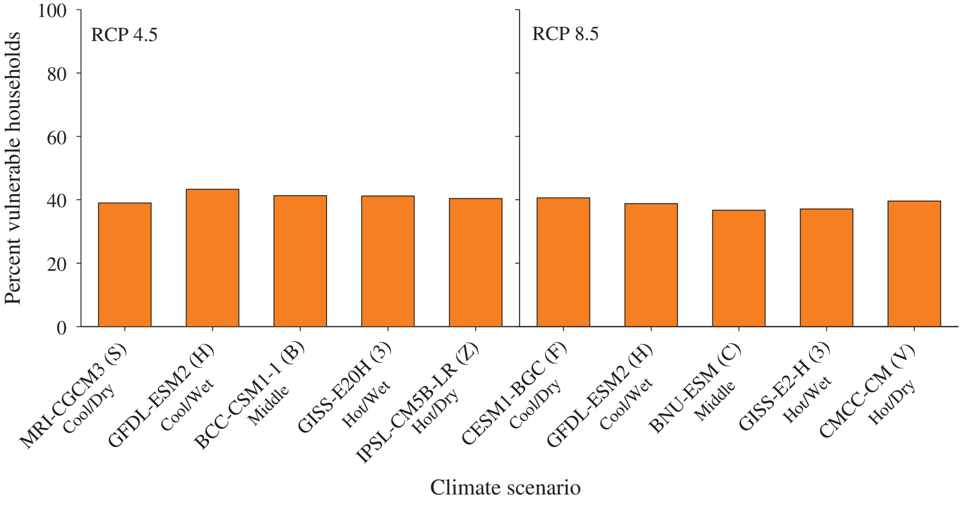


Fig. 10. Percentage of farm households vulnerable to climate change estimated with the TOA-MD regional economic model based on a crop model (APSIM) simulation under RCPs 4.5 and 8.5.

climate change, with the hot/dry scenarios recording the highest level of vulnerability (Fig. 9). The lowest values were recorded for the cool/wet and middle scenarios. There was more variation in projected household vulnerability with crop yield changes projected by DSSAT. Under APSIM simulations, variability across GCMs was marginal (Fig. 10).

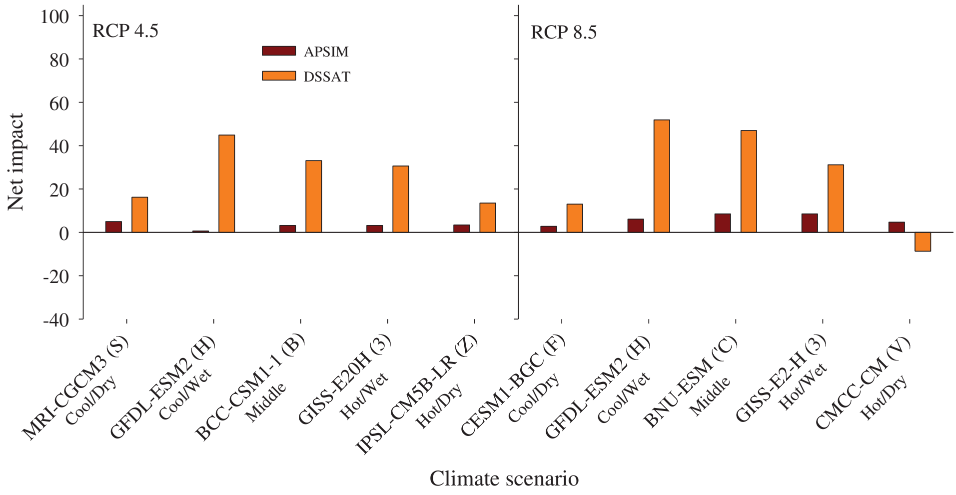


Fig. 11. Net economic impacts as a percent of mean net farm returns estimated by TOA-MD regional economic model based on simulations from two crop models (DSSAT and APSIM) under RCP 4.5 and RCP 8.5.

