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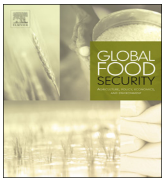

Reducing risks to food security from climate change

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ABSTRACT

Climate change will have far-reaching impacts on crop, livestock and fisheries production, and will change the prevalence of crop pests. Many of these impacts are already measurable. Climate impact studies are dominated by those on crop yields despite the limitations of climate-crop modelling, with very little attention paid to more systems components of cropping, let alone other dimensions of food security. Given the serious threats to food security, attention should shift to an action-oriented research agenda, where we see four key challenges: (a) changing the culture of research; (b) deriving stakeholder-driven portfolios of options for farmers, communities and countries; (c) ensuring that adaptation actions are relevant to those most vulnerable to climate change; (d) combining adaptation and mitigation.

1. Introduction

Reducing risks to food security from climate change is one of the major challenges of the 21st century. The impacts of climate change on crop yield can already be detected in observed data (Lobell et al., 2011). Climate impact studies on crops predominate, but impacts on fisheries and livestock production are no less serious (Creighton et al., 2015; Herrero et al., 2015). Whereas slow changes, such as rising temperatures and sea level, will only have major impacts in the coming decades, farmers already have to deal with changing weather patterns and rising frequency and intensity of extreme weather events, making farming even more risky (IPCC, 2012). Adaptation actions to reduce risks are urgent.

In many applied disciplines, there is a gap between research and implementation, variously termed the research-implementation, research-practice, knowing-doing or science-policy gap (Knight et al., 2008). With climate change there is the additional problem of deep uncertainties – not knowing the exact shape of future climates or even the next season, and these uncertainties are unlikely to go away in the next decade (Heal and Millner, 2014). But decision-making in the face of uncertainty is by no means unique to the climate change challenge (Beven and Alcock, 2012). We must seek tools and processes whereby uncertain knowledge can drive action.

We posit that, given the limitations of doing yet more impact studies (in particular crop-focused studies – Section 2) and given the seriousness of climate change (Section 3), the research emphasis should shift to supporting implementation of solutions for food insecurity (Section 4). As Heal and Millner (2014) note, we have more than enough information about climate change and variability to understand that it is a serious problem that requires immediate attention.

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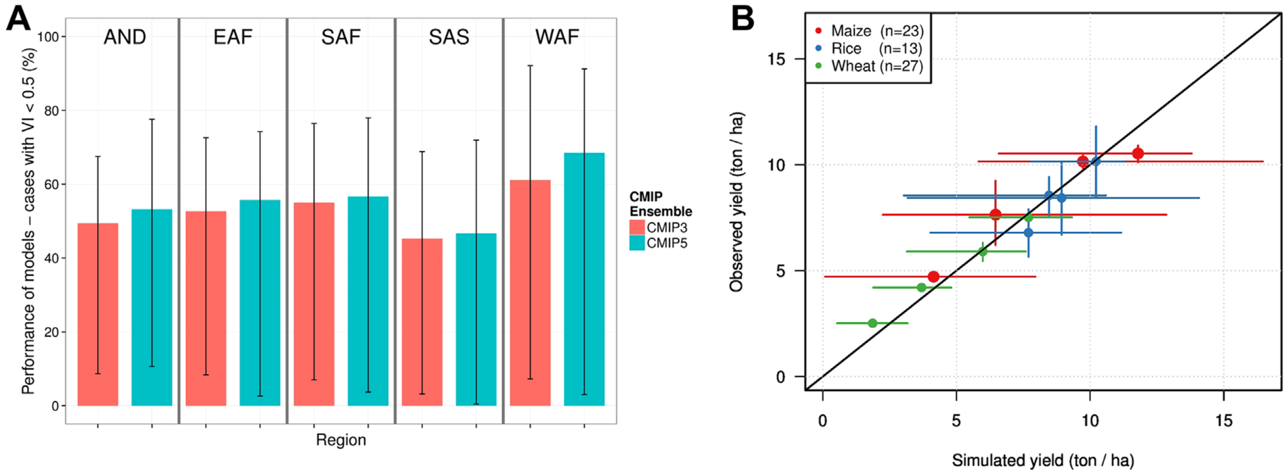

Fig. 1. Climate and crop model performance. (A) Improvement in CMIP climate model performance in representing interannual variability of temperature (from CMIP3 to CMIP5) across different regions (Ramirez-Villegas et al., 2013); (B) Summary of multi-crop-model evaluations for maize (Bassu et al., 2014), rice (Li et al., 2015), and wheat (Asseng et al., 2013). For A, model performance is measured as the number of country* season combinations with a variability index (VI) below VI=0.5, that denotes good model performance. Bars show the average of all GCMs and error lines span the range of variation of individual GCM simulations of each ensemble. AND: Andes, EAF: East Africa, SAF: Southern Africa, SAS: South Asia, WAF: West Africa. For B, each point shows the average of observations and median of simulations for 23 (maize), 13 (rice) and 27 (wheat) crop simulation models for a given site where model evaluations were carried out (4 sites for each crop). Horizontal error bars show maximum and minimum simulated yield in the ensemble of models, and vertical error bars show observational error.

