Potsdam Institute for
Climate Impact Research

Supplementary Material – Climate Risk Analysis for Identifying and Weighing Adaptation Strategies in Ghana

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Contents

Definitions used in the study for key concepts are based on the IPCC fifth assessment report (IPCC, 2014b):

Exposure: The presence of people, livelihoods, species or ecosystems, environ-mental functions, services, and resources, infrastructure, or economic, social, or cultural assets in places and settings that could be adversely affected.

Risk: The potential for consequences where something of value is at stake and where the outcome is uncertain, recognizing the diversity of values. Risk is often represented as probability or likelihood of occurrence of hazardous events or trends multiplied by the impacts if these events or trends occur. In this report, the term risk is often used to refer to the potential, when the outcome is uncertain, for adverse consequences on lives, livelihoods, health, ecosystems and species, economic, social and cultural assets, services (including environmental services) and infrastructure.

Vulnerability: The propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt.

Chapter 1

Present Climate Conditions

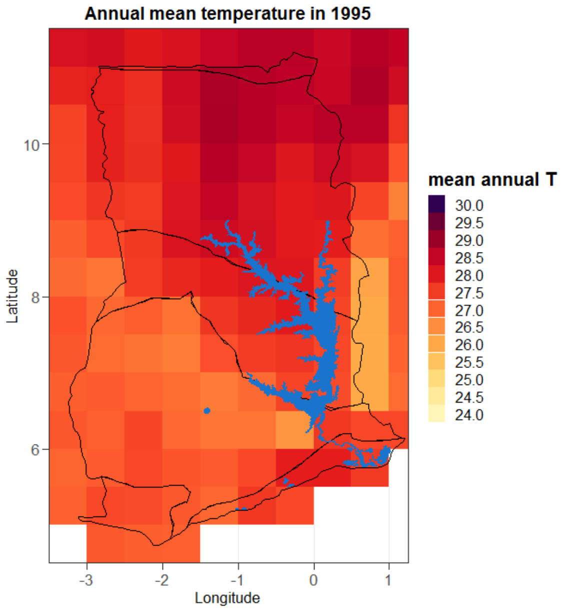


Figure 1: Annual mean temperature in 1995

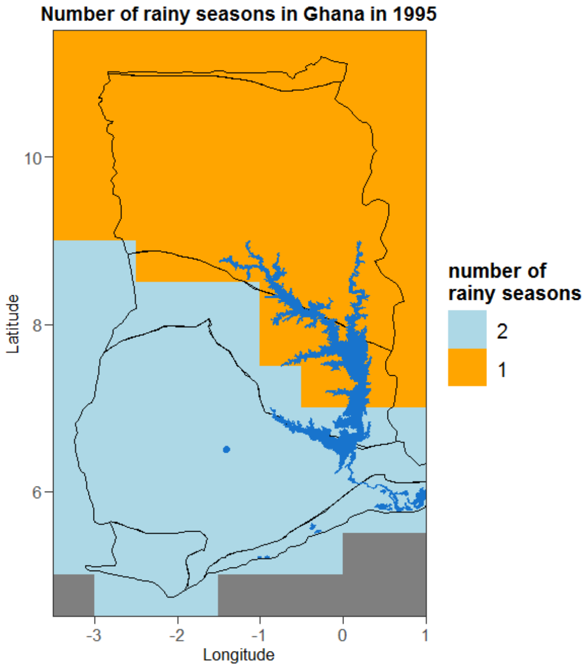


Figure 2: Number of rainy seasons in 1995

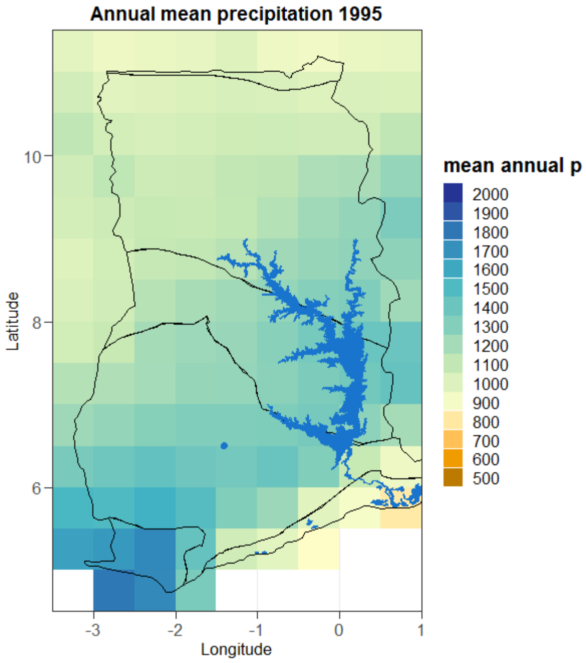


Figure 3: Annual mean precipitation in 1995

Past Climate Conditions

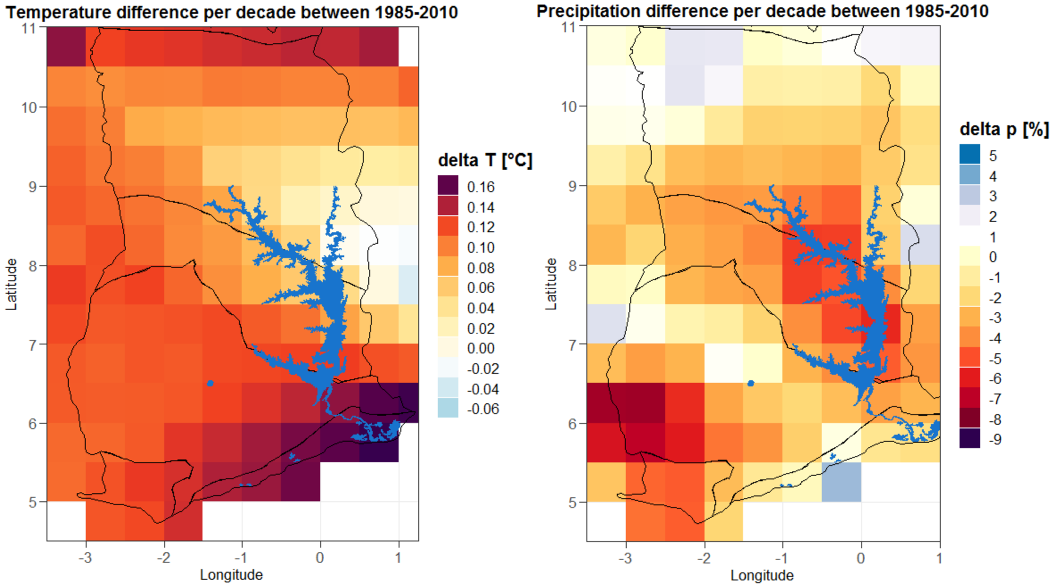


Figure 4: Difference in mean annual temperature and mean annual precipitation per decade between 1985-2010

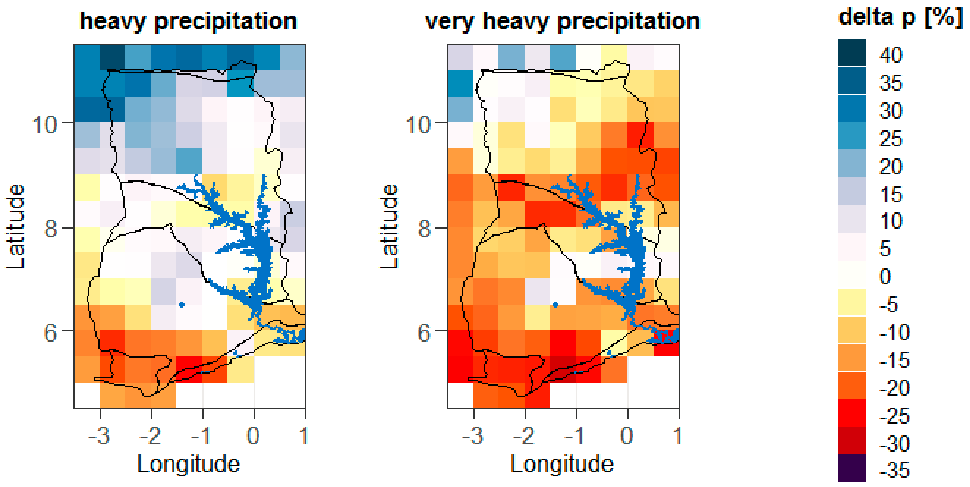


Figure 5: Change in days with heavy precipitation (exceeding 95th percentile) and very heavy precipitation (exceeding 99th percentile) per decade since the 1980s until 2016

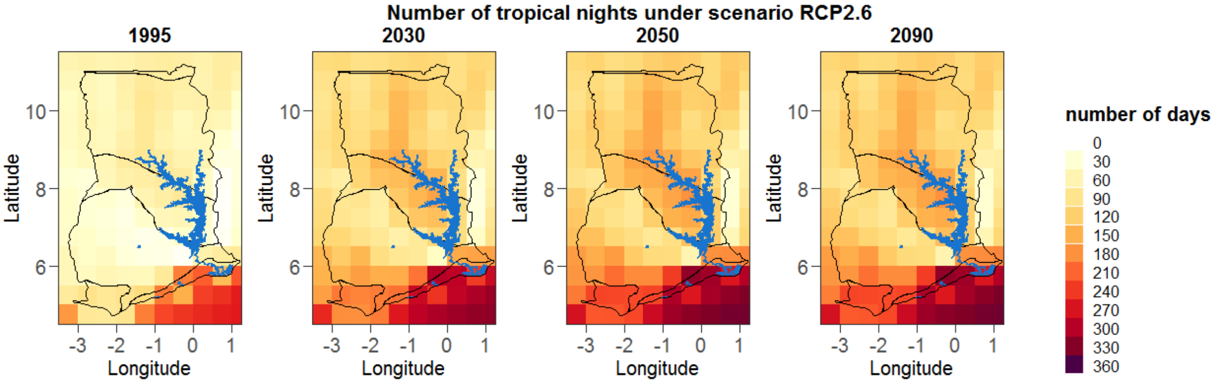


Figure 6: Average number of tropical nights per year in 1995, 2030, 2050 and 2090 under RCP2.6. Results are averages over the four ISI-MIP models.

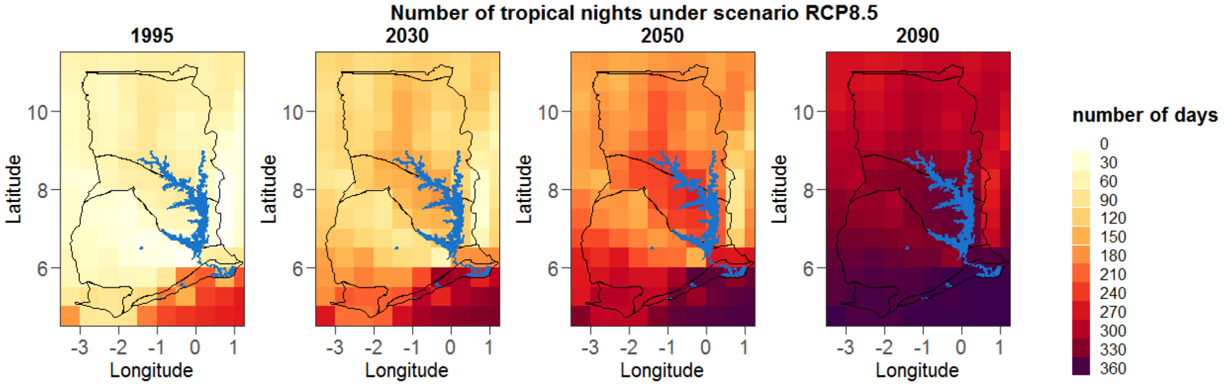


Figure 7: Average number of tropical nights per year in 1995, 2030, 2050 and 2090 under RCP8.5. Results are averages over the four ISI-MIP models.

Climate Models

A climate model is a computer model, describing the state and change rate of different Earth components, for example atmosphere, land surface, vegetation, ocean, sea ice, aerosols and carbon cycle (van Storch, 2005). The components of such a model are sketched in the figure below.