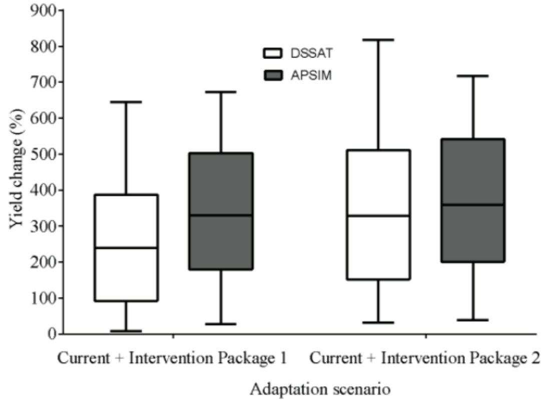
Net economic impacts as a percent of mean net farm returns

The hot/dry scenario in RCP 8.5 under DSSAT displayed a 9% decrease in mean net farm income, while other dry scenarios had small positive impact, ranging between 13% and 16% of mean net farm returns. In contrast, the cool/wet and middle scenarios generated large positive impacts varying between 31% and 52% of mean farm net returns. Using APSIM, net economic impacts as a percent of mean net farm returns were positive but marginal across all scenarios, ranging from 1% to 8% (Fig. 11). The dry climate scenarios were characterized by reduction in rainfall amounts and events resulting in higher moisture stress compared to the wet scenarios.

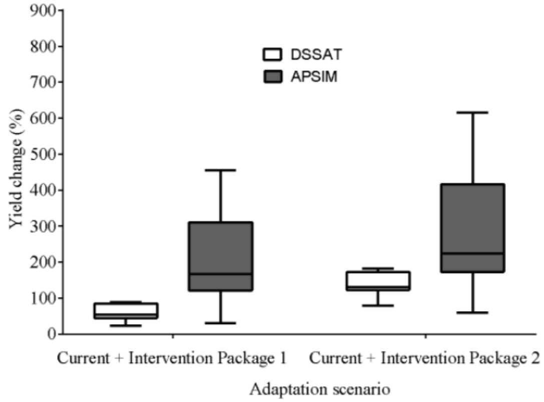
Core Question 2: What are the benefits of adaptation in current agricultural systems?

Maize

Simulated maize yields under current climate and management practices in Nioro were 934 and 617 kg ha^{-1} for DSSAT and APSIM crop models, respectively, while yields of 2214 and 1961 kg ha^{-1} were simulated using DSSAT and APSIM, respectively, under improved management practices (increased fertilizer amount, number of split applications, and plant population). These resulted in maize yield increases of 261% and 343% using DSSAT and APSIM, respectively (Fig. 12). When a virtual cultivar with improved genetics (20% shorter juvenile stage and 20% longer reproductive stage) was used in addition to improved management practices, simulated



(a)



(b)

Fig. 12. Yield gains for adopting intervention packages on (a) maize and (b) millet under the current climate at Nioro, Senegal. Intervention Package 1 is improved management practices (increased fertilizer amount, number of applications, and plant population). Intervention Package 2 includes a genetically modified variety in addition to the management practices in Intervention Package 1.

grain yields increased to 2778 and 2090 kg ha^{-1}, representing yield increases of 351% and 372% for DSSAT and APSIM crop models, respectively, compared to the yields obtained under current management (Fig. 12a).

Given that we are in low input systems with a very large yield gap, any improvement in the agronomic practice will result in significant yield increases. Similar yield responses have been reported by other studies in environments similar to Nioro (Naab *et al.*, 2015; MacCarthy *et al.*, 2009).

Millet

Simulated millet yields in Nioro were significantly enhanced under both the management intervention (increased fertilizer amount, number of split application by one, and plant population) and the intervention with the genetic adaptation package (shortening juvenile stage by 20% and extending reproductive stage by the same magnitude) (Fig. 12b). Under the management intervention, millet yields of 896 and 1107 kg ha^{-1} compared to baseline yields of 585 and 445 kg ha^{-1} were simulated using DSSAT and APSIM models, respectively. With the genetically improved cultivar, average yields increased to 1345 and 1384 kg ha^{-1} for DSSAT and APSIM, respectively. The use of interventions reduced grain yield variability among farms. Yield variabilities of 37% and 13% were simulated with the management intervention and between 39% and 15% were simulated with genetic adaptation compared to between 50% and 57% simulated under current management practices.