2. Knowledge limitations about climate change risks to food security

2.1. Crop-climate models limiting for food production impact studies

Crop-climate modelling is central to the development of future agricultural outlooks that can inform policy processes and/or field-level decisions (Porter et al., 2014). Despite robust outcomes in certain situations model-based assessments of future agricultural productivity are subject to uncertainty. Uncertainties can limit the predictability of the system being modelled, and hence preclude adaptation decisions (Weaver et al., 2013). Thus, understanding relevant predictability limits as well as reducing uncertainty remain critical topics of future research (Vermeulen et al., 2013). In climate modelling, improvements in parameterisation and increases in model complexity and spatial resolution have resulted in enhanced model performance (Delworth et al., 2012). However, progress remains slow considering the requirements of the agricultural community (Fig. 1(A)), thus limiting our ability to project future agricultural productivity and land-use changes. Crop model uncertainty also limits assessments of future food production (Challinor et al., 2014b). Differences in crop model ensemble size, precision, and accuracy across crops and sites mean that the quality and quantity of information available to stakeholders varies depending on the crop system and areas (Fig. 1(B)) (Challinor et al., 2014a). Additional limitations are evident in crop-climate impact studies. Most notably, model limitations have precluded the study of mixed systems and minor crops that are prevalent across the tropics, and of nutritional outcomes (Challinor et al., 2014b; Thornton and Herrero, 2015). Our understanding of climate variability and extreme impacts is also limited (Porter et al., 2014).

2.2. Lack of attention to livestock, fisheries, pests and diseases, and interactions

Rivera-Ferre et al. (unpublished) demonstrate how the IPCC analysis of food security in the Fifth Assessment Report (AR5) is

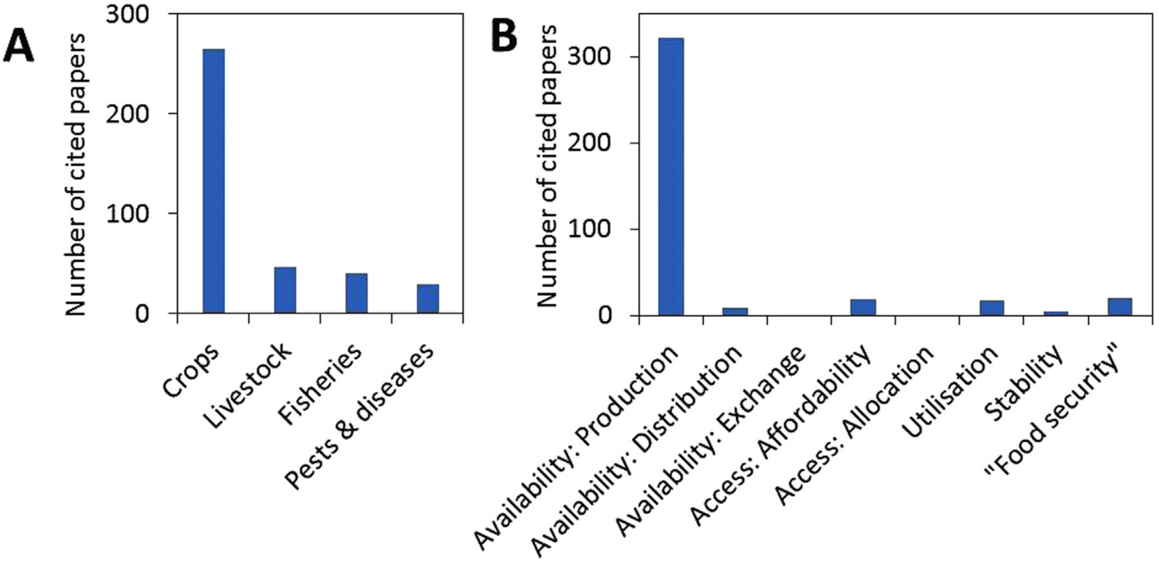

Fig. 2. Coverage in the food security chapter of AR5 of (A) sub-sectors, and pests and diseases; and (B) food security determinants. For (A) some citations are not mutually exclusive amongst categories (e.g. a few crop-livestock citations would be included in both sub-sectors). For (B) "Food security" covers food security in general terms.

largely crop-focussed, with minimal attention to livestock. And even in the cropping studies the focus is rather narrow – on crop yields, with little attention to crops as components of farming systems, value chains or landscapes. We extend their analysis to fisheries, and pests and diseases (Fig. 2(A)), which show similarly low levels of citation. More attention to these components is needed. There are significant increases in meat and milk consumption, with an estimated gross increase in meat and milk demand in the order of 70–80% of current levels by 2050 (Herrero et al., 2015). Thornton and Herrero (2015) call attention the lack of studies on how climate change and variability impact interactions between crops and livestock, given these interactions can be crucial in sustainable intensification, diversification and risk management. More than 1 billion poor people obtain most of their animal protein from fish, and there has been a spectacular growth in aquaculture, with 41% of fish consumed coming from farming (Beveridge et al., 2013). Pest and disease management has played a significant part in increasing production in the last decades. Yet pests and diseases still reduce global harvest by 10–16%, and are particularly problematic in developing countries (Chakraborty and Newton, 2011; Grace et al., 2015).

2.3. Lack of attention to broader food security determinants

Studies of impacts of climate change on food security focus on only one determinant of future food security: quantity of production, and largely from crops. Yet climate change will have impacts on all dimensions of food security, namely availability, access, utilisation and stability, and have impacts over the whole food system (see Vermeulen et al., 2012, for full food system coverage). Calls over the past five years to analyse food security outcomes from climate change in terms of whole food systems, not yields alone (Ziervogel and Ericksen, 2010), have been amplified in the 2014 IPCC report (Porter et al., 2014), which frames, for the first time in the IPCC's history, a food systems approach to understanding climate change impacts and adaptation options for food security. However, even that report maintains a focus on production (Fig. 2(B)). Emerging studies consider broader determinants of food security under climate change and climate variability. Examples include investigating the relationships between future irrigation potential and food trade in integrated impact modelling (Liu et al., 2014), or between food prices and conflict in statistical analysis of past climate volatility (Raleigh et al., 2015). This new food systems approach embraces demand-side solutions to achieving food security under climate change, particularly action on food waste and diets. It also seeks solutions that deliver good nutrition to individuals and households rather than merely securing sufficient available calories at national and global levels (Lang and Barling, 2013).