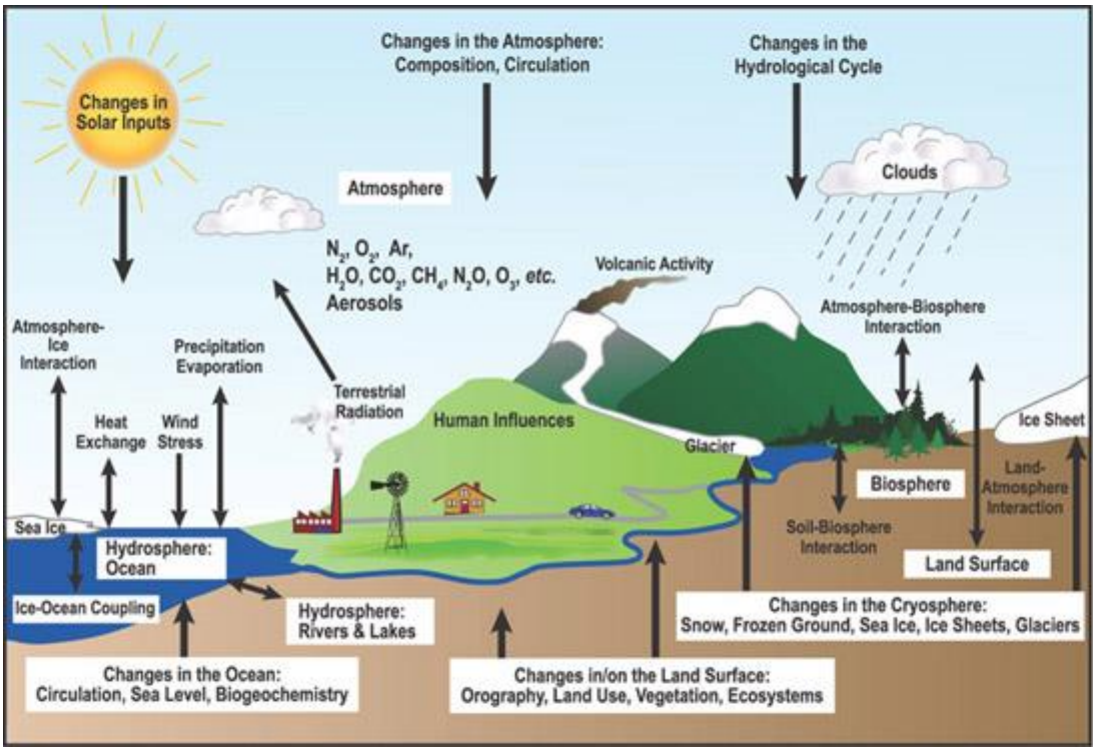


Figure 8: Components of the global climate system (IPCC, 2007).

Climate models have proved to reproduce current climate and past climate changes reasonably well. There is considerable confidence that the models are capable of estimating future climate changes, especially on continental and larger scales. Climate model's predictions come with fewer uncertainties for some climate variables (e.g. temperature) than others (e.g. precipitation). They can represent annual mean values better than extreme events and annual variations (IPCC, 2014a). More detailed information on climate models can also be found in van Storch (2005).

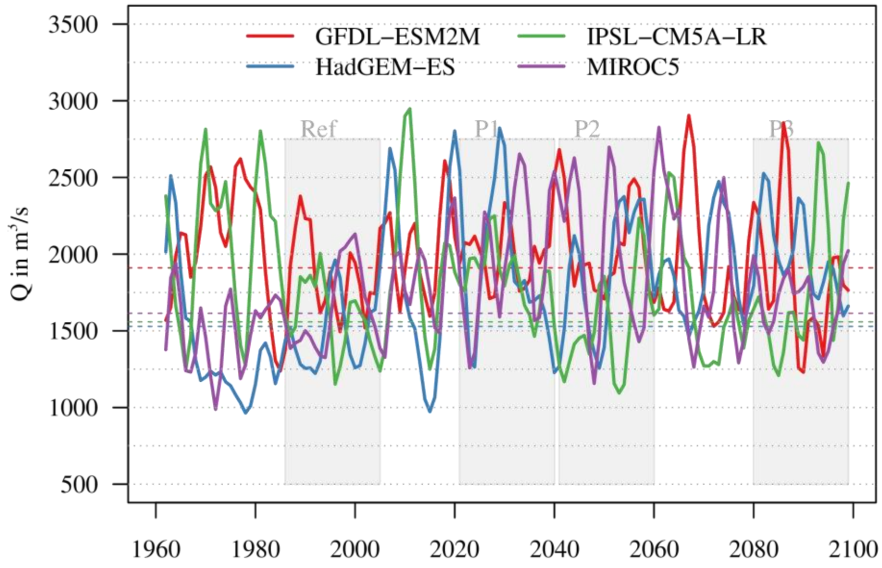


Figure 9: Annual mean discharge at the VRB outlet (3-years moving average), RCP 2.6

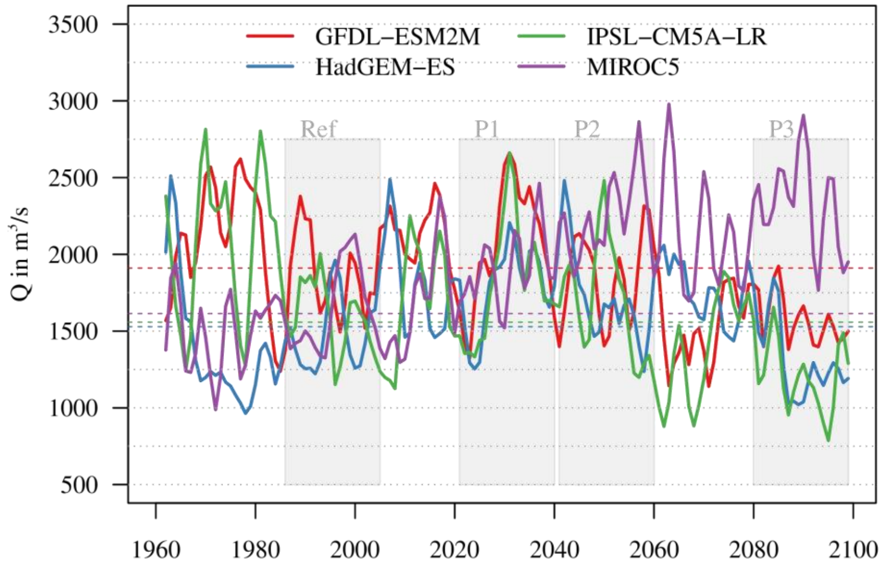


Figure 10: Annual mean discharge at the VRB outlet (3-years moving average), RCP 8.

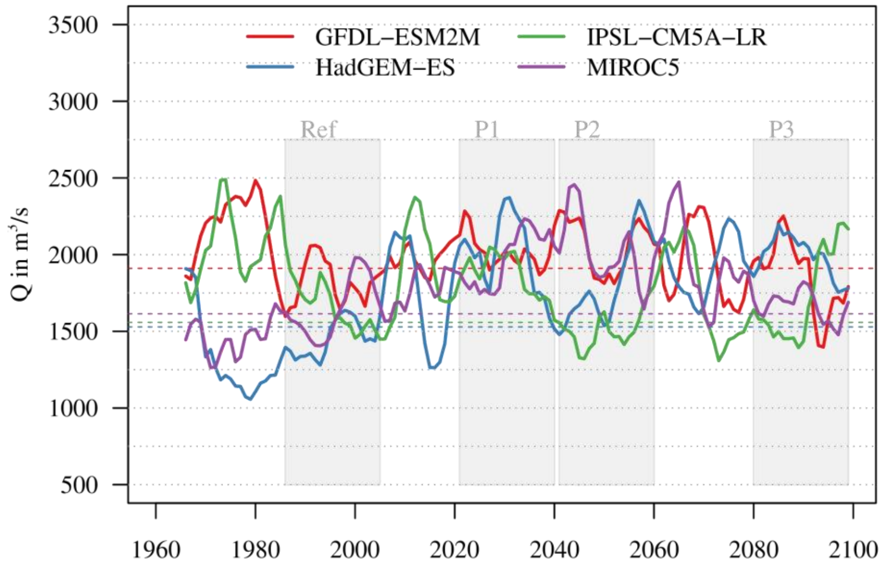


Figure 11: Annual mean discharge at the VRB outlet (7-years moving average), RCP2.6

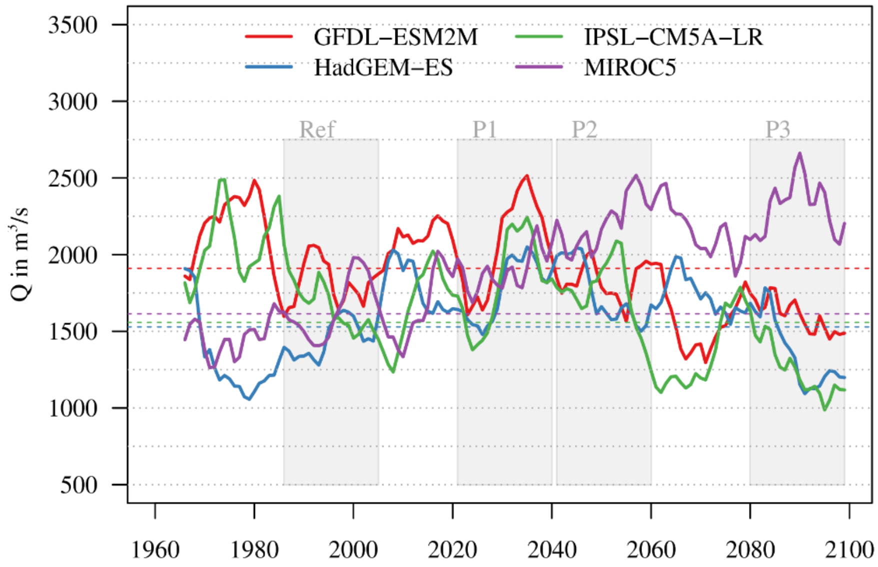


Figure 12: Annual mean discharge at the VRB outlet (7-years moving average), RCP8.5

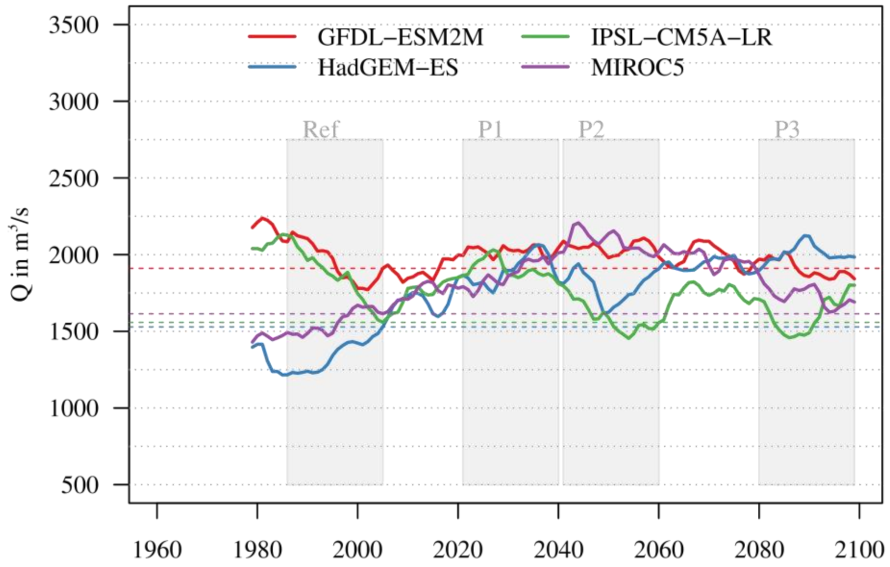


Figure 13: Annual mean discharge at the VRB outlet (20-years moving average), RCP2.6