Peanut

Simulated average yields under current management practices were 665 and 645 kg ha^{-1} for DSSAT and APSIM, respectively. With increases in plant population (from 10 to 20 plants/m^2), peanut yields increased by 27% for DSSAT and 18% for APSIM (Fig. 13). Further yield increases were simulated when genetic improvement (harvest index increased by 20%) was coupled with increased plant population. Simulated average yields of 929 and 784 kg ha^{-1} were simulated for DSSAT and APSIM, respectively, with yield gains of 43% and 22%. Variability in yield was reduced with the management adaptation from baseline values of 45% and

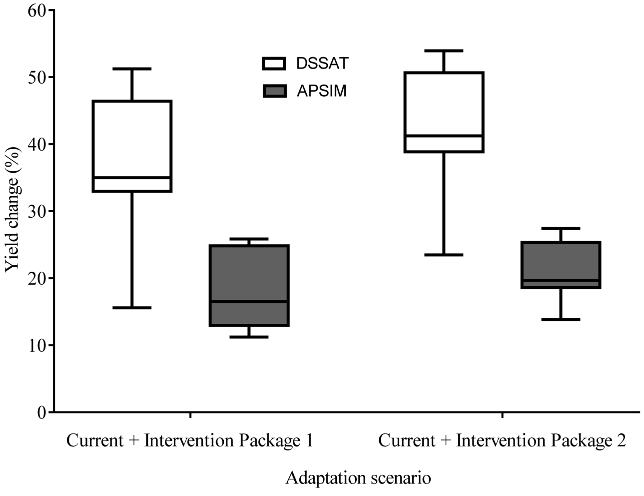


Fig. 13. Peanut grain yield changes under two intervention packages for peanut production at Nioro, Senegal. Intervention package 1 is improved management practices (increased plant population). Intervention package 2 includes genetically modified variety in addition to increased plant population as in intervention package 1.

41% to 37% and 38% with improved management practices, and to 39% and 42% with the addition of genetic improvements for DSSAT and APSIM, respectively.

Economic analysis

With the APSIM simulations, the first intervention package displayed a high adoption rate of 83%. Percent change in net farm returns increased between 63% and 81% (Table 3), while percent change in per capita income (PCI) ranged between 33% and 43%. Large drops in poverty rates were observed within a range of between 21% and 27%. When comparing the two intervention packages, adding new varieties did not lead to significant increase in additional adopters (from 82.6% to 84.5%).

In contrast, the estimation based on DSSAT simulations displayed greater differences in the economic outcomes of the two intervention packages. For instance, the adoption rate for the first intervention package was 72%, while the second package had 82% adopters (Table 3). Percent change in mean farm net returns was 37% from the first intervention and 66% from the second package. Percent change in PCI on aggregate was 20% with Intervention Package 1 and 35% with Intervention Package 2. Finally, in terms of percent change in poverty, the first intervention package generated a 12% drop in poverty and the second intervention yields a decrease of 23%.

Overall, the TOA-MD estimations on the impact of the intervention packages based on APSIM and DSSAT simulations in the current climate led to the following conclusions:

- Intervention Package 1, which comprised increased fertilizer and improved crop management including appropriate plant population density and split fertilizer applications, yielded higher returns, resulting in a simulated higher level of adoption.
- Adding an improved variety to the package brings additional gain in yield and economic return. However, the largest proportion of additional gains came from changes in agronomic management. Assuming there were no differences in the

Table 3. Economic results simulated from two intervention packages (APSIM and DSSAT).

Adaptation Package	**Simulated adoption Rate (%)**	**Net Returns without Adaptation (FCFA)**	**Net Returns with Adaptation (FCFA)**	**Per Capita Income without Adaptation (FCFA)**	**Per Capita Income with Adaptation (FCFA)**	**Poverty without Adaptation (%)**	**Poverty with Adaptation (%)**
APSIM A1	83	676,683	1,100,624	124,745	166,335	83	65
APSIM A2	85	676,697	1,224,541	124,747	178,502	83	60
DSSAT A1	72	676,662	929,650	124,743	149,543	83	73
DSSAT A2	82	677,846	1,127,261	124,862	168,958	83	64

opportunity costs of package 1 vs. package 2, the latter would attract more adopters than the former.

Considering the costs and time associated with crop improvement, and the fact that higher yields and returns can readily be achieved from increased fertilization rate and planting densities, this analysis suggests that in the short term, policies that favor smallholders access to current technologies (fertilizer and seed) are key to reduce yield gaps and poverty.

Core Question 3: What is the impact of climate change on future agricultural production systems?

To represent future agricultural production systems, we included in the two aforementioned Representative Agricultural Pathways biophysical and socio-economic indicators that stakeholders identified as likely to change in future production systems. These indicators were used to re-parameterize the crop and the TOA-MD models. The crop management practices used were the intervention packages in Q2 in addition to modifications to the soil profile and organic carbon in the top soil. Amount of fertilizer applied was stratified based on the amount applied in the baseline survey. For the Sustainable (Fossil Fuel) Development Pathways, 10, 30 and 40 kg N ha^{-1} (20, 30 and 60 kg N ha^{-1}) were respectively applied to farmers who applied 0, less than 15 and more than 15 kg N ha^{-1} in the baseline survey. Under the SDP, soil depth and organic carbon were maintained while under the FFD pathway, soil depth was reduced by 20% as a way to approximate losses in soil and organic carbon.

