Climate change risks for African agriculture

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Abstract

The IPCC assessment of major risks for African agriculture and food security due to climate change during coming decades is confirmed by a review of more recent climate change impact assessments (14 quantitative, 6 qualitative). Projected impacts relative to current production levels range from -100% to +168% in econometric, from -84% to +62% in process-based, and from -57% to +30% in statistical assessments. Despite large uncertainty, there are several robust conclusions from published literature for policy makers and research agendas: agriculture everywhere in Africa runs some risk to be negatively affected by climate change; existing cropping systems and infrastructure will have to change to meet future demand. With respect to growing population and the threat of negative climate change impacts, science will now have to show if and how agricultural production in Africa can be significantly improved.

Climate change is projected to compromise agricultural production – especially in smallholder systems with little adaptive capacity, as currently prevalent in many parts of Africa. In its Fourth Assessment Report (AR4) of 2007, the Intergovernmental Panel on Climate Change (IPCC) evaluated the scientific literature available up to the WGII literature cut-off deadline on April 21, 2006. Focusing on Africa in 2020, a key conclusion in the IPCC Synthesis Report (SYR) and the Summary for Policy Makers of the Working Group II Report (WGII SPM) was that “By 2020, in some countries, yields from rain-fed agriculture could be reduced by up to 50%. Agricultural production, including access to food, in many African countries is projected to be severely compromised. This would further adversely affect food security and exacerbate malnutrition.” (1). This conclusion, or at least its first sentence, has been debated in the media, with criticisms being raised both on the nature of the underlying science (peer-reviewed or other literature) and on procedural issues (was the knowledge contained in the underlying scientific literature properly represented on all levels of the report?). Scrutiny of all statements concerning African agriculture through the interconnected IPCC AR4 reports demonstrates that the assessment is both consistent between the components of the report and supported by published literature. However, the first sentence of this quite general conclusion is based on one single reference (2) that does not allow for a scientific evaluation of its findings (3) (cf. Supporting Online Material) and refers to dry years only rather than to average annual yields (3).

While this is a procedural flaw that might have been avoided through the improved IPCC assessment rules as e.g. suggested by the IAC (4), it is essential to avoid misinterpretations. In fact, the questionable sentence itself is guarded with sufficient qualifying terms (“some”, “could”, “up to”) that it does not draw a strong conclusion anyway. It is, however, because of its short-term perspective (“by 2020”) and its severity (50% reduction) a vivid example that illustrated the accompanying SYR statement “Agricultural production [...] in many African countries is projected to be severely compromised” (1). Here, we do not focus on this single illustrative but debatable example, but on the broader conclusion about African yield risks. For that purpose, we review newer studies on climate change and African agriculture in order to see whether the overall IPCC assessment is still supported by recent scientific findings and if it can be made more informative. Similar to the IPCC, we here also include non-peer-reviewed literature that sufficiently describes its methodology and allows for an evaluation of its findings.

Since approval and publication of the AR4, new literature has emerged about risks for African agriculture and food production that are caused by anthropogenic climate change. These studies employ statistical, econometric or process-based models for different time frames and different basic assumptions, assessing impacts at specific locations, in regions or for the entire continent, for single crops, production systems or the entire agricultural sector. Most studies indicate the potential for positive as well as for negative impacts: for some crops, the published range of projected climate change impacts therefore ranges from impossibility of "normal agricultural activity" (5, 6) to strong increases in agricultural yields (7, 8). Typically, impact assessments are given for specific time horizons and impacts vary considerably by region and/or crop. Figure 1 shows the range of reported impacts on African agriculture per spatial domain (pixel to continent), illustrating the vast range of possible impacts. In most cases, these include severe negative impacts and often also yield substantial potentials for improvement. While the 2020 time slice is hardly assessed by the new literature, any indication of risk in this near future must be of particular concern due to the lack of time for implementation of any adaptation measures. In the more distant future (e.g., towards the end of the 21st century), adaptation may substantially reduce the potential impacts (9). Adaptive capacity may be strengthened by advances in agricultural development, as African agriculture in many places currently operates at very ineffective levels (10) or using very low levels of inputs (11, 12). Even though African farmers already employ a broad variety of mechanisms to cope with variable weather conditions and adapt to climate change (e.g. 13), improved strategies for increasing resilience and coping with risks are still needed in many parts of Africa (14, 15).