2.4. Much analysis, but action paralysis

A strong research-implementation gap is apparent (Knight et al., 2008; Fig. 3). The growing number of climate impact studies on crop yields, we would argue, provides marginal increases in knowledge. At the other extreme of the impacts-options-action continuum, there is minimal work on adaptation options and what works in different contexts, even if we also consider present climate risk management options rather than options needed for future climates. A quarter of the food security chapter of AR5 covers adaptation options, but this is mostly descriptive and theoretical, with less than 1% devoted to actual adaptation experiences. Frustration with this focus on impacts is now apparent in the literature. For example, Herrero et al. (2015) note the vast amounts of information on livestock and the environment, but call for the scientific agenda to turn its attention to practical options in the face of climate change.

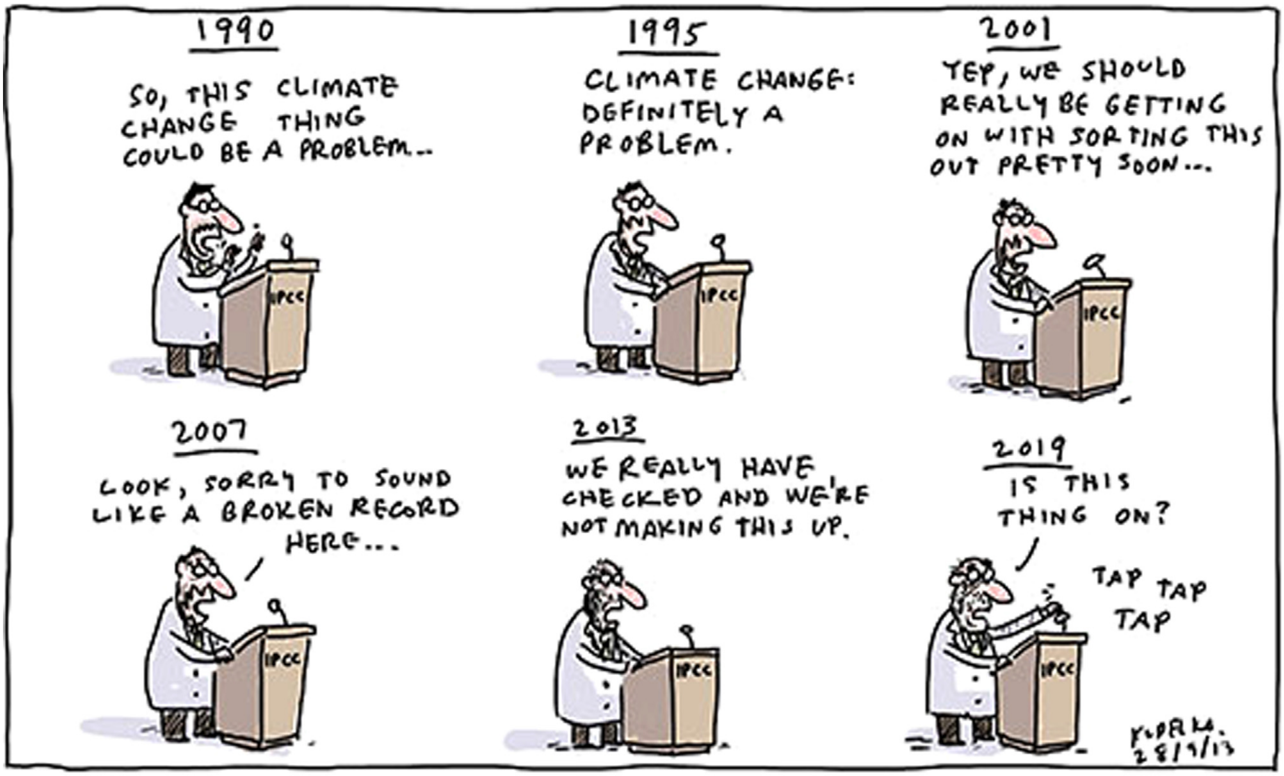

Fig. 3. Cartoon illustrating our frustration with climate impact studies of agriculture, whereby there are marginal improvements in knowledge, but much less focus on solutions and their implementation. Copyright: Jon Kudelka.

