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Review

Options for support to agriculture and food security under climate change

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ABSTRACT

Agriculture and food security are key sectors for intervention under climate change. Agricultural production is highly vulnerable even to 2C (low-end) predictions for global mean temperatures in 2100, with major implications for rural poverty and for both rural and urban food security. Agriculture also presents untapped opportunities for mitigation, given the large land area under crops and rangeland, and the additional mitigation potential of aquaculture. This paper presents a summary of current knowledge on options to support farmers, particularly smallholder farmers, in achieving food security through agriculture under climate change. Actions towards adaptation fall into two broad overlapping areas: (1) accelerated adaptation to progressive climate change over decadal time scales, for example integrated packages of technology, agronomy and policy options for farmers and food systems, and (2) better management of agricultural risks associated with increasing climate variability and extreme events, for example improved climate information services and safety nets. Maximization of agriculture's mitigation potential will require investments in technological innovation and agricultural intensification linked to increased efficiency of inputs, and creation of incentives and monitoring systems that are

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inclusive of smallholder farmers. Food systems faced with climate change need urgent, broad-based action in spite of uncertainties.

1. Introduction: food security and agricultural livelihoods in the face of climate change

Recent decades have seen global food production increasing in line with – and sometimes ahead of – demand. However, FAO projects that demand for cereals will increase by 70% by 2050, and will double in many low-income countries (FAO, 2006). Increasing demand for food is an outcome both of larger populations and higher per capita consumption among communities with growing incomes, particularly in Asia. Supply-side drivers include efficiency gains associated with vertical integration in industrial food supply chains (Reardon et al., 2004). To meet higher demand, food production is obviously of major importance. However, poor households' inability to secure food through markets and non-market channels may limit food security even where food is globally abundant (Barrett, 2002). For those who rely on subsistence agriculture, food security is strongly dependent on local food availability; for the majority who exchange cash, other commodities or labor for food, the access component is of critical importance, especially in relation to dietary diversity and nutrition.

According to FAO's most recent estimate, the number of people suffering from chronic hunger has increased from under 800 million in 1996 to over a billion (FAO, 2009a). Most of the world's hungry are in South Asia and sub-Saharan Africa. These regions have large rural populations, widespread poverty and extensive areas of low agricultural productivity due to steadily degrading resource bases, weak markets and high climatic risks. Farmers and landless laborers dependent on rainfed agriculture are particularly vulnerable due to high seasonal variability in rainfall, and endemic poverty that forces them to avoid risks. Climate change is of particular significance for these countries, which already grapple with global and regional environmental changes and significant interannual variability in climate (Arndt and Bacou, 2000; Haile, 2005). For example, changes in the mean and variability of climate will affect the hydrological cycle and crop production (Easterling et al., 2007) and land degradation (Sivakumar and Ndiang'ui, 2007). In recent times, food insecurity has increased in several such regions due to competing claims for land, water, labor, and capital, leading to more pressure to improve productivity.

Agriculture is highly sensitive to climate change. Even a 2C rise in global mean temperatures by 2100, in the range of the IPCC low emissions (B1) scenario, will destabilize current farming systems (Easterling et al., 2007). Climate change has the potential to transform food production, especially the patterns and productivity of crop, livestock and fishery systems, and to reconfigure food distribution, markets and access (Nelson et al., 2009; Liverman and Kapadia, 2010). The adaptive capacity of rural and urban communities confronted by economic and social shocks and changes is enormous, but needs ongoing, robust support (Adger et al., 2007). Climate change will bring further difficulties to millions of people for whom achieving food security is already problematic, and is perhaps humanity's most pressing challenge as we seek to nourish nine billion people by 2050 (Godfray et al., 2010).

This paper presents a summary of current knowledge on options to support farmers, particularly smallholder farmers, in achieving food security through agriculture under climate change. The paper has three sections, two dealing with adaptation and one with mitigation. Actions towards adaptation fall into two broad overlapping areas: (1) accelerated adaptation to progressive climate change over decadal time scales and (2) better management of agricultural risks associated with increasing climate variability and extreme events. Actions toward mitigation involve both carbon sequestration and reduction of emissions, and need to be designed to avoid negative impacts on livelihoods and food security. Together, actions in these areas provide the basis for achieving both food security and environmental benefits in the face of climate change (Fig. 1), subject to a variety of trade-offs and synergies as this article explores.