Maize

The average future yields of maize assuming no climate change under the SDP and the FFD Pathway were 2165 and 2484 kg ha^{-1} for DSSAT and 1544 and 1749 kg ha^{-1} for APSIM, under the SDP and FFD, respectively. Applying climate change under the SDP, maize grain yields for DSSAT ranged from 1136 to 2484 kg ha^{-1}, while yields for APSIM ranged from 1537 to 1749 kg ha^{-1}. Climate change impact under the SDP resulted in maize yield changes of between −29% and −19% for DSSAT and between −5% and −2% under three climate scenarios, and up to +3% in the other two for APSIM (Table 4).

Applying climate change under the FFD pathway, average simulated maize yields across GCMs ranged from 1136 to 2484 kg ha^{-1} for DSSAT and between 1537 and 1749 kg ha^{-1} for APSIM. Considering the FFD, DSSAT projected greater yield declines than APSIM. Maize yield reductions were between 20% and 52% using DSSAT, while for APSIM yield reductions were between 1% and 9% (Table 4).

The variability in simulated yields under current climate with SDP and FFD were 38% and 51% for DSSAT, and 50% and 60% for APSIM, respectively. Yield variability under future climate scenarios ranged between 43% and 55% under SDP

Table 4. Projected climate change impacts on yield of maize, millet, and peanut in Nioro, Senegal under two contrasting RAPs (SDP: Sustainable Development Pathway and FFD: Fossil Fuel Development Pathway) using DSSAT and APSIM.

Climate Scenario	**Description**	**Maize % Δ**		**Millet % Δ**		**Peanut % Δ**	
		DSSAT	**APSIM**	**DSSAT**	**APSIM**	**DSSAT**	**APSIM**
Sustainable Development Pathway							
GFDL-ESM2M	cool/wet	−18.8 (3.9)	−2.9 (1.6)	1.0 (6.0)	−3.1 (1.3)	26.4 (4.4)	17.6 (1.6)
MRI-CGCM3	cool/dry	−19.6 (7.7)	3.1 (4.3)	−8.5 (5.9)	−3.7 (3.2)	−4.9 (13.4)	28.4 (6.7)
bcc-csm1-1	middle	−18.6 (1.9)	0.6 (2.0)	−3.0 (4.5)	−4.3 (1.7)	14.8 (8.5)	25.6 (4.4)
GISS-E2-H	hot/wet	−28.9 (3.7)	−2.4 (1.3)	−5.6 (3.7)	−6.1 (1.7)	17.4 (9.6)	30.5 (6.6)
IPSL-CM5B-LR	hot/dry	−25.3 (10)	−5.2 (5.6)	−10.5 (14.7)	−8.7 (6.7)	−12.9 (11.4)	22.3 (12)
Fossil Fuel Development Pathway							
GFDL-ESM2M	cool/wet	−29.3 (3.0)	−1.9 (1.0)	3.6 (10.5)	−6.9 (1.8)	34.5 (5.4)	29.9 (1.4)
CESMI-BGC	cool/dry	−25.8 (11.8)	−5.8 (8.4)	−15.3 (6.6)	−17.1 (4.7)	−22.4 (10)	17.1 (5.4)
BNU-ESM	middle	−19.8 (2.9)	−0.7 (1.4)	4.2 (7.9)	−6.8 (1.4)	24.1 (6.9)	33.3 (3.3)
GISS-E2-H	hot/wet	−38.2 (2.7)	−1.4 (1.6)	−5.4 (7.8)	−10.5 (1.8)	11.4 (9.6)	39.0 (7.1)
CMCC-CM	hot/dry	−52.3 (5.7)	−9.4 (6.8)	−24.8 (5.8)	−18.9 (3.2)	−39.8 (9.4)	28.9 (10.9)

Note: Standard deviation of %Δ is in parentheses.

and between 24% and 41% under FFD pathway using DSSAT, while those simulated for APSIM ranged between 55% and 60% under SDP and 37% and 49% under FFD. Climate change thus reverses yield variability outcomes between the two RAPs, making it higher under SDP compared to FFD pathway.