Most studies reviewed here analyze climate-change impacts on African agriculture in isolation, i.e. they disregard changes in the global demand and supply patterns that will affect the production and profitability of agricultural systems worldwide as e.g. shown by Lotze-Campen et al. 2010 (16) for changes in supply patterns under different trade scenarios. A notable exception is the study by Nelson et al. 2009 (8). So far, little is known about changes in the agricultural value-chain other than those on biophysical productivity. This also holds true for the econometric studies, which cannot account for changes in market or production systems (cf. Supporting Online Material).

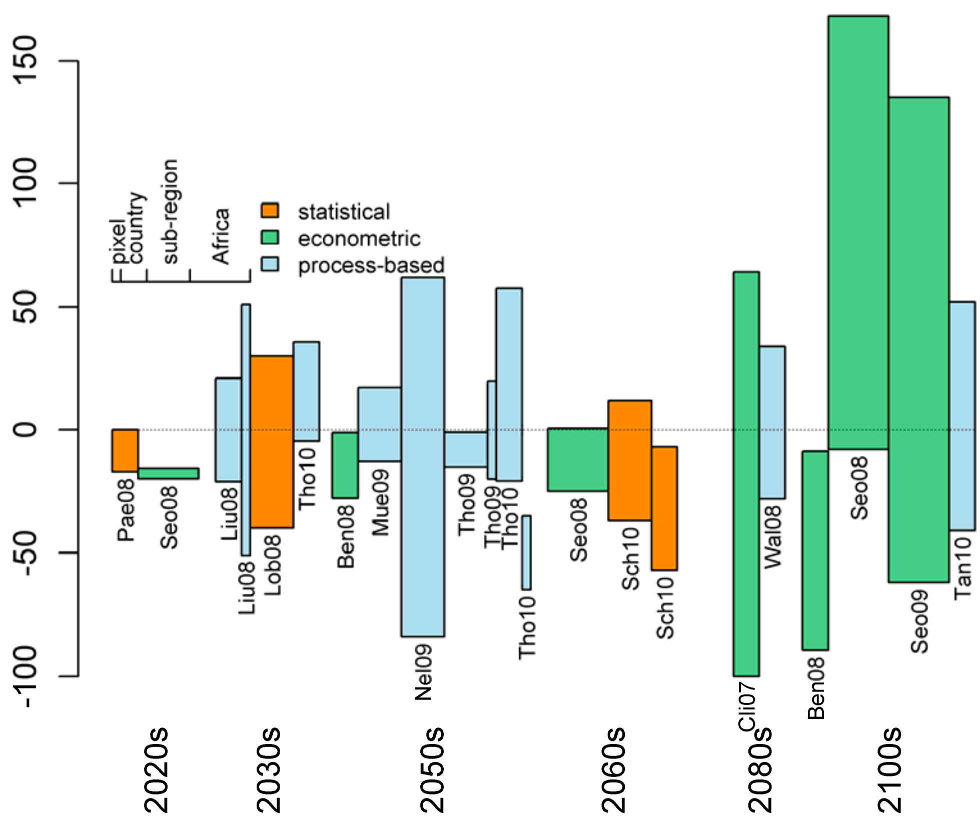

Figure 1: Projected ranges of climate change impacts on African agriculture, expressed as change in percent relative to present conditions*. Bar widths indicate the spatial extent of the projection, shading depicts the methodology. References: Pae08 (17), Seo08 (9), Liu08 (7), Lob08 (18), Ben08 (19), Mue09 (20), Nel09 (8), Tho09 (21), Tho10 (22), Sch10 (23), Cli07 (5), Wal08 (24), Seo09 (25), Tan10 (26).*