2. Accelerated adaptation to progressive climate change

Progressive climate change, which refers to long-term changes in the baseline climate (i.e. changes in absolute temperatures and shifts in rainfall regimes) over timespans of several decades, presents the overarching major challenge to agricultural and food systems in terms of both policy and science. The key question for both food security and the agricultural economy is whether the food system can keep pace with growing demand in the face of climate and other drivers (Hazell and Wood, 2008; Ziervogel and Ericksen, 2010). The major challenge is therefore to enable accelerated adaptation without threatening sensitive livelihood systems as they strive to cope with environmental stresses. Accomplishing this task requires a multi-pronged strategy: analysis of farming and food systems, learning from community-based approaches, generation and use of new technologies, changes in agricultural and food-supply practices including diversification of production systems, improved institutional settings, enabling policies, and infrastructural improvements, and above all a greater understanding of what is entailed in increasing adaptive capacity (Agrawal and Perrin, 2008).

2.1. *Crop breeding*

Overcoming abiotic stresses in crops through crop breeding has proven to be an effective means of increasing food production (Evenson and Gollin, 2003), and arguably mitigating climate change effects (Burney et al., 2010). There is also substantial biological potential for increasing crop yields through conventional crop breeding and biotechnology

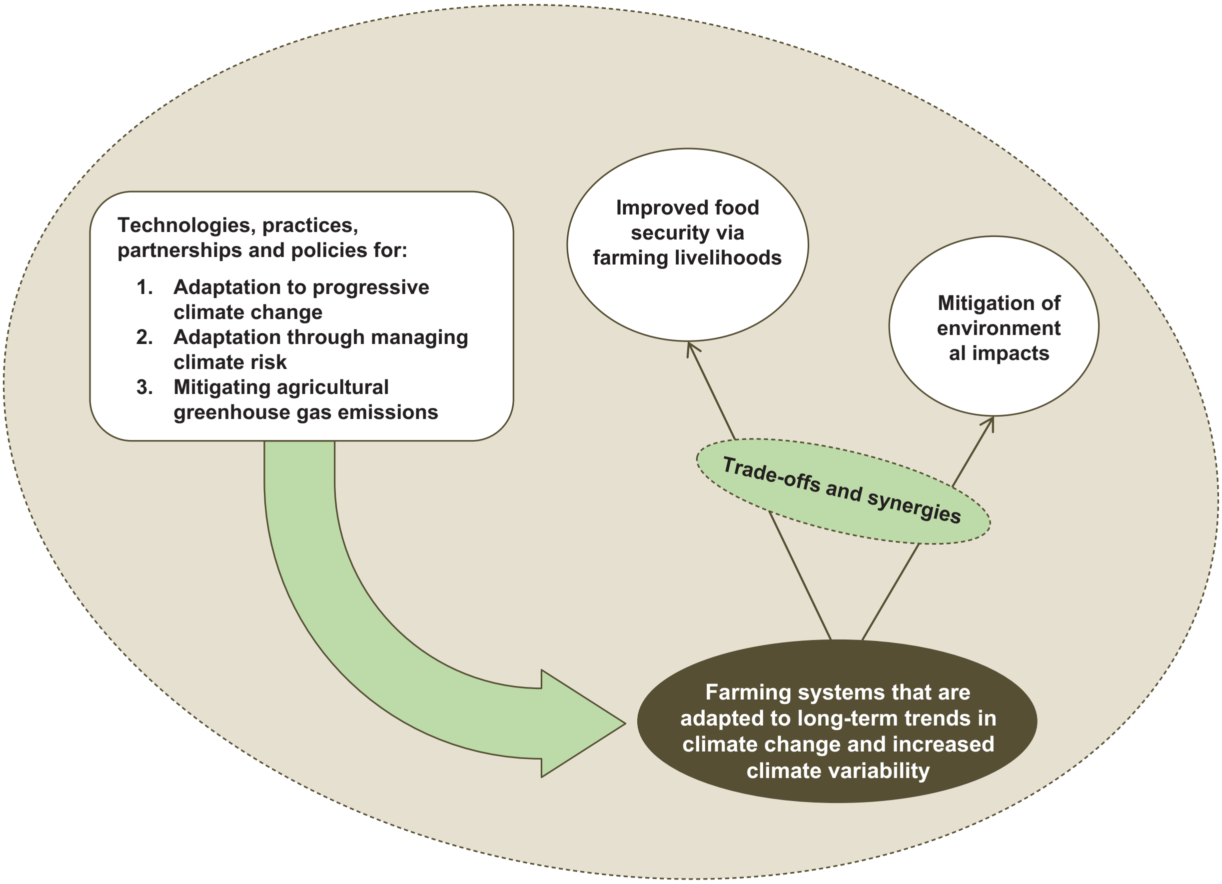

Fig. 1 – Options for support to agriculture and food security under climate change and pathways to impact.