Millet

Simulated future millet yields in Nioro assuming no climate change under the SDP and the FFD Pathway using DSSAT were 1210 and 1304 kg ha^{-1}, while those simulated by APSIM were 1192 and 1508 kg ha^{-1}, respectively. Simulated yields for the future climate under SDP ranged from 1038 to 1175 kg ha^{-1} for DSSAT and from 1081 to 1192 kg ha^{-1} for APSIM across climate scenarios. Thus, climate change under SDP resulted in yield declines under 4 climate scenarios and a marginal yield gain (about 1%) for one climate scenario using DSSAT and yields declined by between −9% and 3% using APSIM model compared to the respective yields under current climate. Yield changes of between −25% and −5% for three climate scenarios and +4% for two climate scenarios relative to the 30-year baseline were simulated by DSSAT whereas with APSIM, yield changes were between −19% and −7% under climate change with FFD (Table 4).

Peanut

Projected average peanut yield assuming no climate change under SDP and FFD Pathway were 826 and 788 kg ha^{-1} for DSSAT and 731 and 716 kg ha^{-1} for APSIM, respectively. Simulated future peanut yields under SDP ranged from 699 to 1030 kg ha^{-1} for DSSAT and from 857 to 937 kg ha^{-1} for APSIM. For DSSAT, all SDP yields under climate scenarios were higher than the yields obtained assuming no climate change except for the relative dry climate scenarios (Table 4). The dry scenarios under DSSAT projected 15% and 5% yield reduction, while yield gains of between 17% and 26% were projected for the other climate scenarios. For APSIM, yield increases of between 18% and 31% were simulated (Table 4). Under the FFD Pathway, yields under future climate scenarios were generally higher than those under current climate with FFD pathway. Peanut yields ranged from 455 to 1046 kg ha^{-1} with DSSAT, which represented yield gains of between 11% and 35% under three climate scenarios, and yield reductions of 22% and 40% under the two dry climate scenarios (Table 1). For APSIM, yields ranged from 826 to 980 kg ha^{-1} representing yield gains of between 17% and 29%.

Household vulnerability to climate change

The impact of climate change on future systems takes into account sensitivity to prices. The price sensitivity analysis assumes a "high price range" based on the global

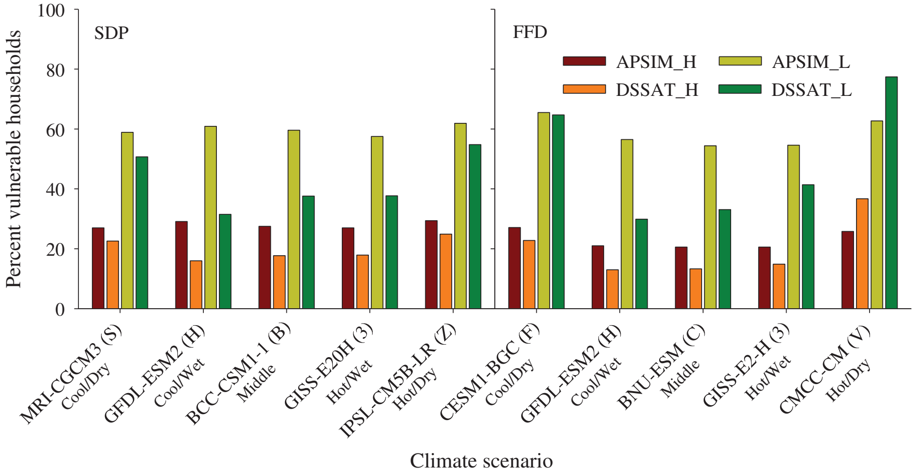


Fig. 14. Percent vulnerable households under high (H) and low (L) prices, 5 climate scenarios, 2 crop models (DSSAT and APSIM) and 2 Representative Agricultural Pathways (Sustainable Development Pathway: SDP and Fossil Fuel Driven Development Pathway: FFD).

economic model projections (IMPACT; Robinson *et al.*, 2015) with and without climate change. Likewise, for the "low price range", the assumptions are that (i) current prices are equal to future prices with no climate change, and (ii) the low price under climate change is set to be 10% lower than the price without climate change.[3]

Under the high price scenario, the percentage of vulnerable farms varied between 13% and 37% across GCMs, development pathway, and crop models. The lowest vulnerability is recorded for the wet and middle scenarios. The hot/dry scenario for FFD presents the highest level of farm vulnerability under DSSAT. Under APSIM simulations, the vulnerability level of farm households were very low across climate scenarios. In future farming systems, the level of farm vulnerability dropped strongly under the high price scenario. The results obtained under the low price scenario showed a high level of vulnerability. Indeed, the percent of vulnerable households varied between 30% and 77%. In general, vulnerabilities were higher for the dry scenarios and lower for the middle and wet scenarios (Fig. 14).