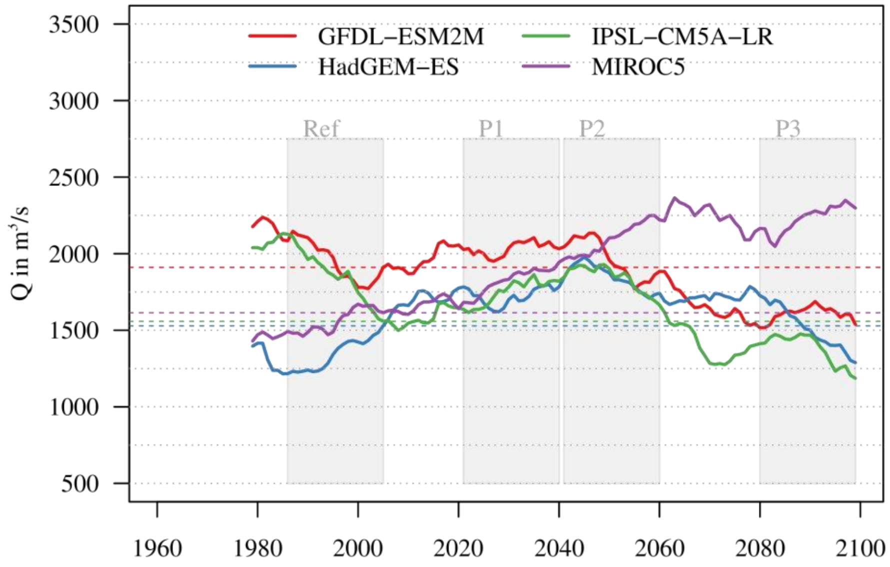


Figure 14: Annual mean discharge at the VRB outlet (20-years moving average), RCP8.5

Chapter 3

SM 1: Methods for Crop Suitability Modelling

SM1.1 Suitability Modelling: the Principle

Crop potential assessments are based on the assumption that at district, regional or national level, the biophysical parameters (e.g. soil organic carbon) and climatic variables (e.g. total amount of precipitation received in the growing season) are still important in determining yields. This is because it assumes that the majority of the farmers in a district or region is rational; they try to achieve the maximum yield possible from the management side and are only limited to do so by biophysical and weather parameters. Crop suitability defines a place's appropriateness to grow a particular crop as a factor of climatic conditions. The crop production risk is therefore directly related to the gap between the expected suitable conditions and those existing in the area. For the same area, the suitability or crop production risk will vary for different crops as they have distinct needs in terms of climatic conditions that will allow them to reach the expected production outcomes. Changing the biophysical environmental conditions such as those changes anticipated under climate change will result in a change in the agricultural potential of an area. This is because as the climate changes, the climatic conditions that determine the growth of crops will also change. This will make other areas more or less suitable and risky for the growth of certain crops compared to current climatic conditions. These suitability models or at least their variants have been used in assessing the impacts of climate change on agriculture in different crops (Bradley et al., 2012; He & Zhou, 2012; Jing-Song, Guang-Sheng, & Xing-Hua, 2012; Zhao et al., 2016).

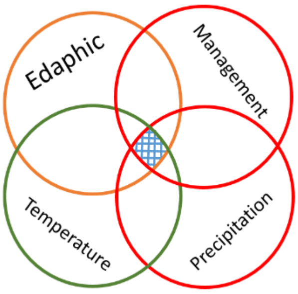


Figure 15: The interaction of various factors in determining the suitability a crop. The centre represents a highly suitable pixel with suitability decreasing centrifugally from the centre and the direction represented by the specific crop requirements.

SM1.2 Biophysical Variables Used for the Modelling

Eight biophysical parameters were used in modelling the suitability of the three crops under current and future climatic conditions. These are: 1) Total rainfall in the growing season; 2) Total rainfall received between March and September; 3) Sum of rainfall in the crop sowing month; 4) Rainfall coefficient of variation; 5) Diurnal temperature range between March and September; 6) Mean temperature growing season; 7) Mean temperature between March and September; 8) Top soil organic carbon. The main growing season was defined as March to July in the south and end of May to September for the North according to distribution of rainfall and agricultural practices in Ghana. These variables were selected because they are known to have the major agronomic influence on maize, groundnut, sorghum and cassava production. The climatic variables were obtained from ISIMIP model projections for the period 2006 to 2016 and for 2041 to 2050 as daily values for precipitation, maximum temperature and minimum temperature (Lange, 2016). The ISIMIP data consist of 4 bias-adjusted GCMs which are GFDL-ESM2M, HADGEM-ES, IPSLCM5A-LR, and MIROC-ESM-CHEM. For future projections, the RCP2.6 and RCP8.5 scenarios were selected so represent the most optimistic and pessimistic scenarios. Top soil organic carbon was obtained from ISIRIC (Dent, 2006; Hengl et al., 2014) on the basis that it has a significant influence on crop potential in the tropics (Bradley et al., 2012; Estes et al., 2013). The same soil organic carbon was used under current and future climate change. All these variables were clipped to Ghana and then projected, ensuring that they have a matching spatial resolution and extent.

SM1.3: Sources of Crop Data

The crop suitability data was derived from the crop yield data obtained from the Ministry of Food and Agriculture (MoFA) at district level. These datasets are received from the wide network of agricultural extension officers in each district who carry out crop cutting estimates to assess the yield and cropped area annually. A suitable district was established as a district whose mean yield between 2006 and 2016 was above the national average yield of 1.68t/ha. These identified suitable districts were then used to generate points that were used for running the suitability models together with pseudo absences. This was done for sorghum, groundnuts, maize and cassava separately. The input data were split into 70% of the suitable sites and pseudo-absence for model fitting and the remaining 30% for model evaluation of prediction.

SM1.4. Approaches for Modelling Suitability of Sorghum, Groundnuts Maize and Cassava

We fitted an ensemble model consisting of nine machine learning algorithms using the points from the districts determined as suitable from observed data and the stack of the seven environmental variables (six weather based and one soil organic carbon) with sampling for pseudo absences, performing three model runs for each. Nine different models which are Maximum Entropy (MAXENT), Generalised Boosted Models (GBM), Generalized Linear Models (GLM), Random Forest (RF), Generalized Additive Models (GAM), Flexible Discriminant Analysis (FDA), (MARS), Classification Tree Analysis (CTA), Artificial Neural Networks (ANN) and Surface Range Envelope (SRE). These models were chosen based on their data requirements that met the available crop data and their ability to produce response curves that can be evaluated for their fit. These methods are also described in detail elsewhere (A. T. Peterson, J. Soberón, R. G. Pearson, R. P. Anderson, E. Martínez-Meyer, M. Nakamura, and M. B. Araújo Peterson, A. T., J. Soberón, R. G. Pearson, R. P. Anderson, E. Martínez-Meyer, 2011; Araújo & New, 2007; Franklin & Miller, 2010). For the prediction, the median of the model result was used as it is more robust to extreme prediction in terms of both statistical model and GCMs compared to the mean. The same set of responses, predictors and scenarios were used within modelling protocol for each crop.

SM1.5 Model Evaluation and Selection

To evaluate the model fit we used the true skill statistics (TSS) and the area under the receiver operating characteristic curves (AUC) measures of model performance. TSS takes both omission and commission errors into consideration and ranges from 1 to 1with values close to 1 being good mode fit. As for AUC, values are poor when in the range 0.5 - 0.7, good to excellent when greater than 0.7 (Allouche, Tsoar, & Kadmon, 2006; Araújo & New, 2007; Coetzee, Robertson, Erasmus, van Rensburg, & Thuiller, 2009). To build the prediction, only the models with AUC and TSS values above 0.75 were kept and their median predication established. Since the spatial resolution of the ISIMIP data was large, we did not apply thresholds to determine suitable area as this would have resulted in over-generalisation of the results.

SM1.5. Limitations and Potential Sources of Uncertainty

- The suitability models are driven by climate data, which in itself has its uncertainties. Future projections of crop production suitability emerge by combining suitability models with projections based on general circulation models (GCMs) that describe potential future conditions. These different GCMs rely on different parameters and incorporate different functions to portray the dynamics of atmospheric circulation, ocean effects, or feedbacks between the land surface and the atmosphere and therefore are prone to disagreements/errors that will be propagated in the modelling.

- The modelling is driven by data inputs and therefore it is sensitive to the quality and quantity of the underlying sample data. For crop suitability, the models rely on false-absences because there can be no "true" absences for crops as they are introduced and produced by people.
- The spatial resolution of the ISIMIP data is too large for suitable area calculation as the pixels are over-generalised at 50km x 50km resolution. The suitability for districts can be determined, but it is too uncertain because of the very coarse resolution of the ISIMIP data. In some cases two districts fall into one pixel.

SM 2: Methods for Technical Evaluation of Adaptation Options for Maize Production

SM 2.1 Process-based Modelling

A process-based crop simulation model represents the response of crops to varying weather conditions that affect germination, growth and development of the harvested portion of the plant by incorporating site-specific soil properties, water availability and management decisions (Robertson, Nelson, Thomas, & Rosegrant, 2013). The Agricultural Production Systems sIMulator (APSIM) is one such model that can be used to simulate in great detail the complex climate-soil-crop systems (Holzworth et al., 2014). In this current study the APSIM-Maize 7.1 (Brown et al., 2014) was used to simulate the yield response of under site specific common management practices and daily weather data from 2005 to 2015. The APSIM-Maize module simulates crop phenology, biomass accumulation, LAI, grain yield, and water, N and P uptake on a daily time-step based on soil and crop management decisions. The APSIM maize module divides the maize crop growth stages into stages and phases, with each stage being determined by accumulation of thermal time. The objectives of using APSIM in this study was to use common district level management data on maize production to calibrate and evaluate the performance of APSIM for Ghana, evaluate the impacts of climate change on yield on maize and identify the most promising management strategies for stabilising maize production under projected climatic conditions.

SM 2.2 Parameterization of APSIM

Soil parameters were derived from published soil profiles and the profiles were assigned to the closest district in which they have been assessed. In addition, APSIM comes with indicative soil profiles from Ghana that were also used. The soil depths of these profiles varied between 50cm to 120cm. Under current conditions, the Obatanpa variety was used as this is reported as the most common variety in Ghana. The parameters for the variety such as thermal time accumulation and photoperiodism. The same was done for evaluation of adoption of the improved variety Dorke. The specific parameters that were used in APSIM for the three districts are detailed in Table 1.

Table 1: Descriptions of parameters that were used in setting up the maize model for the three districts.

Parameters	District		
	Akatsi	West Akim	Nkwata
Altitude (m.a.s.l)	60m	120m	205m
Ecological zone	Coastal savannah and Forest zone	Forest zone	Guinea savannah
Rainfall pattern	Bimodal	Bimodal	Unimodal
Dominant Soil types	Planosols & Cambisols	Lixisols & Acrisols	Leptosols, Planosols & Lixisols
Maize variety	Obatanpa	Obatanpa	Obatanpa
Initial water	50%	50%	50%
Rotation	Maize-cowpea	Maize-cowpea	Maize-fallow
Planting method	Sole	Sole	Sole
Planting density	26000/ha	26000/ha	26000/ha
Sowing depth	40cm	40cm	40cm

Cumulative rainfall triggering sowing	30mm	30mm	20mm
Sowing start date	26 March	1 March	26 May
Sowing end date	30 April	30 April	30 June
Fertiliser at sowing (N Kg)	4	40	20
Top dressing fertilizer (N Kg)	20	40	10
Manure (kg)	—	—	500 (CNR 25)
Stover removal (%)	10	10	95
References	(Darfour & Rosentrater, 2016; MacCarthy, Akponikpe, Narh, & Tegbe, 2015)	(Adu et al., 2014; Akowuah & Boa, 2012; Amanor-Boadu et al., 2015; MOFA, 2006)	(Abdulai, Nkegbe, & Donkoh, 2015; MacCarthy et al., 2015; Tachie-Obeng, Akponikpè, & Adiku, 2013)

SM2.3 Validation of the Process-Based Modelling Approach

To validate the performance of APSIM in representing the maize production we used the Index of agreement (d), correlation coefficient (r), coefficient of determination (R^2) and the room mean squared error (RMSE) between the measured and simulated maize yields between 2006 and 2016. This was done for each site and pooled for the three districts.