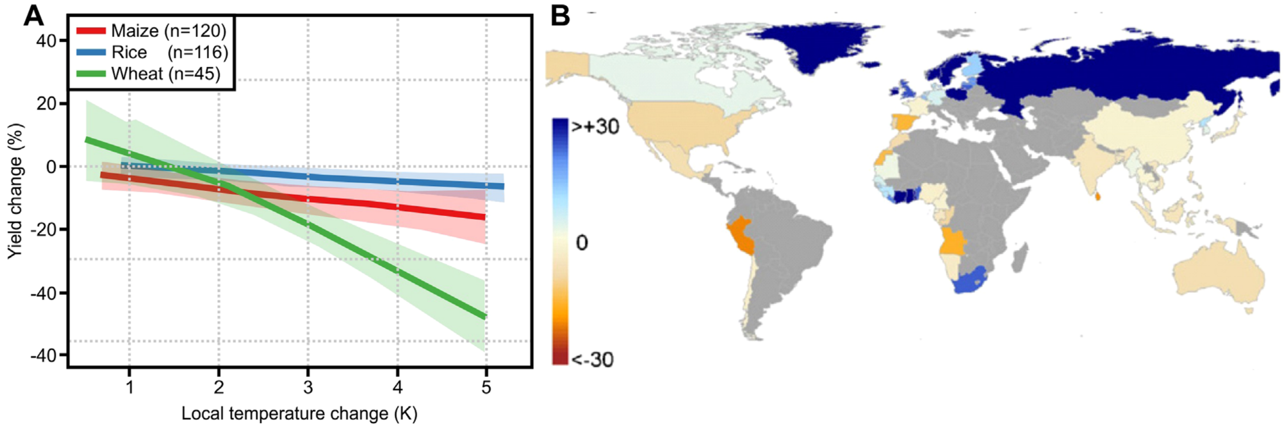

Fig. 4. Impacts of climate change on the productivity of tropical cereal crops (A) and fisheries (B). (A) Adapted from Porter et al. (2014), who develop yield response curves from a meta-analysis of published crop simulations. (B) Percentage change in fisheries production aggregated to the country level for select countries by 2050 (SRES-A1B) (Merino et al., 2012).

3. Impacts of climate change on food security

3.1. Crops, livestock and fisheries quantity and quality

Despite inherent limitations in crop-climate modelling (Section 2.1), model-based projections of climate change impacts indicate near certainty that global crop production will decrease as a result of climate change (Porter et al., 2014). Based on a meta-analysis of ~1700 model simulations, the most recent IPCC assessment demonstrated that, despite uncertainties, on average, global mean crop yields of rice, maize and wheat are projected to decrease between 3% and 10% per degree of warming above historical levels (Fig. 4(A)) (Challinor et al., 2014b). Consistent with this, a more recent global study estimated global wheat yield reductions of 6% per degree of warming (Asseng et al., 2014). Additionally, most evidence suggests reduced quality due to decreases in leaf and grain N, protein and macro- and micronutrient (Fe, Zn, Mn, Cu) concentrations associated with increased CO_2 concentrations and more variable and warmer climates (DaMatta et al., 2010).

Impacts on livestock systems will be mediated through reduced feed quantity and quality, changes in pest and disease prevalence, and direct impairment of production due to physiological stress. Growth and meat, egg and milk yield and quality decrease as temperatures go beyond 30 °C due to reduced feed intake (Thornton and Gerber, 2010). Barange et al. (2014) project 5–10% decreases in potential fish catch in tropical marine ecosystems by 2050 (though with much spatial variation) (Fig. 4(B)). Changes in the distribution of fish and plankton are also expected as suitable habitats shift with warming ocean temperatures, changes in winds, ice thickness, pH, and nutrient supply (Brander, 2010). Climate change will also change the prevalence of pests and increase the frequency of shock pest events, putting agricultural systems at greater risk during the 21st century (Bebber et al., 2013).

3.2. Access (affordability, functioning markets and policies)

Climate change will affect people's ability to access food chiefly via purchase. Most of the work in the AR5 (Fig. 2) on access relates to affordability of food in the future. Suites of interlinked climate, crop and economic models can be used to project agricultural commodity prices and trade into the future under different climate change and socio-economic scenarios, and results can be used to infer impacts on food affordability for specific populations. Studies have also been carried out on possible price impacts of sudden biophysical shocks (Nelson et al., 2014a). Such studies can give important indications about macro-level impacts of climate change on affordability in the future: food prices are projected to increase across a wider range of scenarios, but there are considerable differences between the results of different macro-economic models (Nelson et al., 2014b). Until this between-model uncertainty is reduced, analyses using ensembles of economic models may be needed. Affordability also depends on purchasing power of households (White et al., 2010), which may be affected by climate, especially among agricultural households. Considerable research has been done on exploring how households and communities adapt to climate shocks (Rufino et al., 2013). Both macro- and micro-level analyses are needed to understand how local communities may be affected as well as the covariate risks of climate change that affect broad regions. Climate change is also likely to affect the geography of production at large scales – shifts in areas of crop or livestock production suitability, for example (Havlik et al., 2014) – which could have substantial impacts on prices, trade flows and food access. Physical access to food may be affected by climate change via effects on transport systems and physical well-being (White et al., 2010). There are also issues associated with the allocation of food within households, for example to women and children, and how such allocation may be affected in a more variable climate.

3.3. Food quality and diversity

Climate change impacts food utilisation primarily through two dimensions: food safety through the supply chain, and health impacts from climate change that mediate nutritional outcomes. In general, climate change is likely to reduce food safety due to higher rates of microbial growth at increased temperatures (Hammond et al., 2015), particularly in fresh fruit and vegetables (Liu et al., 2013) and fisheries supply chains (Marques et al., 2010). Climate affects health via myriad pathways, including vector-borne diseases, heat stress and natural disasters, which in turn affect people's nutrition, plus their ability to provide care for children and dependents' food security (Costello et al., 2009). Water-related impacts of climate change, such as lower availability of water for sanitation (McDonald et al., 2011), or increased contamination of water due to increasing severity and frequency of floods (Uyttendaele et al., 2014), can also compromise food safety and health. Concern has been expressed that rising disease incidence will lead to overuse of pesticides and veterinary medicines, especially in fisheries (Tirado et al., 2010). Indirect effects of climate change on health, such as loss of jobs and livelihoods, or migration, or interrupted public health services, will disproportionately affect people who are already poor (Costello et al., 2009) and indigenous peoples (Ford, 2012), with negative outcomes for food security.