The range of projected impacts is very broad, due to the range of underlying assumptions, such as greenhouse gas emission trajectories, climate model parameterizations, biophysical impact estimates, management practices and socioeconomic conditions in the future. Most studies present only an arbitrary selection of available climate projections, despite the considerable spread between them, especially with respect to precipitation patterns, which may even yield different signs of the effect (27). Guidance for policy can best be drawn from a risk management perspective, studying specifically the probability of high impact scenarios. Rainfall patterns are the dominant climatic factor for agricultural production in Africa, although a new review of historical events has shown that sensitivity to higher temperatures could also be considerable (28). Of all major world regions, Africa is projected to rank highest in drought-caused yield reductions (29). Increasing temperatures exacerbate the effects of water and rainfall reductions and can partially remove any advantage occurring due to increased precipitation (21).

Overall, the more recent literature shows that the conclusion of the AR4 SYR, “Agricultural production […] in many African countries is projected to be severely compromised” (1), remains valid, also in its confidence rating (*high confidence*). Although there is still no comprehensive continent-wide assessment for all major cropping systems in Africa, the new results show more clearly how the current production systems might be impacted in regionally differing ways: Some regions are at risk of severe reduction or even total loss of agricultural production (6), while others could benefit from improved production conditions due to projected increases in precipitation. Some crops (like wheat) are more susceptible to warming than others (like millet), which is also reflected in model projections (7, 8). Climate impacts will vary by farm types, likely causing economic damage to farmers and national gross domestic product (GDP) (9, 19, 25). Future agricultural and development policies will have to consider these risks to current production systems, the livelihood of African farmers and the associated market and infrastructure (30).

Besides direct climate change impacts, it is also likely that climate change will exacerbate additional risks (31). Most of the quantitative assessments are mono-disciplinary and therefore disregard any mechanisms that affect agricultural productivity other than direct climate change effects. There are some qualitative studies that discuss the potentially severe impacts of indirect climate change effects such as cropland inundation, erosion, and salinization caused by sea level rise (32), altered crop resistance to insect damage (33), and the response of pests and pathogens to climate change (34). Against this background, the quantitative results presented in recent studies must be considered rather optimistic. The strength of CO_2 'fertilization' has a large effect on projected impacts (8), and is about the only process that could actually buffer against some of the more detrimental impacts of climate change. There is also some uncertainty embedded in the different methods used to project climate change impacts on African agriculture. Econometric models derive statistical relationships between farmers' incomes, production systems and environmental conditions, which is strongly limited by available reference data and the assumption that statistical relationships can be extrapolated over several decades into the future (25). Statistical models of agricultural productivity often have little explanatory power (18) and generally are – like econometric approaches – unsuitable for extrapolation to novel conditions such as climate change. Process-based models are often limited by the lack of site-specific parameterization of management options and varieties (8, 20) and the risk of over-tuning (35). A more detailed discussion of sources of uncertainty in projections of climate change impacts on African agriculture is presented in the supporting online material and in (35).

Climate change represents a significant threat to current African production systems, infrastructures and markets, and therefore farmers' livelihoods.

Undoubtedly, agriculture will have to change dramatically to meet future demands. This will be irrespective of climate change, given the largest population growth rates worldwide as well as the shifting patterns of food intake in the course of urbanization and development. Africa has huge potentials to increase its agricultural productivity with yield gaps of 10% (Egypt) to 90% (Angola) (10). Much of these inefficiencies in African agriculture can be explained by limited market access (10), affecting inter alia availability of fertilizers and pest control (12, 36). In economic terms, the risk of severe climate change impacts on agricultural production systems in Africa is therefore likely to affect a food production system which already struggles to meet the challenges of a changing global society (37).