SM2.4 Evaluation of Adaptation Methods

To evaluate effectiveness of the different adaptation measures, we ran APSIM under projected climatic conditions for each of the three sites. The projected were based on the **four** bias-adjusted GCMs which are GFDL-ESM2M, HADGEM-ES, IPSLCM5A-LR, and MIROC-ESM-CHEM. This produced the likely impact of climate change in each of the districts. We then changed the parameters like variety, manure and sowing dates under future climate change. The percentage change in yield under adaptation measures was assessed compared to current yield for each site, and the effectiveness of a measure was assessed accordingly. Three adaptation measures were assessed as detailed in Table 2.

Table 2: Details of evaluation of the three adaptation measures under climate change.

Measures	Principle	Implementation in APSIM
Varietal improvement	Improving or sourcing improved genetic materials is key in building crop resilience under climate change. An improved variety is able to maintain or improve yields under constrained climatic conditions. This is achieved by a shorter growth cycle, more thermal tolerance or development of physical protective mechanisms for yield and moisture stress. Improved germplasm need to be productive or stable under projected inter annual variability, natural multi-decadal wetting and desiccation cycles and long-term changes in moisture regimes associated with changes in temperature using current technology and inputs.	We evaluated two varieties which are the Dorke and a hypothetical variety we called ObatanB. The Dorke maize is an improved variety released in the 1990s which has high yield potential of 3.8t/ha, tolerance to pests/diseases such as blight, rust, streak, and stem borers and a shorter maturity period of 95 days. To simulate ObatanB, we improved the characteristics of the common and popular Obatanpa variety by 10% of its current characteristics. This was done futuristically to be headed in the direction ofgenetic improvement.

Late sowing	The current planting systems depend on calendar based planting but changing the sowing date is aimed at minimizing water stress during the entire growing period. That is done to significantly increase the crop production or to match the shifts in the new trends of precipitation.	To simulate late sowing, we shifted the sowing window for each of the sites by two weeks from the current farming calendar. This means that the start date of the sowing period and the ende were both delayed by 14 days. The maize module was then run with just this change and the yield change evaluated.
Enhanced use of manures	Manures provide more nutrients to the crop that stimulate crop growth in addition to being more water conserving, as they improve the soil's water holding capacity. The most common sources of organic manure used in crop production are livestock dung, composted and green crop residues, farmyard matter and organic manure from natural systems and material production systems (considering emission risk).	We also evaluated the potential of enhanced manures as a climate change adaptation strategy by introducing them in the south and doubling the quantities for the north where they are already being used for maize production. We assumed that the manures could come from different sources such as composts and would have an average CNR of 20 for good manures. The fertilizer levels and other production systems were kept the same.

Chapter 4

Crop Importance Ranking

Table 3: Economic, food security and productivity indicators for Ghanaian crops

	Economic indicators	**Food security indicators**	**Productivity indicators**	**Total score (weighted)**
Cocoa	0,48	0,42	0,50	0,46
Maize	0,09	0,37	0,41	0,29
Yams	1,00	0,41	0,20	0,53
Rubber	0,00	0,00	0,08	0,03
Groundnut	0,09	0,32	0,24	0,22
Rice	0,08	0,33	0,44	0,28
Plantain	0,42	0,40	0,19	0,33
Sorghum	0,01	0,17	0,23	0,14
Cashew	0,01	0,15	0,52	0,22
Cassava	0,96	0,39	0,49	0,60

Table 4: Final crop importance ranking for Ghana

Total score	**Ranking (1-12) based on score 1=highest, 12=lowest**
Cassava	0,60
Yam	0,53
Cocoa	0,46
Plantain	0,33
Maize	0,29
Rice	0,28
Groundnut	0,22

Cashew	0,22
Sorghum	0,14
Rubber	0,03

List of expert interviews

Table 5: List of experts interviewed for the study.

Interview	Organization	Gender	Date	Location
Interview1	CSAYN Ghana	Male	09.09.2018	Accra
Interview2	IFAD Ghana	Male	10.09.2018	Accra
Interview3	FARA Ghana	Male (2)	10.09.2018	Accra
Interview4	FONG	Female	10.09.2018	Accra
Interview5	Rural Environmental Care Association	Female	12.09.2018	Accra
Interview6	IPA Ghana	Female	13.09.2018	Accra
Interview7	World Vision Ghana	Male	14.09.2018	Accra
Interview8	SNV Ghana	Male (2)	14.09.2018	Accra
Interview9	Farmradio International - Ghana	Male	14.09.2018	Accra
Interview10	AGRA Ghana	Male	15.09.2018	Accra
Interview11	Syecomp	Male	18.09.2018	Skype
Interview12	Researcher	Male	21.09.2018	Skype
Interview13	Ghana Development Communities Association	Male (2)	24.09.2018	Skype
Interview14	IITA Ghana	Male	27.09.2018	Skype
Interview15	Bitland	Male	27.09.2018	Skype
Interview16	GAIP	Male, Female	24.10.2018	Skype

Interview approach

Semi-structured expert interviews (key informant interviews)

Criteria for inclusion in sample:

Purposeful sampling: experts on agriculture and climate change in Ghana, civil society, researchers, small agribusinesses, NGOs, farmers' representations, with the aim to represent the perspective of people usually not consulted in the policy- and decision-making process.

Justification for inclusion of Skype interviews:

Conducting interviews via Skype lends itself to expert interviews, as it is common for experts to not all be present in the same location at the same time, making it difficult to speak to all/many relevant experts for a research question. In the case of the present study, some experts are located in the Northern city of Tamale, thus being close to a particularly climate-vulnerable part of the country, whereas other experts at the time of interview conduction were outside of the country on business travel. In order to not miss interesting and relevant information, it was decided to include also Skype interviews

Chapter 5

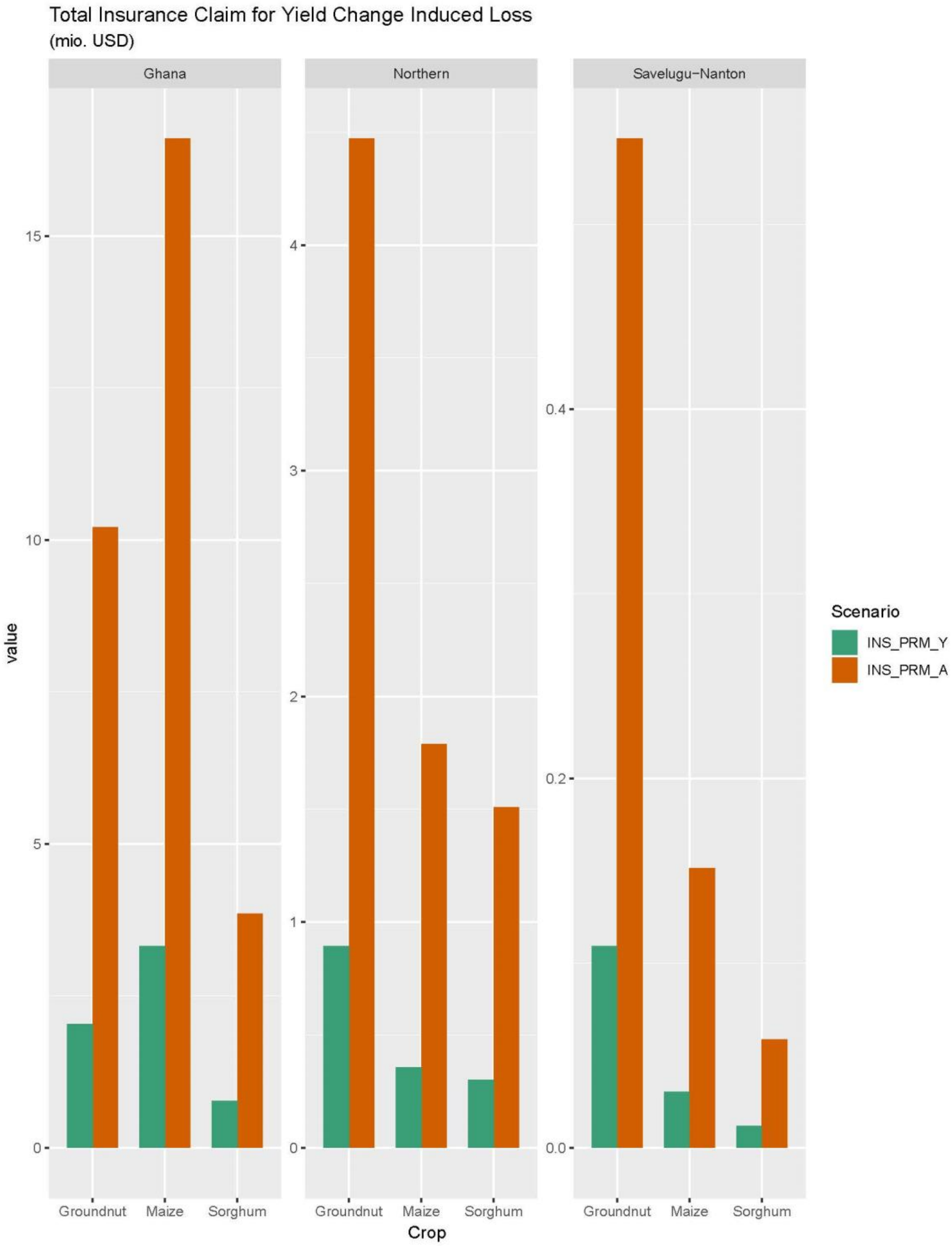


Figure 16: Total insurance claim for yield change induced loss.