3.4. Stability and environment

Food security is linked directly and indirectly to ecosystems through provisioning (e.g. food, water, timber, genetic resources), regulating (e.g. climate, flood, disease, pollination), and supporting (e.g. soil formation, water cycling, nutrient cycling) services (Millennium Ecosystem Assessment, 2005). Climate change exacerbates the pressures on ecosystems (Cabell and Oelofse, 2012). For example, increasing temperatures and extreme events are leading to decreases in biodiversity and shifts in relationships within community assemblages (Oppenheimer et al., 2014), threatening productivity and resilience of current food systems (Khoury, 2014). Climate change and variability are also seen to undermine social and economic components of agricultural systems. Resource-poor and marginalized populations are the most vulnerable to climate change and threats to these groups may undermine communal resource regimes and exacerbate conflict (Oppenheimer et al., 2014).

4. Moving to an action agenda: four challenges

Research that informs action is needed to address the urgent climate risks to food security and the global challenge of reducing greenhouse gas emissions from all sectors, including agriculture. Research should address both incremental changes in production systems (e.g. constant attention to new varieties, different agronomic practices) as well as transformative changes such as exiting from agricultural livelihoods, changing diets (Hedenus et al., 2014), new trade regimes (Baldos and Hertel, 2015), and the implementation of widespread payments for environmental services and carbon markets (Newell et al., 2014). In this paper we propose four immediate challenges: changing the research culture to become more action-oriented; identifying climate-smart options for action; addressing social inequality in the action agenda; and addressing the mitigation challenge.

4.1. Changing the culture of research to focus on an action agenda

Incentives in most research systems reward publication of papers over solving problems and achieving outcomes. This leads to ever more sophisticated knowledge with little or no connection to policy-makers and practitioners (Knight et al., 2008). Climate change and food security research is bedevilled by uncertainty and needs to focus on delivering multiple and often conflicting objectives involving a range of stakeholders (e.g. different kinds of farmers, local service agencies, development agencies) where there are often winners and losers (Heal and Millner, 2014; Naess et al., 2015). Given the incentive system and the complexity the research-implementation gap is not surprising. The research-implementation gap has to be narrowed if progress on the urgent challenge of climate change (including variability) is to be achieved. By focussing on current climate variability, there is less excuse for inaction due to uncertainty.

Vermeulen and Campbell (2015) suggest that one of the principles to drive action-oriented research is “Allocate resources in three thirds – needs, research, capacity” (Fullana i Palmer et al., 2011). This stresses deep stakeholder engagement, with a third of resources devoted to working with next-users to build relationships and to define their needs from research, a third on research per se, and a third on enhancing next-users’ capacity to improve uptake of the research. Another principle is “Tackle power and influence”, a common theme in much political ecology literature (Naess et al., 2015): understanding, through engagement, where decisions are made, by whom and how decisions influence diverse stakeholders. With this knowledge, future research and engagement of particular stakeholders can be better targeted.

Multi-stakeholder platforms can be key mechanisms for engagement, dialogue and co-learning (Shackleton et al., 2015) (e.g. climate-smart villages – Box 1). Scenario development processes can also be powerful means to engage key stakeholders (e.g. change makers from public and private spheres) and develop plans that are implemented (Box 2) (Vervoort et al., 2014).

Whatever the tools or processes used, success needs to be measured by the degree to which they foster outcomes (e.g. scaled up practices, policy reforms that drive implementation). The disciplines or sectors involved need to be tailored to the challenges and opportunities – disciplinary perspectives should not be the starting point for problem identification. Modelling will often play a crucial role, but should not dominate the engagement process.

Box 1–Climate-Smart Villages (CSVs)

The adoption rate of technologies with the potential to reduce risks in agriculture is low in countries more vulnerable to climate change. For example, despite clear evidence, the adoption of improved water management practices and technologies among farmers in India in the last 40 years is only about 12% (Palanisami et al., 2015). CGIAR-CCAFS, in collaboration with national programmes, is partnering with rural communities to develop CSVs (generally clusters of villages or landscapes in some cases) as platforms where researchers, local partners, farmers’ groups and policy makers collaborate to select and trial a portfolio of technologies and institutional interventions. The focus is on the objectives of climate-smart agriculture (Lipper et al., 2014): enhancing productivity, incomes, climate resilience and mitigation (Aggarwal et al., 2013), though context-specific objectives are established by the stakeholders. The model puts emphasis on the involvement of farmers, village officials, civil society organizations, local government officials, community-based organizations (e.g. water user groups, forest user groups, and micro-finance institutions), private sector representatives, and researchers from the national agricultural research systems in design, implementation and monitoring of CSVs. By involving policy-makers, district officials and the private sector, lessons learnt can influence higher-level decisions so that successes can be scaled. The focus is on a basket of synergistic options, rather than on single technologies (Herrero et al., 2015). Major initiatives include (Fig. 5): i) strategic design of land use options based on agro-ecological analysis and farmer typologies, ii) promoting climate-smart technologies and maximizing synergies amongst interventions; iii) providing value-added weather services to local farmers to manage variability; iv) promoting weather-based insurance options for climate risk management; v) facilitating community partnership for knowledge sharing; and vi) capacity development in climate change adaptation. Adaptation technologies in the CSVs include water-smart practices (rainwater harvesting, laser land levelling, micro-irrigation, raised bed planting, change in crop establishment methods), weather-smart activities (ICT-based agro-advisories, index-based insurance, stress tolerant crop varieties), nutrient-smart practices (site specific nutrient management, precision fertilizers, residue management, legume catch-cropping), carbon- and energy-smart practices (agroforestry, conservation tillage, residue management, legumes, livestock management) and knowledge-smart activities (farmer-to-farmer learning, capacity development, community seed banks and cooperatives, crop diversification, market information and off-farm risk management).