Net economic impacts as a percent of mean net farm returns

Under future agricultural systems and the high price scenario, climate change produced high positive net economic impacts on farmers' livelihoods under both SDP

[3]The initial assumptions under the low price scenario were as follows: (i) current prices are equal to future prices with no climate change; and (ii) deviation of prices with climate change relative to no climate change prices is the same for high and low prices. Consequently, the relative price (or the deviation range from the "no climate change" to the "with climate change" case) is estimated and used to predict future price with climate change. But compared to results under the high price scenario, there was not much difference in the economic outcomes. Hence, we modified the assumptions.

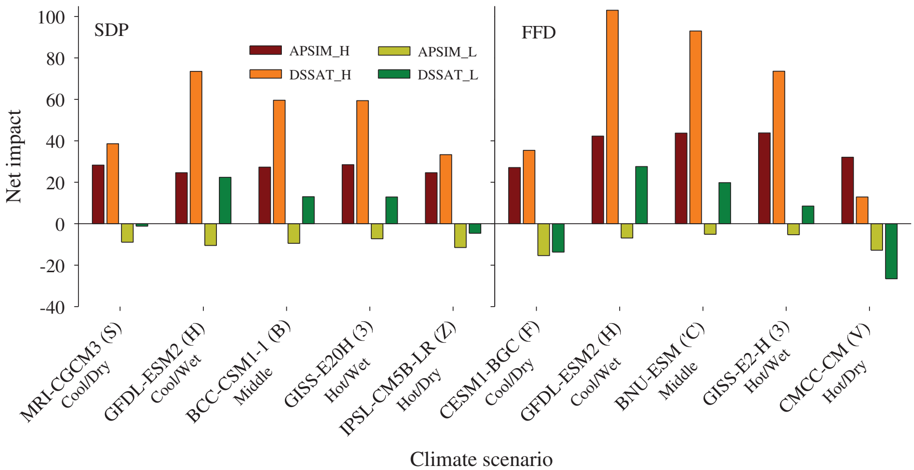


Fig. 15. Net economic impacts under different prices, climate scenarios and crop models and Representative Agricultural Pathways (Sustainable Development Pathway: SDP and Fossil Fuel Driven development pathway: FFD).

and FFD. The exception is the hot/dry scenario under FFD, where net economic impacts as a percent of mean net farm returns is relatively modest at 12%. Generally, net economic impacts on farmers' livelihoods were higher under the FFD compared to the SDP except for the two dry climate scenarios. The middle and the wet climate scenarios under FFD yielded the highest economic impacts on households.

Under the low price scenario, net economic impact as a percent of mean net farm returns was negative with APSIM and varied between −5% and −15%. In contrast, only the dry scenarios under DSSAT displayed negative impacts between −1% and −27%, mainly because simulated yields under these scenarios recorded higher yield losses (Fig. 15). Additionally, the magnitude of yield losses under the two dry climate scenarios were more severe under FFD pathway.

Core Question 4: What are the benefits of climate change adaptations?

Here, we explore the effect of adaptation packages on reducing climate change impact under future agricultural production systems (SDP vs. FFD pathway). Adaptation packages involved the use of heat-tolerant crop varieties, as well as narrowing of the planting window. The effects of the package on crop yields and socio-economic indicators are presented in this section.

Maize

Average simulated SDP yields with climate change and without the use of the adaptation package ranged from 1523 to 1799 kg ha^{-1} for DSSAT and from 1448 to

Table 5. Impact of adaptation strategies on the yields of maize, millet, and peanut in Nioro, Senegal under two contrasting RAPs using DSSAT and APSIM.