(Godfray et al., 2010). Investment in crop improvement to address specific characteristics of a progressively changing climate (e.g. heat, drought, water logging, pest resistance) is therefore an important component of any global effort to adapt farming systems. Research from India, for example, shows that targeting investment effectively requires understanding exactly where different abiotic stresses dominate and matching crops to future climates in a way that accounts for uncertainties (Challinor et al., 2009). Crop breeding for future climates has greater chance of success if conducted with farmers, taking account of their ability and willingness to adopt new risks or input-intensive methods.

2.2. *Better agricultural practices*

Today's farming systems are adapted to current climate conditions, yet we know little about how well they will stand up to progressive climate change, particularly as they come under increasing pressure from other global drivers and entirely novel climates are encountered in many places (Williams et al., 2007). Many broad-scale analyses identify regions and crops that will be sensitive to progressive climate change (Parry et al., 2007; Jarvis et al., 2008; Lobell et al., 2008), but there is sparse scientific knowledge as to how current farming systems can adapt, and which current farming systems and agricultural practices will enable adaptation. As climates effectively migrate, the transfer of best practices from one site to the next will be crucial, though highly contingent on effective learning processes, local institutions, and farmers' perceptions of the value of participation. Many promising practices are grounded in local knowledge. For example, mid-season drainage in rice paddies, which reduces methane emissions but is also an adaptation strategy for water use efficiency, derives from traditional practice in China and Japan (Wassmann et al., 2009). The diversity of traits and characteristics among existing varieties of agricultural biodiversity (both inter- and intra-specific) provide enormous potential for adaptation to progressive climate change (Lane and Jarvis, 2007).

2.3. *Enabling policies in food systems*

Significant opportunities exist for national and sub-national policies that help enable adaptation at the community and household level. For example, policies that improve access and rights to water through investments in storage facilities or community-managed irrigation systems could aid rural communities in overcoming short- or long-term periods of drought (IWMI, 2009). The development of communal plans and strategies, such as the pooling of financial resources or food storage facilities, may also prove invaluable. At the national level, concrete policy options include subsidies and incentives for crop substitution or expensive farming inputs (e.g. agrochemicals, bovine vaccines), as well as investment plans for improved infrastructure for food systems (e.g. transport). Public and private sectors and civil society organizations must work together to ensure that adaptation plans and strategies are coordinated through food systems. For example, since climate change will likely lead to extreme seasonal or annual production shocks, and countries have historically responded by restricting trade or pursuing large purchases in international markets (e.g. Chinese rice in 2008, Russian wheat in 2010), global strategies may be necessary to address agricultural price volatility (Battisti and Naylor, 2009) and to manage impacts such as large-scale land acquisition for food production for foreign markets (Vermeulen and Cotula, 2010). Under uncertain and highly dynamic changes in food systems, there is a considerable risk of conflicting policies and investments contributing to maladaptation.

2.4. *Bringing understanding to the regional scale*

Studies of adaptation to progressive climate change yield different results depending on the crop and region studied. Even within a single country, crop varietal requirements under climate change can vary significantly. This makes regional studies such as those of the IPCC assessments an important part of interpreting models and statistical studies. However, in spite of this regional variation, there are common messages: the importance of extremes of temperature in sub-Saharan Africa (Lobell et al., 2011), Europe (Semenov and Shewry, 2011) and north-east China (Challinor et al., 2010), and the importance of changes in the length of the growing period across large geographical regions (e.g. Africa, Thornton et al., 2010; India, Challinor and Wheeler, 2008). Downscaling of climatic models and impact assessment to the regional level and decadal timescales is now among the key challenges for research.