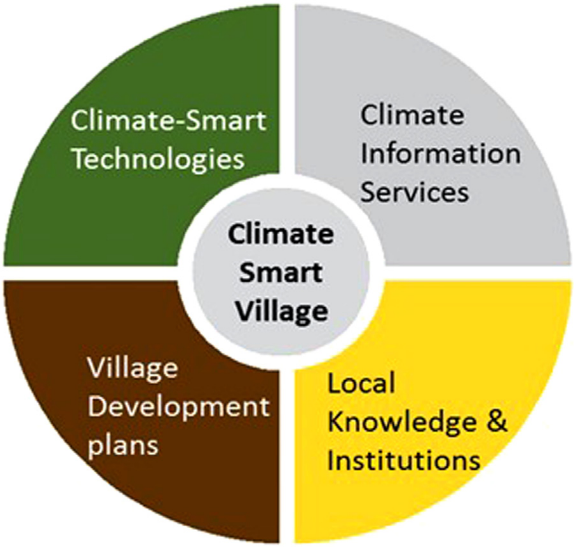

Fig. 5. Components of Climate-Smart Village.

Box 2–Scenarios: An innovative way to ′future-proof′ public and private planning and investments related to climate change

> How can private sector and government investments and policies guide appropriate actions at multiple levels, while taking diverse and uncertain interacting driving factors into account? CGIAR-CCAFS and partners have established regional and national scenario processes in several countries (Vervoort et al., 2014). Government officials, researchers and private sector representatives analyse challenges and opportunities presented within the different scenarios they envision. Scenarios can be quantified using economic models. The Costa Rica case shows how scenarios focus on practical questions and outcomes. In July 2015, with only 3 months left to submit its Intended Nationally Determined Contribution (INDC) to the UNFCCC, the Costa Rican government did not have official data on current emissions and future projections ready. “We did not have the data, how could we decide how to reduce emissions? What we needed was to focus those [national dialogue] workshops on policy discussions, not on data. It is about narratives, about visions in policies…” (pers. comm. Franklin Panigua, Ministry of Environment and Energy, Costa Rica). Using the scenarios approach, a first workshop was organized with national experts and decision makers in climate change issues from all sectors. They created four 2030 scenarios for Costa Rica under climate change that included emissions reduction in five sectors. They tested reduction strategies in the four scenarios to explore which of them would be effective under different future conditions, and what changes would be needed to implement the strategies. This resulted in a set of robust strategies for each sector within the INDC.

Modelling provides the means to evaluate alternative scenarios, explore trade-offs and clarify assumptions (Little and Lin, 2015). However, following Beven and Alcock (2012) it is recognized that given uncertainty and imperfect knowledge, sensible directions have to be driven by stakeholder choices, current challenges related to climate variability, and possible options.

4.2. Deriving stakeholder-driven portfolios of options for farmers, communities and countries

The second challenge relates to what action should look like in different contexts, from farm to national levels. Resources are scarce and should be directed to those actions with greatest benefits. Action is needed in the short-term and must be driven by careful prioritization. Addressing food security in the face of climate change requires multi-dimensional, cross-scale, and context-specific action. Action plans are frequently established in sectoral silos, limiting opportunities to build synergies and allocate investments in effective and efficient ways from a systems perspective. A portfolio approach for planning and implementing actions is intended to improve integration between actions, as suggested for climate-smart villages (Box 1), but can be applied at all levels. The resulting portfolio is a menu of best-bet options (Hallegatte, 2009). Planners tend to focus on on-farm technical interventions, but portfolios should also include services and programs to support technologies and wider development.

A number of criteria can be used to define what is a ‘best-bet’, for example options that have high expected impact, have synergistic effects, link with local knowledge and preferences, can be feasibly adopted, address current or future threats and changes, or minimize trade-offs across multiple-criteria (Herrero et al., 2015). Priority options vary among users and depend on biophysical, social, political and economic contexts. Timeframes for implementation are also critical, as some practices might be optimal for immediate implementation (e.g. in relation to climate variability)

Box 3–Climate-Smart Agriculture Prioritization Framework

> Given multiple objectives, multiple options and generally limited funding, decision-support frameworks help determine investment priorities. The CSA Prioritization Framework (CSA-PF) guides decision-makers through a process of narrowing down long lists of applicable CSA practices and services to investment portfolios (Fig. 6). The process integrates analytic tools into a process that ensures that stakeholder priorities are at the core of investment choices (Corner-Dolloff et al., 2014). A long list of CSA options is identified and the expected impact of interventions is qualitatively and quantitatively assessed based on co-designed indicators for food security/productivity, adaptation/resilience, and mitigation/low emissions development. The different goals of CSA (productivity, adaptation, mitigation) or the specific indicators of these goals (e.g. yield, labour, water use efficiency, emissions intensity, etc.) can be weighted based on the priority outcomes stakeholders hope interventions to achieve. A multi-stakeholder workshop explores the analyses. Through participatory methods stakeholders select a short list (usually 10-15) of options for further investigation. The short-listed options are then analysed in terms of economic costs and benefits, usually through a standard cost-benefit analysis that includes externalities of high concern to stakeholders. Through a stakeholder workshop, trade-offs within and between options in the short-list are explored. CSA options can be ranked in various ways, such as according to their aggregate impact on the CSA goals, or based on certain cost-benefit indicators (e.g. net present value, internal rate of return, payback period, etc.). The trade-offs between individual options as well as between portfolios of options are explored to determine the priority set of CSA options for investment. Differentiated portfolios can also be developed, for example for different user groups (e.g. resource-poor farmers, women), for specific challenges (e.g. drought), or for specific time scales (e.g. immediate vs. long-term planning). Barriers to adoption of practices on-farm and constraints within the socio-political environment for scaling-out CSA are also identified to determine the feasibility and timeline for investment, allowing actors to ground action plans for CSA activities within contextual realities.