Climate Scenario	**Maize %Δ**		**Millet %Δ**		**Peanut %Δ**	
	DSSAT	**APSIM**	**DSSAT**	**APSIM**	**DSSAT**	**APSIM**
Sustainable Development Pathway						
Cool/wet	17.8 (17.7)	4.7 (4.6)	14.9 (14)	11.5 (4.7)	4.3 (1.5)	0.5 (0.2)
Cool/dry	14.4 (12.4)	5 (5)	20.7 (30.4)	12 (3.8)	5.7 (2.5)	0.7 (0.2)
Middle	16.4 (18.2)	4.5 (4.2)	16.5 (16.6)	11.8 (4.9)	5.2 (2.2)	0.8 (0.2)
Hot/wet	22.8 (28.2)	5.4 (5.9)	16.9 (18.4)	12.7 (7.5)	5.4 (2.5)	0.6 (0.1)
Hot/dry	4 (28)	0.1 (5.3)	12.1 (6.3)	8.2 (7.8)	6.2 (3.7)	0.5 (0.1)
Fossil Fuel Development Pathway						
Cool/wet	14.9 (14.3)	2.8 (2.5)	15.1 (14.1)	12.1 (2.4)	4.7 (1.7)	0.4 (0.1)
Cool/dry	6.6 (12.8)	2.1 (3.6)	17.5 (21.2)	11.6 (3)	5.7 (2.4)	0.6 (0.2)
Middle	10.9 (14.9)	2.6 (2.4)	16.2 (17.7)	12.1 (3.1)	5.7 (2.5)	0.6 (0.2)
Hot/wet	20.2 (21.3)	3.3 (3.1)	16.2 (17.7)	13 (3.9)	5.5 (2.3)	0.4 (0.1)
Hot/dry	7 (20.2)	1.0 (6.0)	18.8 (27.2)	11.7 (3.2)	3.5 (1.9)	0.1 (0.1)

Note: Standard deviation of %Δ is in parentheses.

1556 kg ha^{-1} for APSIM across GCMs. Likewise, average simulated FFD pathway yields ranged from 1136 to 1997 kg ha^{-1} for DSSAT and from 1537 to 1733 kg ha^{-1} for APSIM. The use of adaptation packages resulted in SDP yields ranging from 1536–2042 kg ha^{-1} using DSSAT and from 1451 to 1630 kg ha^{-1} using APSIM. Likewise, average simulated FFD, yields ranged from 1199 to 2161 kg ha^{-1} using DSSAT and from 1568 to 1779 kg ha^{-1} using APSIM. These represent average increases of 4–23% (DSSAT) and 0–5% (APSIM) under SDP, and 7–20% (DSSAT) and 1–3.3% (APSIM) under FFD pathway (Table 5).

Millet

Average simulated SDP yields with climate change and without the use of the adaptation package ranged from 1038–1216 kg ha^{-1} for DSSAT and from 1081–1154 kg ha^{-1} for APSIM across GCMs. Likewise, average simulated FFD pathway yields with climate change ranged from 961–1342 kg ha^{-1} for DSSAT and from 1223–1404 kg ha^{-1} for APSIM.

The use of adaptation packages resulted in SDP yields ranging from 1157–1382 kg ha^{-1} using DSSAT and from 1172–1285 kg ha^{-1} using APSIM. Likewise, average simulated FFD pathway yields ranged from 1104–1532 kg ha^{-1} using DSSAT and from 1365–1573 kg ha^{-1} using APSIM. These represent increases of 12–20% (DSSAT) and 8–13% (APSIM) under SDP, and 15–19% (DSSAT) and 12–13% (APSIM) under FFD pathway (Table 5).

Peanut

Average simulated SDP yields with climate change and without the use of the adaptation package ranged from 699–1030 kg ha^{-1} for DSSAT and from 857–937 kg ha^{-1} for APSIM across GCMs. Likewise, average simulated FFD pathway yields with climate change ranged from 455–1046 kg ha^{-1} for DSSAT and from 826–980 kg ha^{-1} for APSIM.

The use of adaptation packages resulted in SDP yields ranging from 758–1077 kg ha^{-1} using DSSAT and from 863–942 kg ha^{-1} using APSIM. Likewise, average simulated FFD yields ranged from 474–1102 kg ha^{-1} using DSSAT and from 829–984 kg ha^{-1} using APSIM. These represent increases of 3–9% (DSSAT) and 1% (APSIM) under SDP, and 4–6% (DSSAT) and 0.2–0.6% (APSIM) under FFD pathway (Table 5).

Simulated benefits of the adaptation packages were always higher with DSSAT than with APSIM, irrespective of the crop and agriculture development pathway. This phenomenon can be attributed to structural differences between the two models (Falconnier *et al.*, 2020; Adiku *et al.*, 2015).

Economic analysis

In this section, we report on the four outcome variables (adoption rate of adaptation packages, change in net farm returns, change in PCI, and change in poverty) (see Table 6).