Climate change impacts on African agriculture are of major concern not only to African farmers, but also to national governments, regional decision makers, and international organizations: Variability of crop yields has long been a major cause of migration in Africa (38). In one study, global warming is projected to increase the likelihood of civil wars in Africa (39), partly due to the potentially devastating effects on crop yields, although this view has been disputed (40, 41). Being already burdened with poverty, food insecurity and low adaptive capacity, African societies are most vulnerable to climate change. While vulnerability to climate change is very unevenly distributed across Africa (42), the potentially damaging climate effects and risks pose serious threats to sustainable development in many parts of Africa (43). The crucial role of climate change – with both its beneficial as well as its damaging potential – are beginning to be reflected in development cooperation programs and will need to continue to do so (44).

The overall picture may seem diffuse and unsuited for clear conclusions: following the IPCC confidence rating guideline (45), there is *very high confidence* that climate change will negatively affect at least parts of African agriculture (14 out of 14 studies), while simultaneously, there is also *high confidence* that African agriculture will be partly affected positively by climate change (12 out of 14). As there are so many climatic and non-climatic aspects that determine agricultural productivity that are mainly not considered in these studies, there is only *low confidence* in what the overall impact of climate change on African agriculture will be. Despite all uncertainty in climate change and impact projections and incomplete coverage, there are already robust conclusions for policy makers and research agendas. There is broad consensus among the studies that all of African agriculture runs some risk to be negatively affected by climate change, i.e. no one is on the safe side. Existing cropping systems will have to change and scientists need to provide more information on what suitable adaptation options are. Assessing potential impacts has helped to make the AR4 finding indisputable that "Agricultural production […] in many African countries is projected to be severely compromised", but now this needs to be accompanied by an evaluation of adaptation measures as well as strategies for increasing resilience and coping with risks (14). There are also first indications on which adaptation measures are more promising than others: changes in crop mixes (7, 8) need to be accompanied by increased international trade (46) which needs to be facilitated by better infrastructure, in particular roads (8). How African societies can generate the income to increase imports as proposed by Parry et al. 2005 (46) and others remains yet to be answered. International engagement in African agricultural production systems, in which foreign countries or companies claim parts of Africa's productive cropland, may yield some development and income opportunities but also constitutes risks to food security (47) and needs to be critically evaluated by policy makers. Science will have to show if and how "Agricultural production [...] in many African countries" can be significantly improved (48).

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Supporting Online Material for

Climate change risks for African agriculture

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Table S1: 'Line of sight' from the key statement about African food security in the IPCC Synthesis Report (SYR) to underlying chapters and summaries

	SYR	**"By 2020, in some countries, yields from rain-fed agriculture could be reduced by up to 50%."**, preceding the main point in the associated paragraph: **"Agricultural production, including access to food, in many African countries is projected to be severely compromised. This would further adversely affect food security and exacerbate malnutrition."**
based on	WGII SPM	**"In some countries, yields from rain-fed agriculture could be reduced by up to 50% by 2020"**, at the end of a paragraph on food security in Africa: **"Agricultural production, including access to food, in many African countries and regions is projected to be severely compromised by climate variability and change. The area suitable for agriculture, the length of growing seasons and yield potential, particularly along the margins of semi-arid and arid areas, are expected to decrease. This would further adversely affect food security and exacerbate malnutrition in the continent. In some countries, yields from rain-fed agriculture could be reduced by up to 50% by 2020"**. The WGII SPM conclusion is linked to sections 9.2, 9.4 and 9.6 which integrate present sensitivity, projected effects and interactions with non climate stressors to provide the basis for the conclusion.
referring to	WG II 9.4.4	**"In other countries, additional risks that could be exacerbated by climate change include greater erosion, deficiencies in yields from rain-fed agriculture of up to 50% during the 2000-2020 period, and reductions in crop growth period (Agoumi, 2003)."** (1, page 448). The paragraph in which this text occurs describes a range of risks additional to those discussed in preceding paragraphs, including declines in net crop revenue and loss of national agricultural production in Egypt. In each case the **"deficiencies in yields form rain-fed agriculture of up to 50% during the 2000-2020 period"**, are described as a climate change impact in Agoumi 2003 (2, page 5)
referring to	Agoumi 2003	**"Studies on the future of vital agriculture in the region have shown the following risks, which are linked to climate change: […] deficient yields from rain-based agriculture of up to 50 per cent during the 2000–2020 period"**, which in turn is based on *Initial National Communications to the UNFCCC* by three countries (Algeria, Morocco, and Tunisia)[1]:
referring to	Morocco 2001	Morocco projects cereal production to experience up to 50% reductions due to climate change: **"The study of CC impacts on agriculture (dominated by cereal cultivation) in 2020 unfolds the following results: A decrease in cereal yields by 50% in dry years and 10% in normal years."** (3, page 11)
	Tunisia 2001	Tunisia does not assess any impact on agriculture: **"As for the vulnerability, apart from the impact of Sea Level Rise, no study has been conducted, to this date, on the vulnerability of forests and continental agriculture to Climate Change, and on the identification of adaptation measures."** (4, page 25)
	Algeria 2001	Algeria applies assumptions on technological and management improvements that lead to considerable yield increases in 2020. Climate change impacts are projected to **reduce cereal yields by 0.1 to 13.9% in 2020** (5, page 95, table 47).