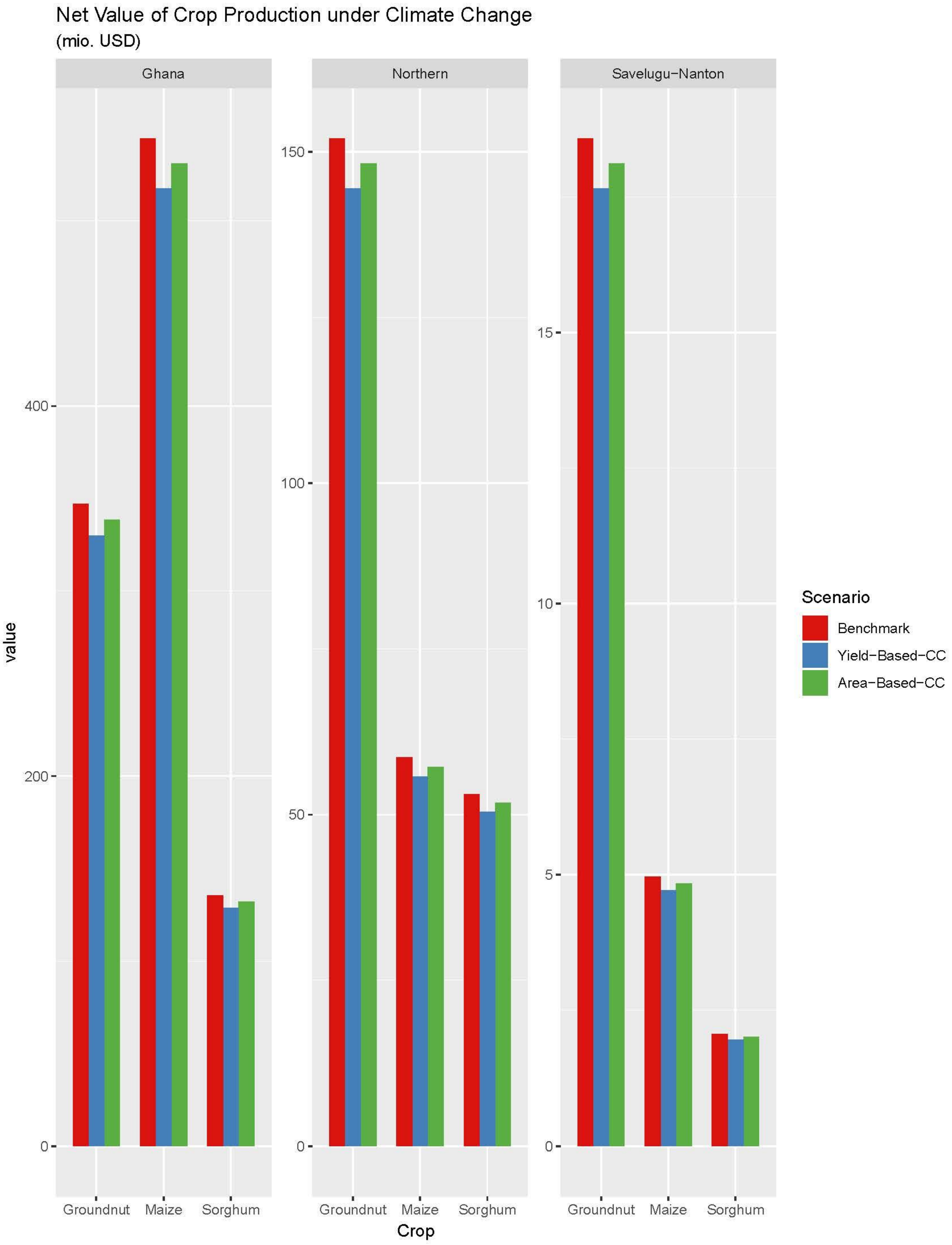
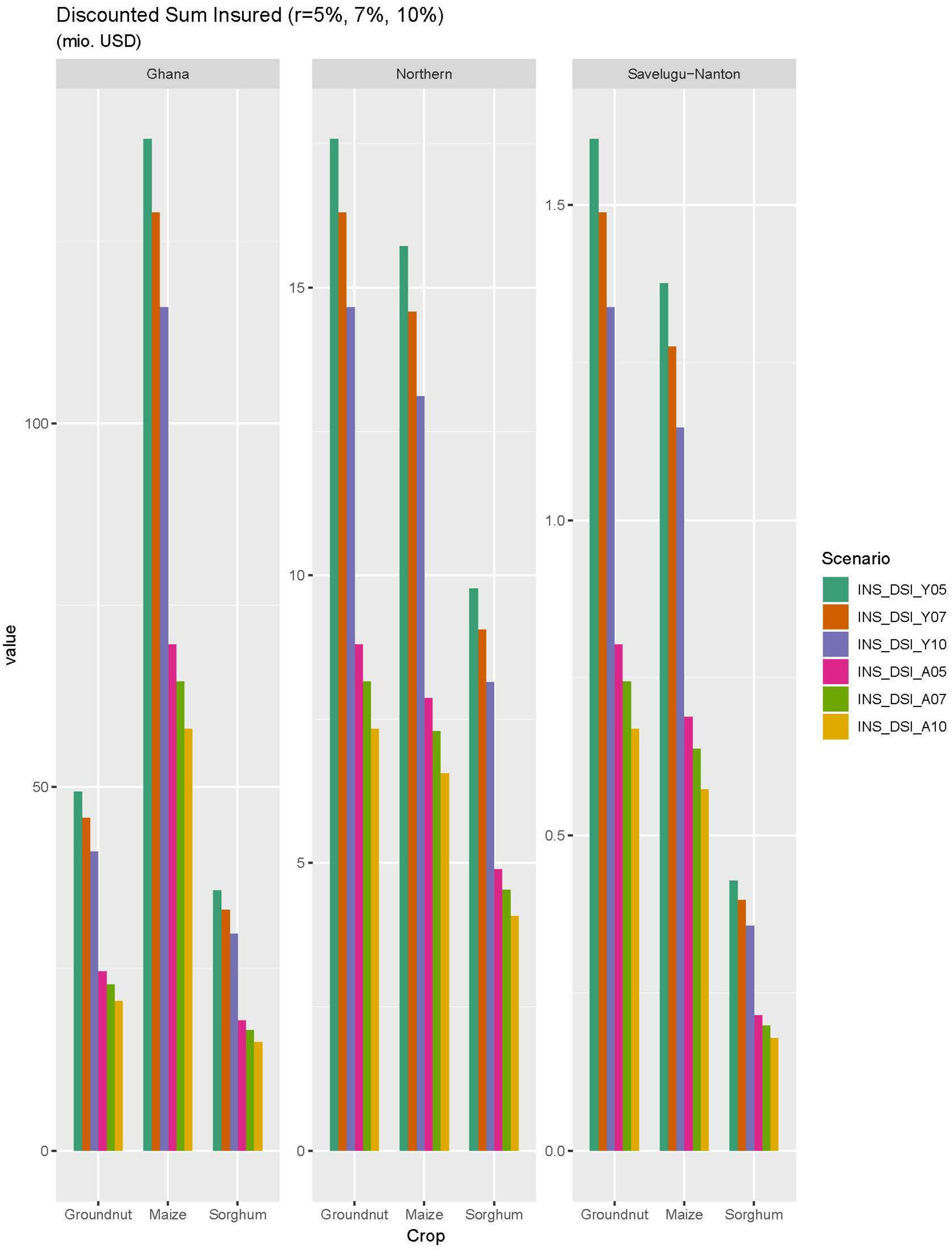


Figure 17: Net value of crop production under climate change.


Discounted Sum Insured (r=5%, 7%, 10%)
(mio. USD)
Ghana
Northern
Savelugu−Nanton
value
100
50
0
15
10
5
0
1.5
1.0
0.5
0.0
Groundnut
Maize
Sorghum
Groundnut
Maize
Sorghum
Groundnut
Maize
Sorghum
Crop
Scenario
INS_DSI_Y05
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INS_DSI_A05
INS_DSI_A07
INS_DSI_A10

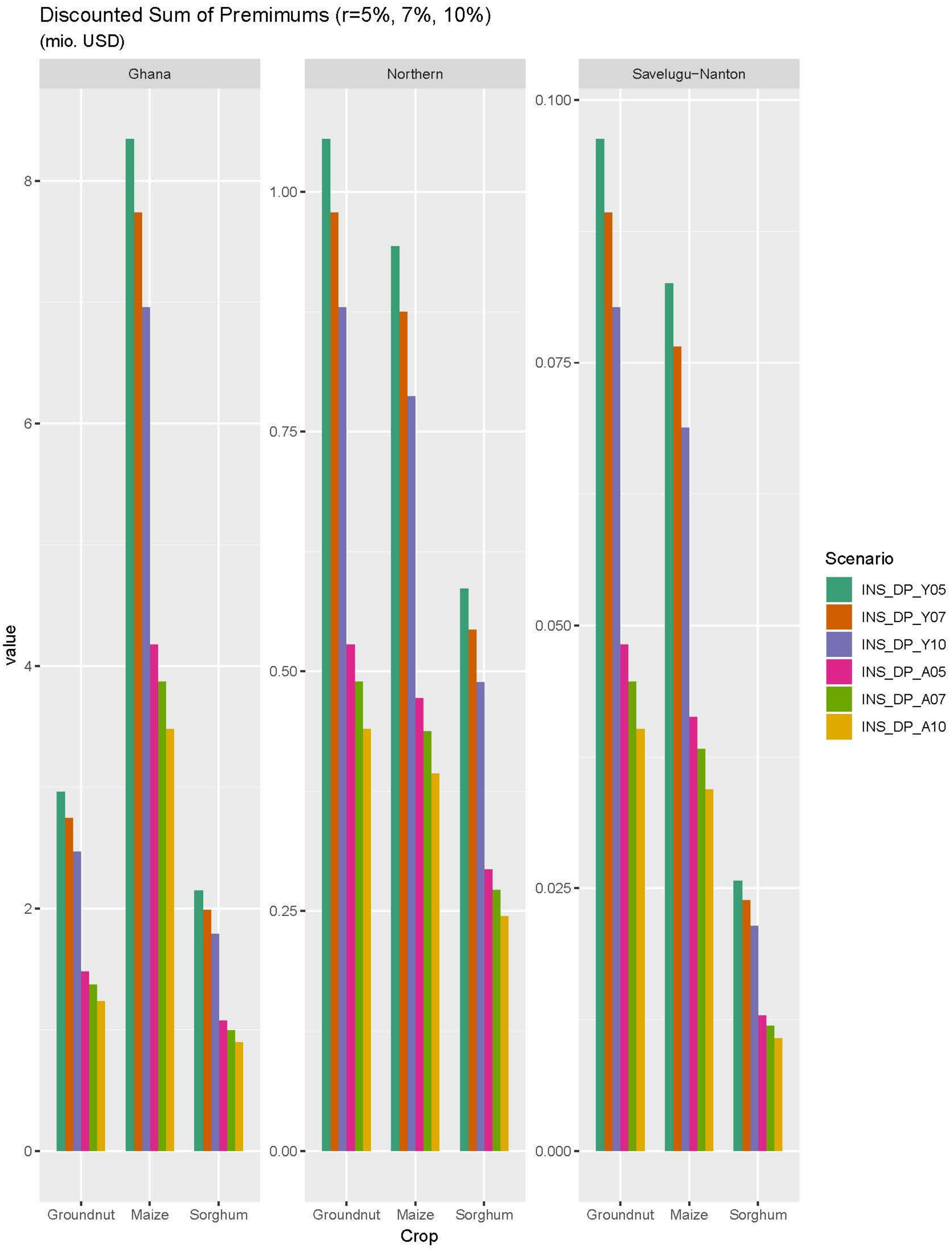

Figure 18: Discounted sum insured for each crop.

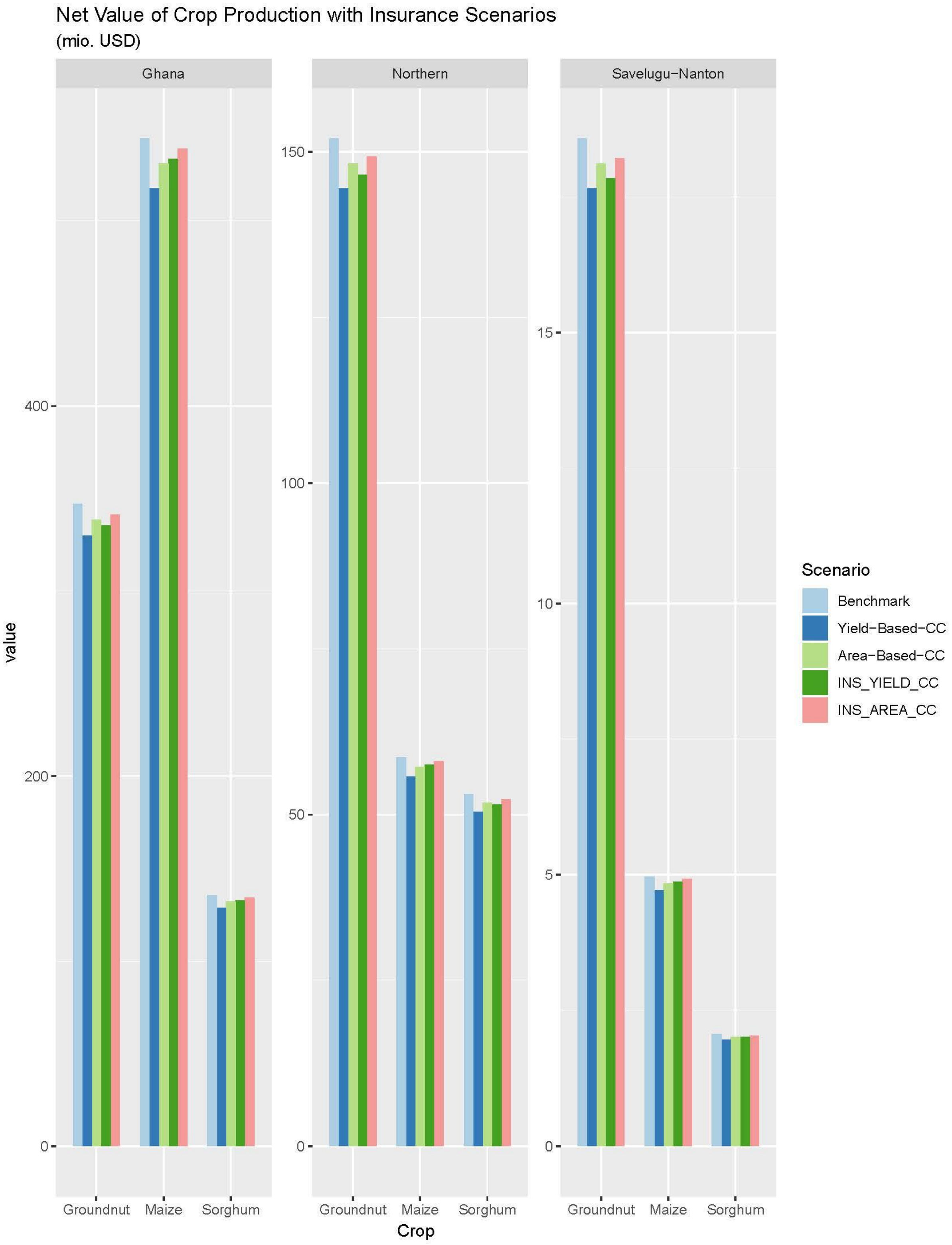

Figure 19: Net value of crop production with insurance scenarios.