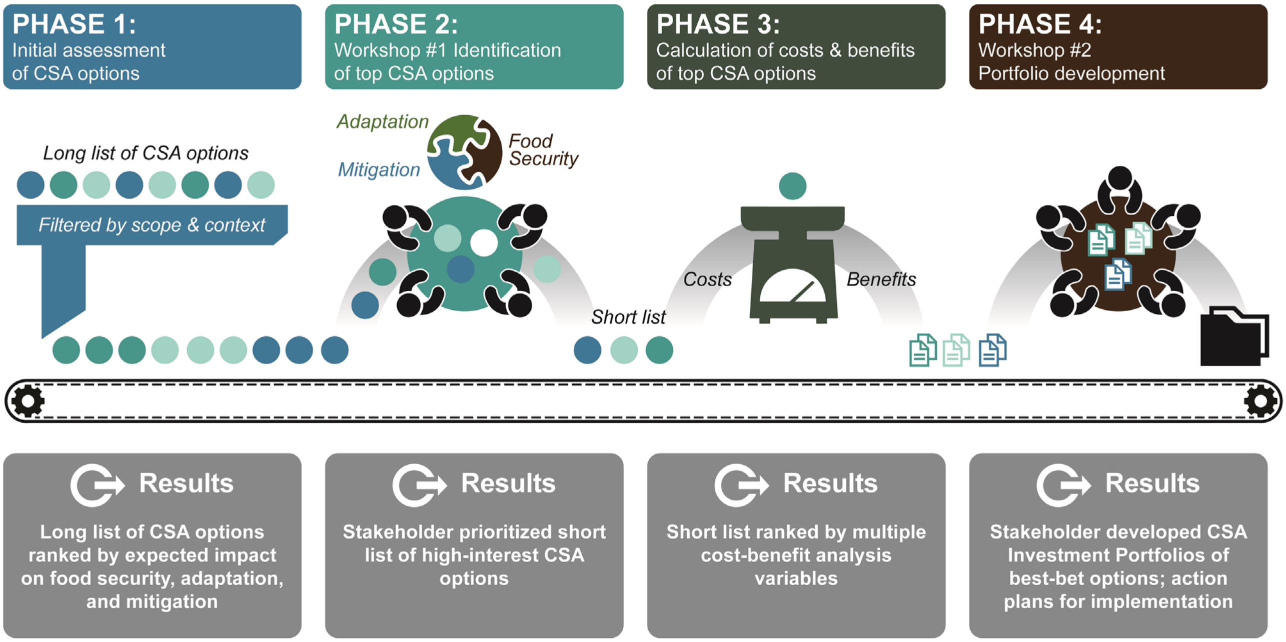

Fig. 6. Components of the Climate-Smart Agriculture Prioritization Framework process and subsequent results.

while others may be best applied in the future given projected changes in either climate or the policy environment. Priorities for portfolios can be identified and compared through various types of decision-support tools, such as top-down modelling approaches ( ) or bottom-up community planning approaches (Box 1), or tools that can be flexibly adjusted to different levels and systems to account for multiple perspectives (Box 3). “Likely if” options are developed through stakeholder-driven processes, as actual and perceived risk, uncertainty, and costs and benefits can shift with stakeholder priorities and contexts. The need for inclusive approaches and capacity development of end-users and implementing agencies, such as local governments, is generally well recognized (Chaudhury et al., 2013). Box 3 provides an example of a prioritization framework currently implemented in several countries at national and subnational levels, mostly with national government planners.

4.3. Ensuring that adaptation actions are relevant to those most vulnerable to climate change

The third challenge then is to ensure that adaptation actions take into account differential vulnerability to climate change. Vulnerability to climate change is determined by geographical, social, class, economic, ecological and political factors, which determine an individual or household's resources to achieve food security in the face of climatic shocks and trends (Sugden et al., 2014). Gender affects individuals’ and families’ exposure to risk, as well as their access to and control of resources, finance, land, technology and services (Quisumbing et al., 2015). In the context of agrarian stress, men's out-migration is a primary factor in climate change vulnerability. Reduced household resources put women at increased risk to shocks such as droughts, and reduce capacity to invest in off-farm activities (Sugden et al., 2014). Women's lack of access to information and extension, weaker participation in some social institutions and increased workloads under climatic stresses all affect adaptation (Wood et al., 2014). How can we be sure to implement actions that do not lead to further inequality?