[1] Initial National Communications to the UNFCCC from Algeria, Morocco, and Tunisia, presented at COP-7 in October 2001. These communications are available at the Web site of the United Nations Framework Convention on Climate Change (UNFCCC).

Table S2: Recent studies about quantitative climate change impacts on African agriculture (published after IPCC AR4 WGII literature cut-off deadline, April 21, 2006)

Reference	Method	Reference area	Time horizon	Resolution	Max damage [%]	Min damage / max benefit [%]
Cline 2007 (6)	Ricardian	Africa	2080s	countries	-100	64
Benhin 2008 (7)[2]	Ricardian	South Africa	2050 2100	-/-	-27.74 -89.39	-1.15 -8.82
Liu et al. 2008 (8)	process-based model (GEPIC)	SSA	2030s	grid (30‘ lon / lat)	<-50	>+50
Liu et al. 2008 (8)	process-based model (GEPIC)	SSA	2030s	countries	<-20	>+20
Lobell et al. 2008 (9)	statistics	SSA	2030s	sub-regions	-40	+30
Paeth et al. 2008 (10)	statistics	Benin	2020s	Benin	-17	-9.1
Seo et Mendelsohn 2008 (11)	econometric, livestock sector	Africa	2020 / 2050 / 2100		-25	+168
Walker & Schulze 2008 (12)	process-based model (CERES)	South Africa	stylized scenarios (2070-2100)	catchments	-28	+33.8
Müller et al. 2009 (13)	process-based model (LPJmL)	SSA & North Africa/Middle East		regions	-12.9	+17.3
Nelson et al. 2009 (14)	process-based model (DSSAT)	SSA & North Africa / Middle East		regions	-84.2	+61.8
Seo et al. 2009 (15)	Ricardian	Africa	2100	Agro-Ecological Zones	-62	+135
Thornton et al. 2009 (16)	process-based model (DSSAT)	East Africa	2050	sub-regions	-15	-1
Thornton et al. 2009 (16)	process-based model (DSSAT)	East Africa	2050	grid (10’ lon/lat)	<-20	>+20
Thornton et al. 2010 (17)	process-based model (DSSAT)		2050	random selection of highly impacted grid pixels (10’ lon/lat)	-65	-35
Schlenker et Lobell 2010 (18)	statistics	SSA	2046-2065	-/-	-37	12
Schlenker et Lobell 2010 (18)	statistics	SSA	2046-2065	Maize in SSA countries	-57	-7
Tan et al. 2010 (19)	process-based	Bawku savanna zone in NE Ghana,	Time series but only 2100 is discussed	-/-	-41	52

[2] Already assessed in the AR4 WGII report as ref. (*7*)