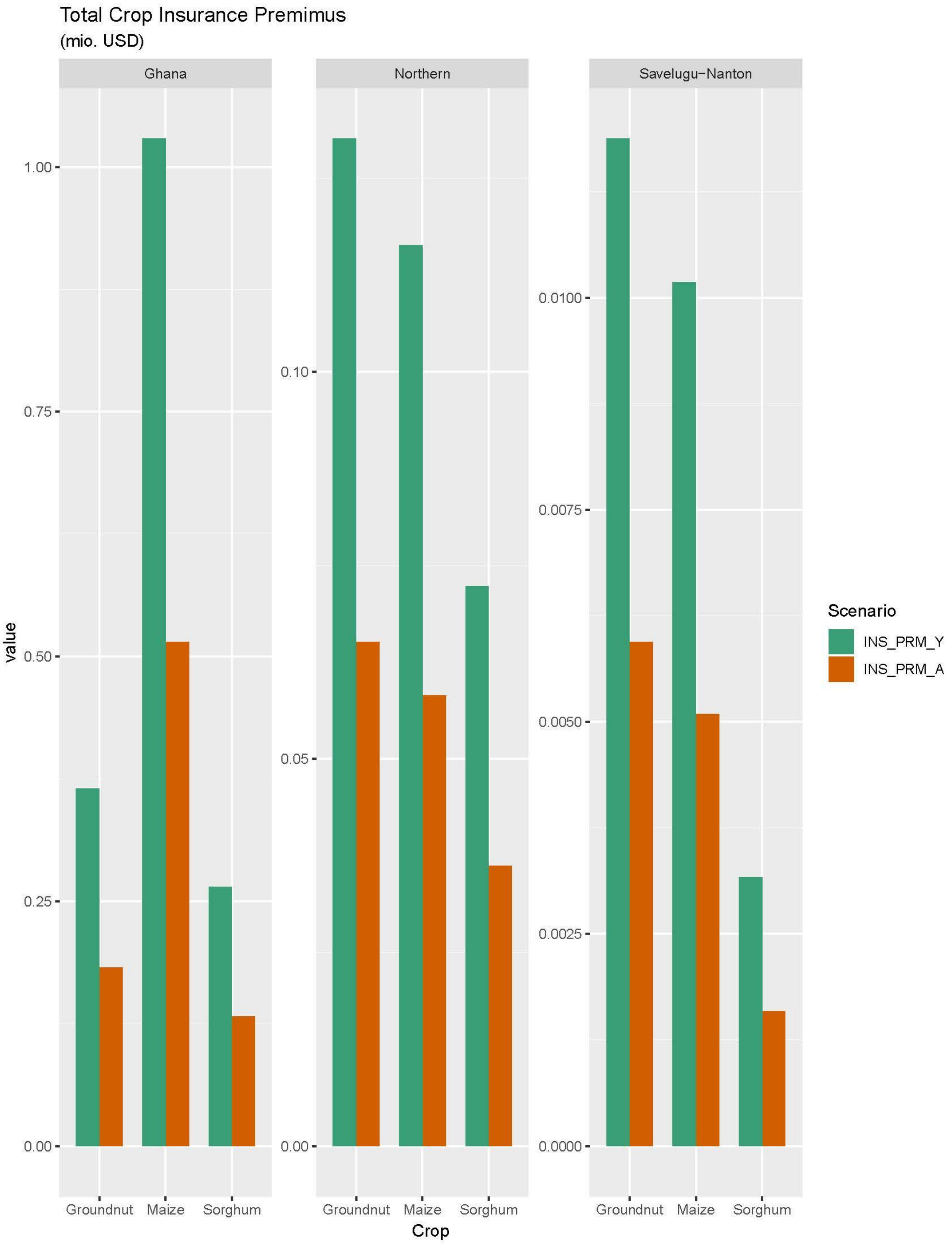

Figure 20: Total crop insurance premiums.

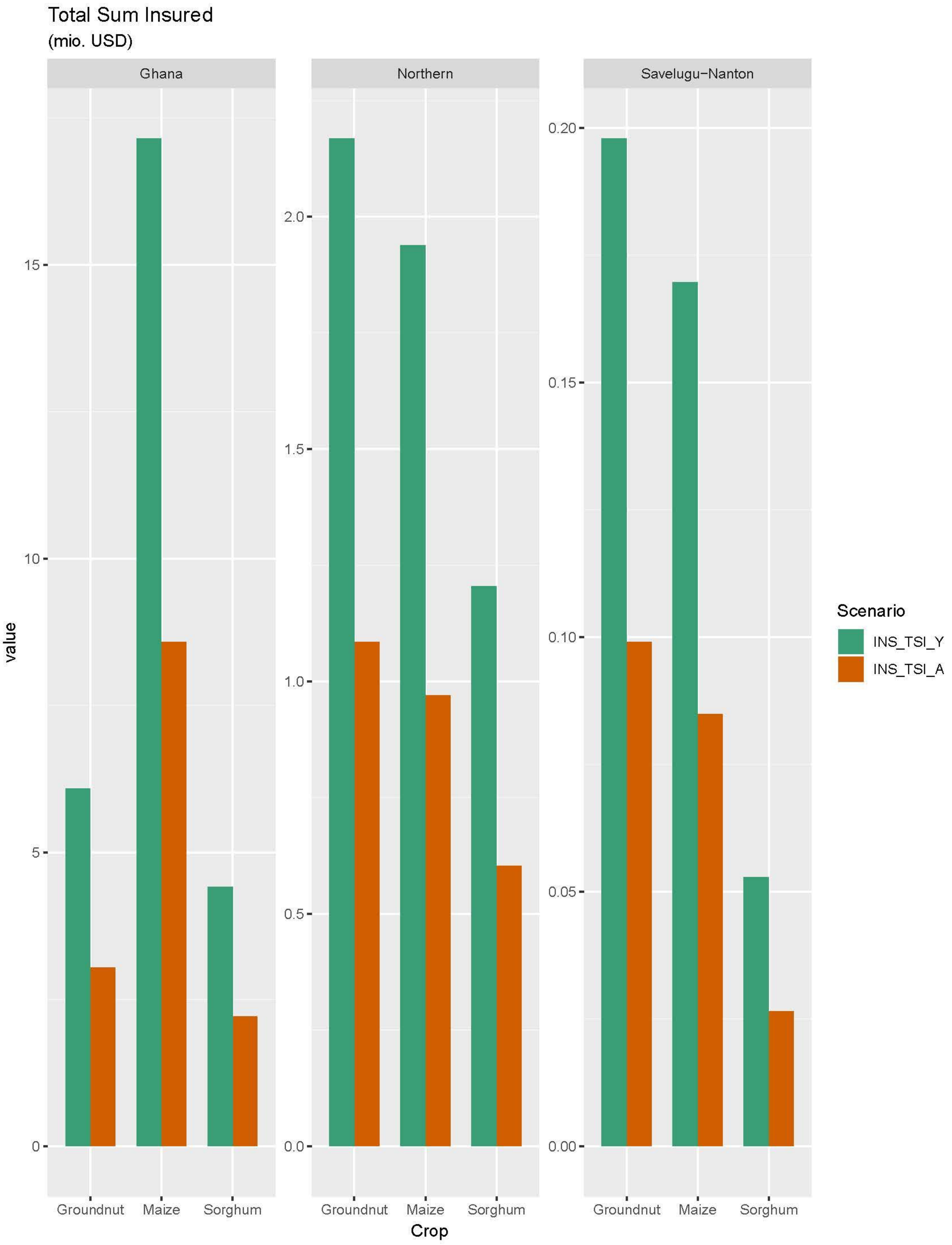

Figure 21: Total sum insured.

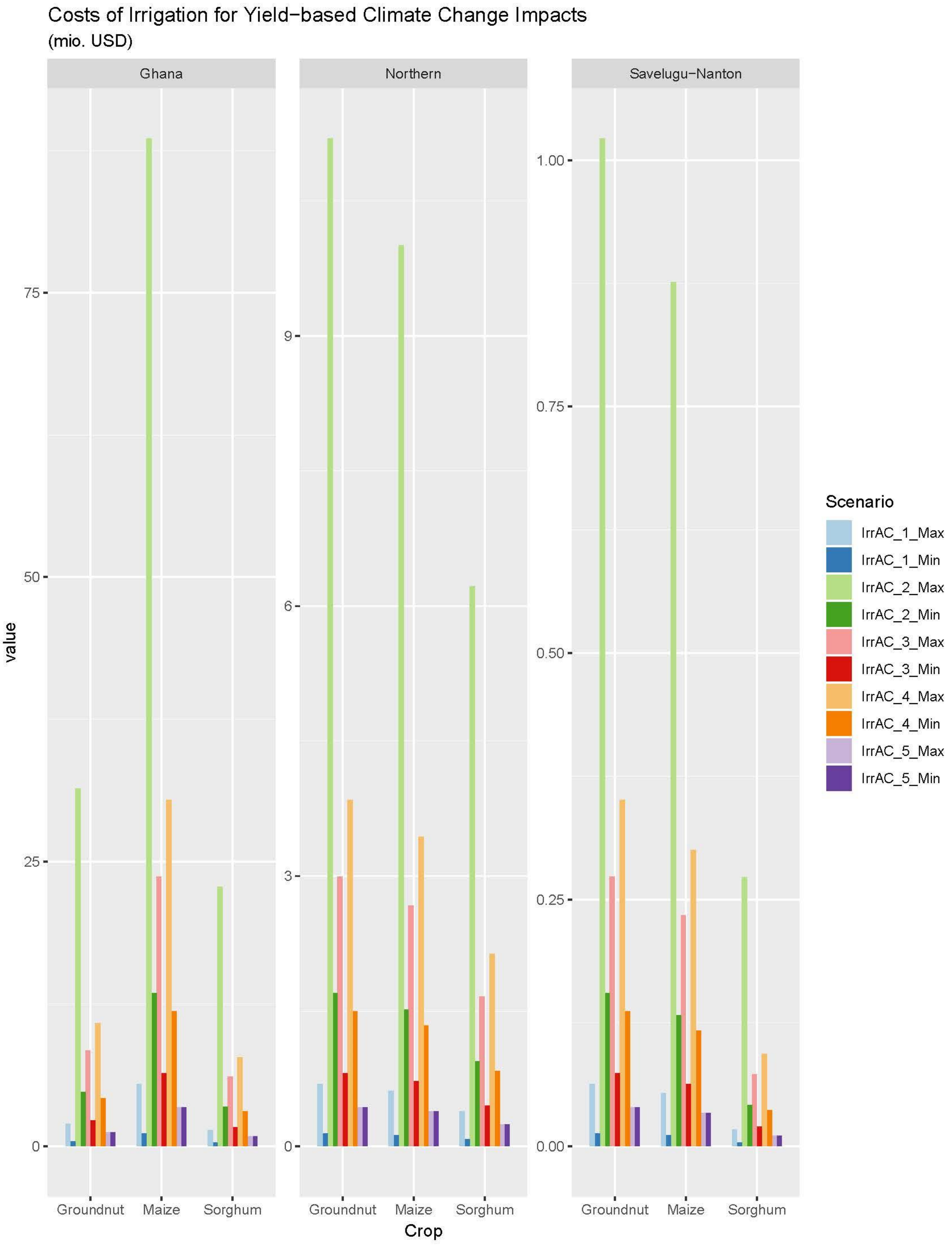

Figure 22: Costs of irrigation for yield based climate change impacts.