New tools are emerging to understand social differentiation and enable more inclusive approaches to adaptation (Jost et al., 2014). For example, in Bolivia men prioritize interventions such as irrigation, while women prefer new crop varieties or diversified production (Ashwill et al., 2011). Farmer-led and gender-responsive technological innovation approaches in Honduras saw women re-design eco-stoves and develop improved agroforestry management systems. These women innovators have become more outspoken and active in the community beyond farming activities (Waters-Bayer et al., 2015). Gender-appropriate information channels and content – addressing women's activities and interests, literacy constraints and accessibility needs – will widen access to climate and weather information (Huyer, 2012). Conservation agriculture approaches that reduce women's labour and increase diversity can increase yields while also increasing household nutrition levels (Beuchelt and Badstue, 2013).

4.4. Combining adaptation and mitigation, while ensuring food security

Increasing food production by 60% by 2050 to meet future consumption trends (Alexandratos and Bruinsma, 2012) will also increase greenhouse gas emissions from agriculture, particularly from regions with low current productivity. Yet, to limit global warming by 2 °C above pre-industrial levels by 2100, IPCC scenarios indicate that agriculture must reduce emissions. To meet future food goals while minimizing further impacts on the climate, low emissions development (LED) options for producing food are needed. The fourth immediate challenge is to identify and test options and incentive systems that secure food using low emissions pathways. In this way, society can tackle the dual challenges of adaptation and mitigation.

The most promising outcomes compatible with future food security will arise from sequestering carbon through increased agroforestry or soil carbon and from avoided future emissions, through increased productivity, improved efficiency of inputs, reduced food loss or waste, diets based on lower emissions foods, and avoiding conversion of high carbon trees and forests. Future food production can be assessed using measures of the efficiency of emissions relative to food yields, or emissions intensity (Murray and Baker, 2011), to show whether relative emissions reductions occur as food production increases. Closing the emissions intensity gap by both increasing production and decreasing emissions should be the goal for sustainable food systems that include climate goals.

Box 4–Reducing emissions in paddy rice: the case of alternate wetting and drying (AWD) in rice

Alternate wetting and drying (AWD) is a technology with multiple benefits. It was introduced as a water saving technology in rice production in the early 2000 s but has since been found to reduce methane emission in rice production by an average of 43% compared to continuously flooded irrigated rice systems (Sanders et al., 2015). It also has other co-benefits like better root development, reduced lodging, lower damage due to pests and diseases, better soil conditions for machine operations, all without reducing yield (Richards and Sanders, 2014). AWD involves alternate draining and re-flooding 1-2 weeks after transplanting. The rice field is drained until the water level recedes to some 15 cm below the soil surface after which the field is re-flooded to a depth of around 5 cm before re-draining again. AWD has potential to reduce high emissions from irrigated rice. In Vietnam, AWD is now promoted in development projects and included in the National Green Growth Strategy, National Action Plan and National Target Programme on Climate Change Response, and Intended Nationally Determined Commitment (INDC). About 50,000 ha of rice lands are now under AWD, with another 245,000 ha having partial application. Key challenges in upscaling are identifying areas where AWD works as a mitigation option, dealing with real and perceived added costs and risks of applying AWD, for example labour inputs, and developing effective collaboration among stakeholders involved in irrigation and on-farm water management.

Many promising technical options for incremental change are already available, including increasing carbon sequestration in agricultural landscapes, reducing methane from paddy rice (Box 4) and livestock, and decreasing nitrous oxide from fertilizer use in cereal crops systems. While many of these actions are already promoted as best management practices, several challenges to action persist. Robust evidence is needed to demonstrate to investors and national governments that mitigating agricultural greenhouse gases can be achieved while also increasing yields in farmers' fields and not imposing other costs or constraints on farmers. Better information is needed about the financial viability and investment required to scale-up practices, including the costs and benefits for farmers for the transition to the new practice and its maintenance; the cost of improved technical advice, credit and inputs; and the cost of monitoring changes. Priority farming systems, agroecological zones and geographic areas need to be targeted to identify where currently known LED practices are most suitable and can achieve the most rapid and significant mitigation. This should involve future scenarios of crop demand and land use change (Box 2). Also, the impacts of proposed practices on vulnerable populations, including women, will need to be anticipated and monitored to insure socially inclusive development.

More transformative changes will also be needed, with promising opportunities for reaching large-scale impacts in the breeding of reduced methane ruminants and rice, breeding of nitrification inhibition traits in maize and wheat, shifting from beef to lower emissions food, and reducing food waste and loss. Policy-level incentives, whether carbon prices or enforcement of emissions targets, will be needed to stimulate political action and investment in higher cost and more extensive mitigation measures.

5. Conclusions

There are many studies of projected impacts of climate change on crop yields. Under-researched areas include impacts on broader cropping system issues (e.g. crops in a landscape context, value chains), on livestock and fisheries production systems, on pests and diseases, and on food security dimensions other than production. Despite uncertainty involved in climate impact studies and limitations to climate and crop models, it is clear that climate impacts on food security will be serious, and thus we advocate for more research that directly informs the actions needed to tackle food security challenges. While food systems will need transformative options in the coming decades, we identify four immediate challenges. The first is to change the culture of research to focus on outcomes. This will involve extensive stakeholder engagement. The second is to design and trial portfolios of options. Solutions will be highly context-specific, so we need a focus on prioritization approaches for the benefit of communities, projects and countries. Again stakeholder engagement is central to success. The third challenge is to achieve social inclusion through a focus on people who are most vulnerable to climate change. The final challenge is to address adaptation and mitigation together in the context of food security, at farm, national and global levels. To meet these challenges, science must work hand in hand with practitioners and policy-makers, to devise sensible options that meet current needs and capacities, try out best bets, and learn from experience.

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