Table S3: Recent qualitative impact assessments of climate change on African agriculture (published after IPCC AR4 WGII literature cut-off deadline, April 21, 2006)

Reference	Method	Reference area	Time horizon	Statement
Burke et al. 2009 (20)	analysis of GCM projections	Africa	2025 / 2050 / 2075	"If breeding efforts cannot sustain yield for maize for these hottest climates in the face of warming temperatures, switches to potentially more heat-and drought tolerant crops, such as sorghum and millet, could be necessary." "With maize, for example, 28% of the population of Africa lives in countries where less than half of the area will have an analog in the current climate of locations in their own country."
Funk et al. 2008 (21)	empirical relationships, analysis of GCM projections	Eastern & Southern Africa	21st century	"These anthropogenic drought tendencies may be indicative of other 'Indian Rim' and South American countries as well, because similar precipitation reformulations also suggest 21st century main season declines (40), with the result that main growing season droughts may disproportionately affect tropical and subtropical countries. Global assessments of anthropogenic precipitation (13) and yield (18) changes may be underestimating these drought signals."
Jones and Thornton 2009 (22)	analysis of GCM projections	Africa	2050	"Under even a moderate GHG-emission scenario for the coming decades, there are likely to be substantial shifts in the patterns of African cropping and livestock keeping to the middle of the century." "Climate change impacts in some of the marginal cropping lands of Africa are likely to be severe, and poverty rates in these areas are already high. Results of this analysis suggest further that the poor in the more remote transition zones are likely to be disproportionately affected."
Li et al. 2009 (23)	drought risk assessment, analysis of GCM projections	global	2050 / 2100	"Among the regions, Africa is ranked as the highest, with a baseline drought risk index value of 95.77 which increases to 205.46 in 2100 projections. Correspondingly, the rates of yield reduction related to drought disaster for major crops will increase significantly with future climate change, by >50% in 2050 and almost 90% in 2100 for the major crops."
Battisti and Naylor 2009 (24)	historical analogues, analysis of GCM projections	global	2050	"If growing season temperatures by the end of the 21st century remain chronically high and greatly exceed the hottest temperature on record throughout much of the world, not just for these three examples, then global food security will be severely jeopardized unless large adaptation investments are made. Climate model projections from the IPCC 2007 assessment suggest that this outcome is indeed very likely (Fig. 3). Figure 3A shows that, as early as 2050, the median projected summer temperature is expected to be higher than any year on record in most tropical areas. By the end of the century, it is very likely (greater than 90% chance) that a large proportion of tropical and subtropical Asia and Africa will experience unprecedented seasonal average temperature [..]"
Blignaut et al. 2009 (25)	statistical analysis	South Africa	historic	"A 1% decline in rainfall is likely to lead to a decline in maize production of 1.16% and a decline in wheat production of 0.5%. Such a decline in rainfall is also likely to lead to a decline in net income in the most productive provinces."

Text S1: Sources of uncertainty in recent assessments of climate change risks for African agriculture

The published impact assessments employ various methods, input data, and assumptions to project climate change impacts. For a better understanding of the different levels of uncertainty, we give a short overview of the different sources of uncertainty, comprising the level of aggregation, input data used (i.e. climate projections), other system dynamics considered (e.g., CO_2 fertilization, adaptation).

The first level of uncertainty in climate change impact assessments is inherent in the range of climate change projections, which are used as input for climate change impact assessments. Projections of climate change as provided by climate models are driven by emission scenarios. Emission scenarios are plausible future projections of energy demand and supply. These may include assumptions about technological progress (26) as well as other socio-economic factors, which are all inherently uncertain. Guided by the IPCC process, a broad range of possible emission scenarios has been implemented by a number of climate models, which also differ significantly in their projected patterns and magnitude of changing temperature and rainfall (27, 28). Nearly always, only a small selection of available climate change projections is used in impact assessments, and only occasionally the uncertainty inherent in different climate change projections is addressed explicitly (13). Most of the time, between two and five climate realizations are analyzed in parallel, or stylized scenarios are being employed (12). Climate scenarios are usually computed and provided at much coarser scales than typical operational scales of crop models. Most model applications need to downscale climate projections, adding a new dimension of uncertainty (e.g. 29). Consequently, most projections of climate change impacts on African agriculture exclude important aspects of climate change such as e.g. changes in short-term weather variability.