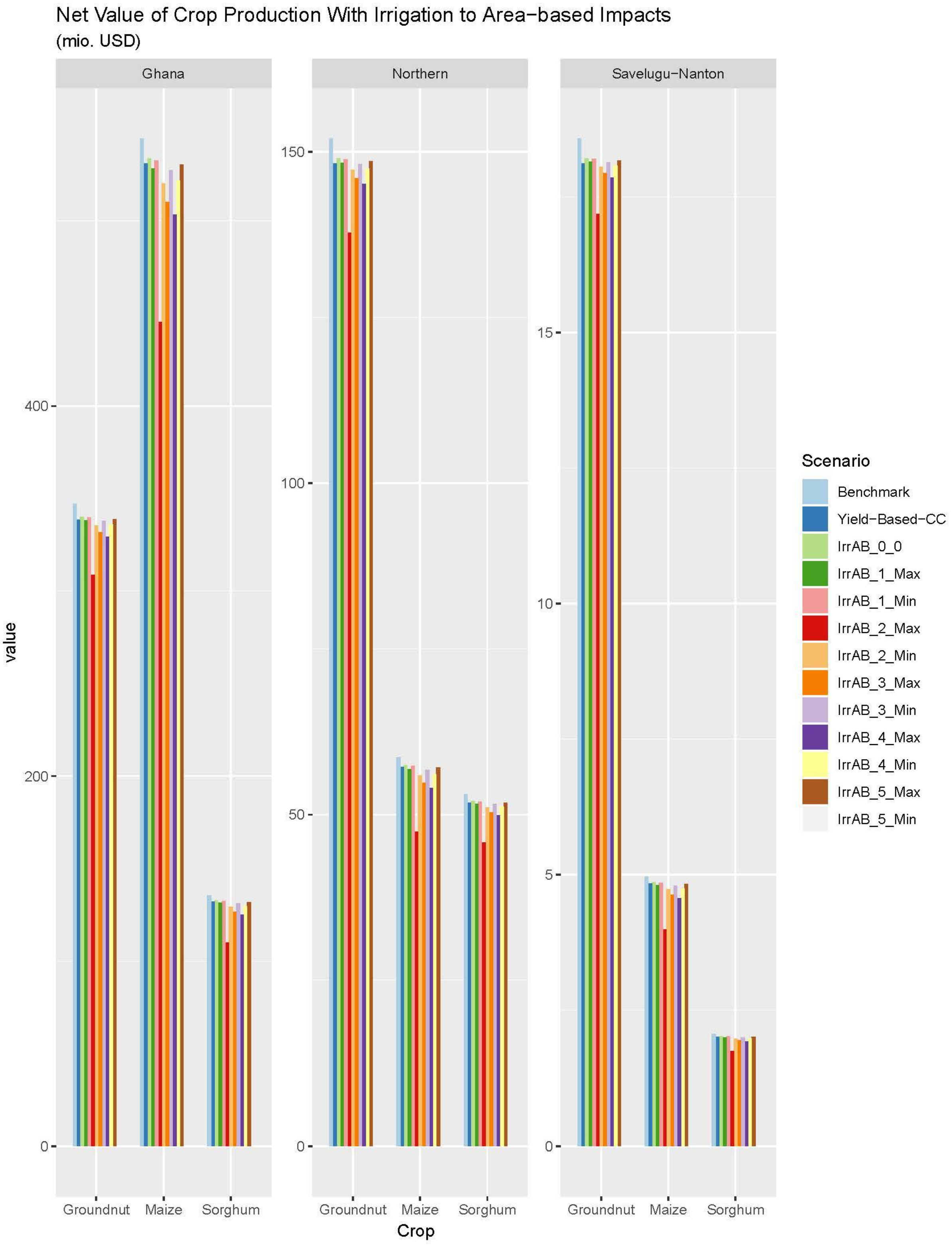

Figure 23: Net value of crop production with irrigation to area-based impacts.

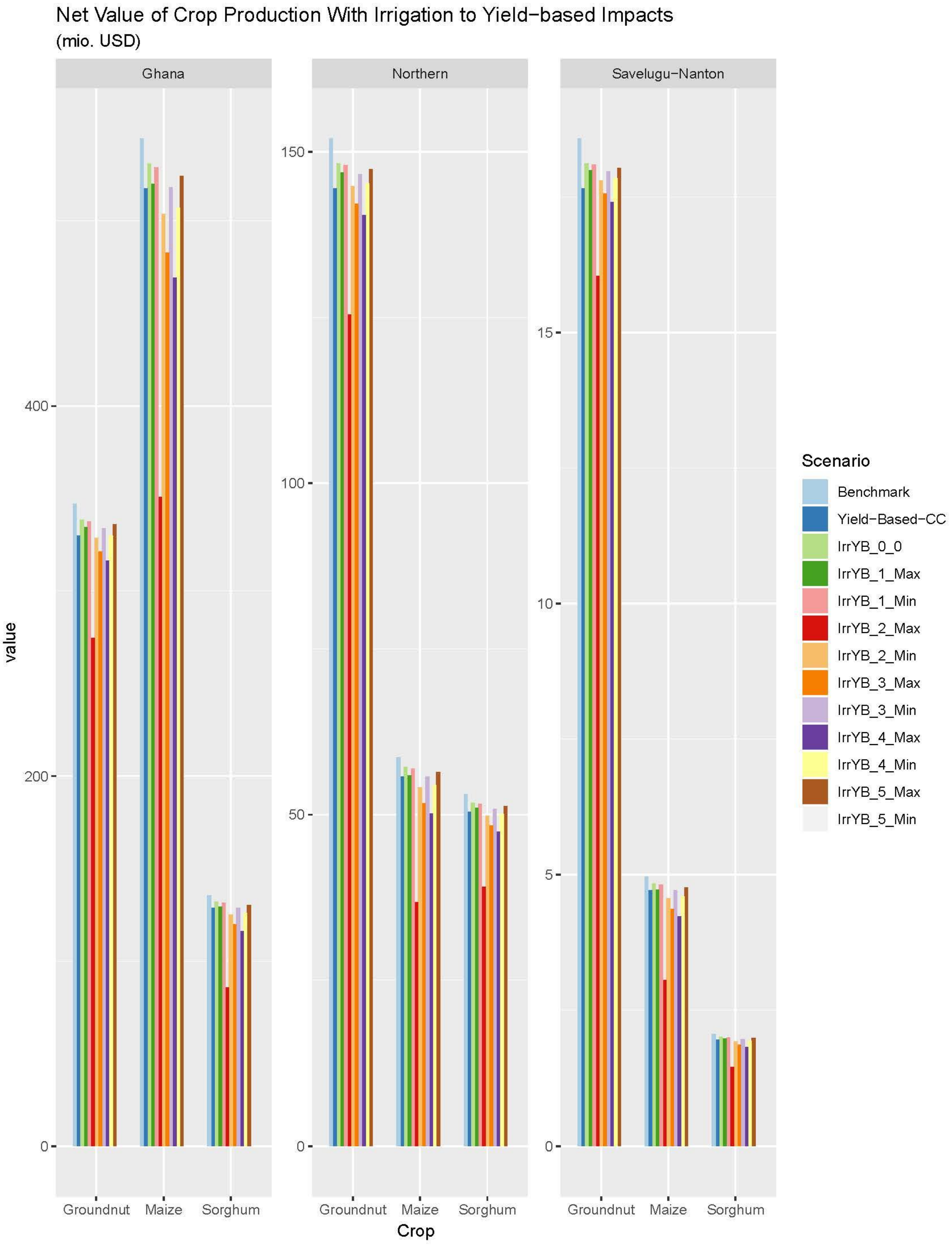

Figure 24: Net value of crop production with irrigation to yield-based impacts.

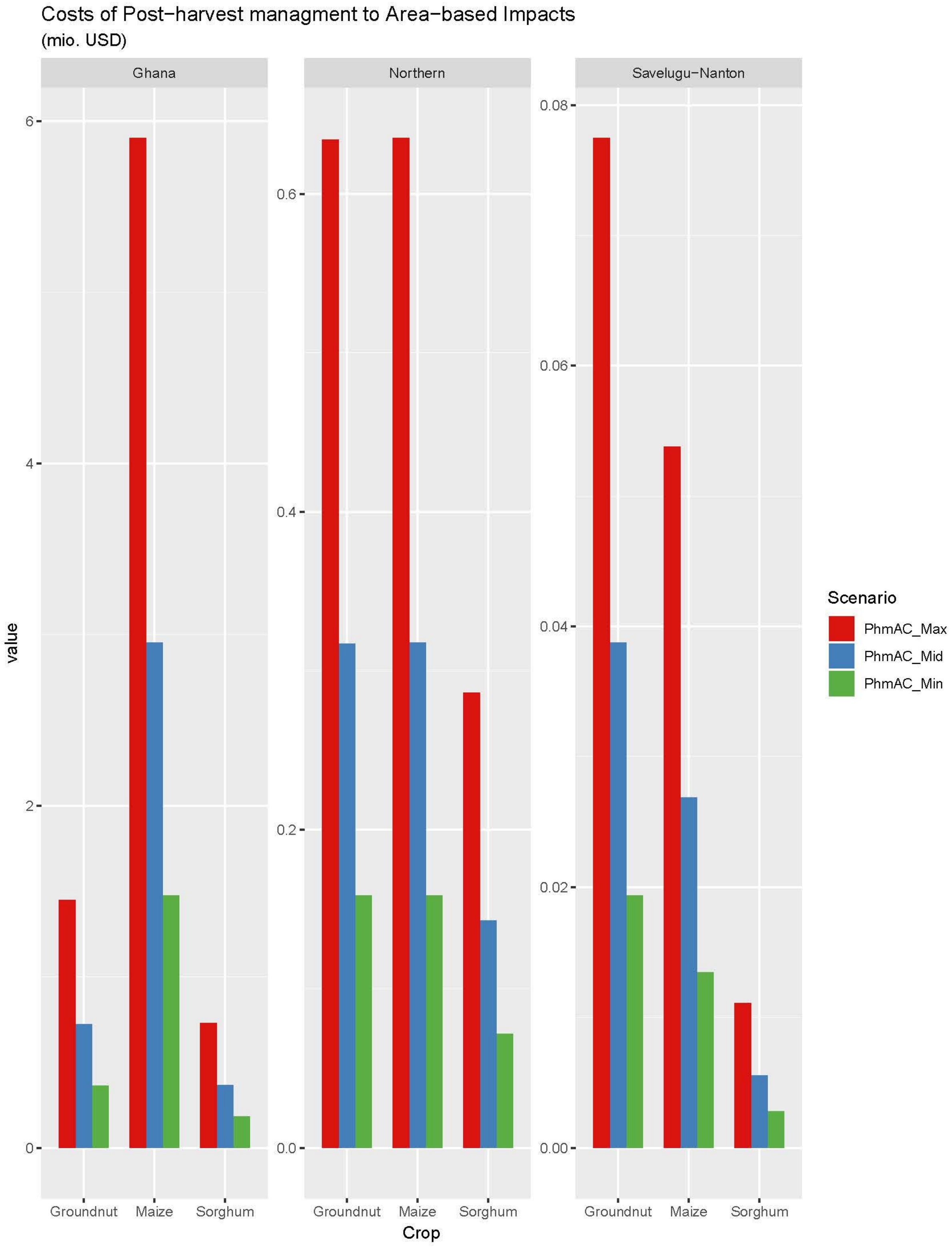

Figure 25: Costs of post-harvest management to area-based impacts.