Adoption rate. There were between 47% and 63% adopters of the adaptation package across all climate scenarios, crop models, RAPs, and prices. In both price scenarios, adoption rates were higher for the SDP. DSSAT consistently displayed higher adoption rates across RAPs and prices mainly due to the higher sensitivity of DSSAT to the climate change adaptation packages. There were more adopters under low prices when we control for RAPs and crop models. *This means that more farmers*

Table 6. Economic outcome variables under high and low prices, crop models, and RAPs.

Economic Outcome	Crop Model	High Price		Low Price	
		SDP	**FFD**	**SDP**	**FFD**
Adoption rate	APSIM	50–53	47–48	58–61	54
	DSSAT	53–57	51–52	60–63	57
Change in net returns	APSIM	15–17	13	29–31	18–19
	DSSAT	16–19	15	30–35	20
Change in per capita income	APSIM	10–11	8–9	17–18	9
	DSSAT	11–15	10	17–23	9–10
Change in poverty	APSIM	[−16] [−17]	[−10]	[−17] [−19]	[−11]
	DSSAT	[−17] [−21]	[−11] [−12]	[−18] [−26]	[−12]

tend to adopt the adaptation package when they produce under unfavorable price conditions.

Changes in net farm returns and PCI. Under the high price scenario, changes of net farm returns range between 13% and 19% and are quite stable across climate scenarios, crop models, and RAPs. Likewise, the low price scenario under FFD displayed similar results with changes varying between 18% and 20%. In contrast, under the low price scenario and SDP, changes in net returns almost doubled, with values between 29% and 35%. Results of the PCI provided similar trend (mean net farm returns). *We noticed therefore, under the SDP that the adaptation package generated higher returns to farmers.*

Changes in poverty. The low price scenario yielded higher decreases in poverty with 17% to 26% reduction under the SDP and 11% to 12% under the FFD Pathway. Under the high price scenario, the two crop models produced almost the same outcome: Poverty dropped by 10 to 12 points under the FFD, while it showed a bigger drop of 16 to 21 points under SDP. *As with the other variables, it is clear that the green road (SDP) yields greater outcomes when the adaptation package was applied.*

Conclusions and Next Steps

AgMIP provides powerful decision support tools for understanding climate change impacts and adaptation. We studied the probable changes in climate, crop, economic, and livelihood outcomes in smallholder agriculture, as well as adaptation benefits by applying the most advanced RIA methods available, based on quantitative multi-model simulations informed and verified by multiple stakeholders.

The study resulted in the following conclusions:

- Temperatures will increase in the near future by 1 to 3°C across climate scenarios and showed potential for either increase or decrease in precipitation.
- Cereal yields will be negatively impacted by climate change with maize being the most vulnerable, while millet was less impacted.
- Peanut productions will in the majority of climate scenarios benefit from climate change mainly due to CO_2 fertilization effects on peanuts.
- Except for the hot/dry climate scenario which combines high temperature and low rainfall, climate change applied to the current production system in Nioro is expected to have positive impact on farmers' livelihoods mainly because it is a peanut-dominated farming system in which generally positive climate change impact on peanut offset projected negative impacts on the other crops.
- Intensifying current production systems with increased fertilization and appropriate cultural practices has the potential to significantly increase yields of maize and millet in low input systems in Nioro, under current climate.

- In the current climate, at least three out of four smallholder households are potential adopters of a basic increased fertilizer and improved crop management package; if a suitable improved variety is available as a bundled option, this proportion increases to four out of five smallholder households.
- In future production systems, climate change impact on maize and millet will be more negative in magnitude than under current production systems, while peanuts continue to benefit except for the dry climate scenarios.
- The positive response of peanuts to climate change along with future socioeconomic conditions would also have positive impact on Nioro farmers' livelihoods in all cases simulated, under high price scenarios mainly due to the importance of peanut in the households.
- However, under low price scenarios, climate change would have a negative impact on Nioro farmers' livelihoods in most cases, especially under FFD pathway.
- The use of heat-tolerant cultivars and narrowing planting windows is a potential adaptation strategy to nullify the negative effect of climate change on maize and millet, while peanut will continue to benefit from this adaptation.
- In the future, at least one smallholder household out of two will be a potential adopter of a basic package of using heat-tolerant crop varieties.

We need to further engage with higher levels of policy makers and decision makers. The goal is to co-design the most desirable outcomes in order to move away from business as usual and to address the major obstacles for agricultural development in the region (low input use, increased weather variability, high risks, and lack of financing). These AgMIP RIA analyses enable us to pinpoint the main hurdles that need to be tackled in the changing environment and help define potential solutions co-generated with the key stakeholders, such as policy makers, elected officials, farmers' organizations, and NGOs.

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