Impact models used to assess the effects of climate change on African agriculture employ a variety of methods that differ in their suitability for climate change impact projections. Statistical methods, both used in bio-physical as well as econometric analyses are generally unsuitable for extrapolation to novel conditions. Climate change is projected to move weather patterns out of the range of observed variability (20), limiting the applicability of statistical methods. Econometric models are strongly limited by data availability, as they derive statistical relationships between farmers' incomes, production systems and environmental conditions (15). Statistical models that describe agricultural productivity as a function of weather conditions often have little explanatory power (9). Process-based models are often limited by the lack of site-specific parameterization of management options and varieties (13, 14) and the risk of over-tuning (30).

The level of aggregation is another reason for differences in reported impact ranges. For specific locations and crops, impacts are reported to range between severe damages and significant increases: Some regions in Africa are likely to undergo changes to more severe conditions (drier, hotter) (21), while others may experience improved cropping conditions (wetter, warmer in temperature-limited highlands). Crops also respond differently depending on their sensitivity to changing heat, water stress, and possible CO_2 fertilization. Wheat, for example, has a low temperature optimum and is projected to experience strong yield reductions in Africa, while millet, with its higher temperature optimum, is projected to mainly benefit from climate change (8, 14). The complexity of different cropping systems, crop types, and crop varieties is often poorly represented in impact models, although there are attempts to link crop variety parameters to environmental conditions, assuming an adaptation of crop varieties to climate change (31). Due to the heterogeneous spatial patterns of climate change and the complexity of cropping systems, reported climate change impacts tend to be more moderate if reported at higher aggregation levels, as positive and negative responses to climate change may cancel out. This has been demonstrated by e.g. Liu et al. 2008 (8) and Thornton et al. 2010 (17), who provide results at grid cell level as well as national summaries.

Uncertainties from climate forcings and impact models are compounded by system dynamics other than climate change and the assumptions that are being made about them. One of the most crucial aspects is the direct impact of enhanced atmospheric CO_2 on plant growth, which should principally be capable of increasing crop yields considerably due to two processes: i) enhanced carbon assimilation rates, and ii) improved water-use efficiency (32). There is some experimental evidence for "CO_2 fertilization" in various crops such as wheat and cotton (33), but the validity of these findings for larger regions and entire cropping systems is uncertain. First of all, increased carbon assimilation rates can only be converted into productive plant tissue or the only economically relevant part, the harvested storage organs, if sufficient nutrients are available to sustain the additional growth. Where growth is already constrained by nutrient limitations, additional growth will be very limited (33). On top of that, there are indications that key factors of quality of agricultural products may decrease under increased CO_2, e.g., by reduced protein content (34). Some crops grown under elevated CO_2 have been found to be more susceptible to insects and pests (35, 36) or display reduced ability to assimilate nitrogen (37).

Other examples of non-climatic drivers of change include the development of management schemes, technological progress, land-use change, or soil degradation. For some of these non-climatic drivers of change, adaptation may be assumed to occur easily (e.g., by adjustment of cropping periods with changing climate), others are unlikely to happen without major adaptation efforts (24). For a more detailed discussion of non-climatic drivers of changes in agricultural productivity see Chalinor et al. 2007 (30).

Text S2: Additional explanations to the figure in the main text

The reference Ben08 (7) had already been assessed for the AR4 WGII report as (38); Seo08 refer to the livestock sector only; Tho10 report pixel-based results only for a random selection of strongly impacted pixels; Sch10 show country data only for maize; Wal08 employ stylized scenarios that are representative for the climate in 2070-2100; Tan10 refer to NE Ghana only.

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