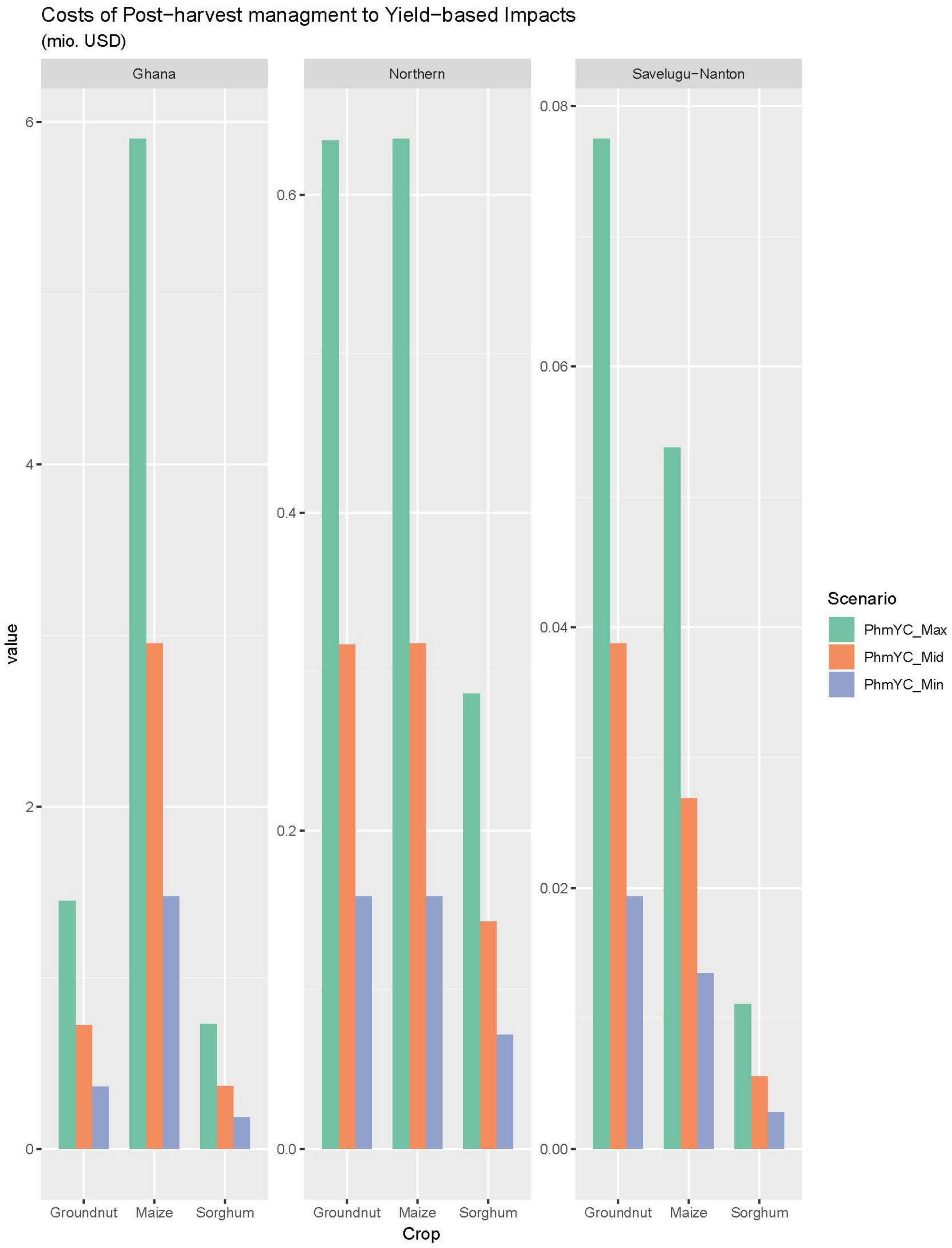

Figure 26: Costs of post-harvest management to yield-based impacts.

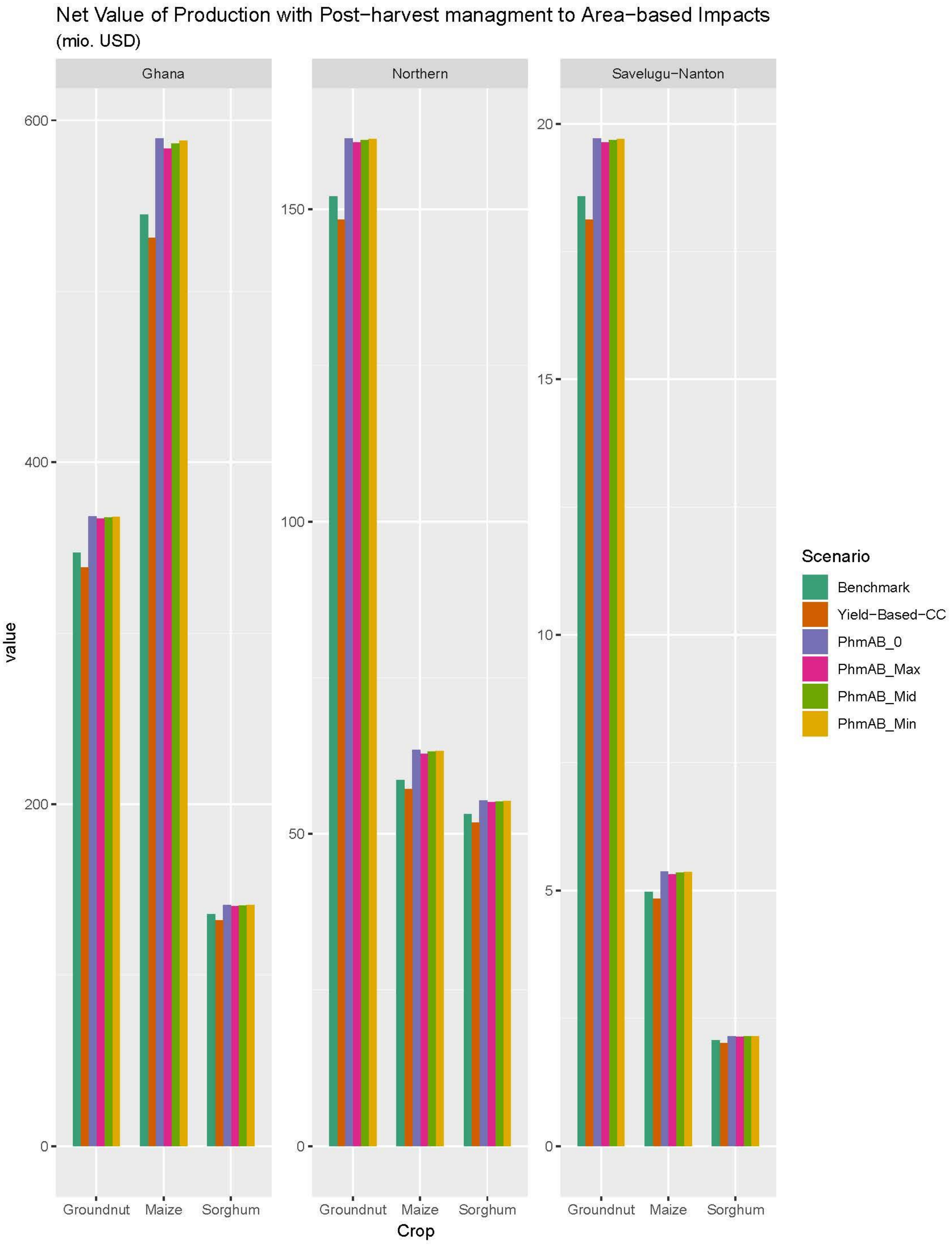

Figure 27: Net value of production with post-harvest management to area-based impacts.

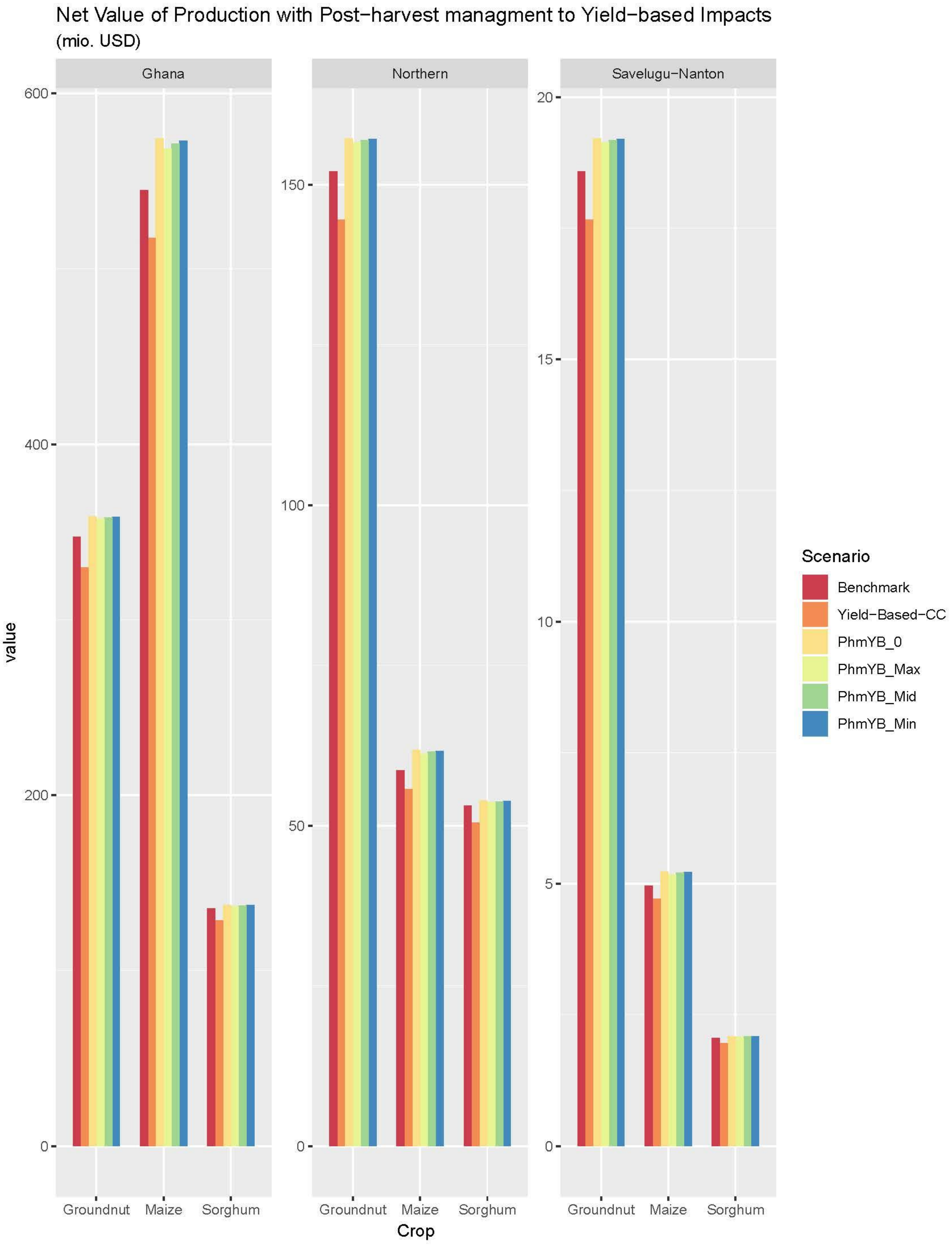

Figure 28: Net value of production with post-harvest management to yield-based impacts.

Bibliography

IPCC, (2007). Climate Change 2007 Synthesis Report. Fourth Assessment Report. https://doi.org/10.1256/004316502320517344

IPCC, (2014a). Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp.

IPCC, (2014b): Annex II: Glossary [Mach, K.J., S. Planton and C. von Stechow (eds.)]. In: Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, pp. 117-130.

von Storch, H., (2005). Models of Global and Regional Climate. In *Encyclopedia of Hydrological Sciences*. https://doi.org/10.1002/0470848944.hsa035