3. Managing climate variability and risk

Climate change will be experienced largely as shifts in the frequency and magnitude of extreme events. Since many of the projected impacts of climate change are amplifications of the substantial challenges that climate variability already imposes on agriculture, particularly for smallholder, rainfed farming systems in tropical and sub-tropical drylands, better managing the risks associated with climate variability provides an immediate opportunity to adapt to future climate change. Climate shocks such as drought, flooding or heat waves lead not only to loss of life, but also long-term loss of livelihood through loss of productive assets, impaired health and destroyed infrastructure (Dercon, 2004; Carter et al., 2007). The uncertainty imposed by climate variability is a disincentive to investment in improved agricultural technology and market opportunities, prompting the risk-averse farmer to favor precautionary strategies that buffer against climatic extremes over activities that are more profitable on average (Hansen et al., 2011). Apart from effective intervention, projected increases in climate variability can be expected to intensify the cycle of poverty, vulnerability and dependence on external assistance. A comprehensive strategy for adapting agriculture and food systems to a changing climate must therefore exploit the full range of promising strategies for managing current climate-related risk.

3.1. *Seasonal forecasts for adaptive management*

Interaction between the atmosphere and the oceans provides the basis for forecasting climate conditions several months in advance. Seasonal climate forecasts, in principle, provide the opportunity for farmers to choose whether adopt new technologies and intensify production, or to opt for lower risk, lower return strategies. Research with smallholder farmers in low-income countries reveals a high level of interest and a range of promising management responses, but also highlights widespread communication failure (Hansen et al., 2011). Furthermore, there is a mismatch between farmers' needs and the scale, content, format, or accuracy of available information products and services. These factors have limited the widespread use of seasonal forecasts among smallholder farmers. Adoption rates and reported benefits have been moderately high in pilot projects in Zimbabwe and Burkina Faso that have overcome some of the communication barriers (Patt et al., 2005; Roncoli et al., 2009).

3.2. *Index insurance*

Index insurance is an innovation that triggers payouts based on a meteorological index correlated with agricultural losses (e.g. rainfall or modeled water stress), rather than actual observed losses. Basing payouts on an objectively measured index overcomes problems with moral hazard, adverse selection and the high cost of verifying losses (Hess and Syroka, 2005). Index insurance avoids the problems that make traditional crop insurance unviable for smallholder farmers, and has proven to be successful for example in India and Mexico (IFAD, 2010). Recent reviews of index insurance initiatives in low-income countries emphasize the need to develop a framework for targeting particular index insurance products to particular agricultural systems, build capacity in the private sector, bundle insurance within broader suites of services, and develop better indices, particularly where meteorological data are sparse (Hellmuth et al., 2009; Hazell et al., 2010).

3.3. *Managing climate-related risk through the food system*

The actions that governments and aid organizations take in response to climate shocks can have major impacts on farmers and local agricultural markets. Climate-driven price fluctuations can lead to acute food insecurity for the relatively poor who spend most of their incomes on food. Using climate-based forecasts of food production to better manage trade and stabilize prices offers considerable potential benefits to both agricultural producers and consumers (Arndt and Bacou, 2000; Hallstrom, 2004). Experience in sub-Saharan Africa shows that assistance, particularly food aid, in response to a major food crisis can have complex impacts on farmers and on agricultural markets (Barrett, 2002; Abdulai et al., 2004). Assistance can protect productive assets, foster investment and intensification through its insurance effect, and stimulate agricultural value chain development, but can also contribute to price fluctuations, disincentives to agricultural production and market development, and a cycle of dependency in poorly targeted and managed farming communities. Analysis of the timing and effectiveness of crisis relief in Africa shows that use of consumption and health indicators can improve targeting, but may delay relief sufficiently to increase the long-term livelihood impacts of the crisis (Haile, 2005). Improving the lead-time and accuracy of early-warning information provides an opportunity to support more timely interventions.

3.4. *Climate information services*

Several of the promising opportunities to manage agricultural risk depend on climate information and these are yet to be fully exploited, in part because of gaps in existing climate information services. The gaps appear to be widespread globally. A multi-stakeholder assessment of the use of climate information in Africa describes inadequate use of climate information across sectors and from local to policy levels (with a few noteworthy exceptions), relative to the scale of the development challenge (IRI, 2006). It attributed the substantial gap in the provision and use of climate information to market atrophy associated with long-term ineffective demand by development practitioners and inadequate supply of relevant climate information services. Positive responses to this gap include Regional Climate Outlook Forums (RCOFs), which bring together national meteorological services and a set of users from a region to produce authoritative, consensus seasonal climate forecasts, and to discuss their potential application (Patt et al., 2007).

3.5. *Local impacts and diversification*

The actual impacts of climate change on agricultural systems depend on location and adaptive capacity. There are very likely to be limits to how far households can adapt to a changing climate, and there will be places where climate change may necessitate major changes in livelihood strategies. Climate-induced livelihood and lifestyle transitions have long been documented in the drylands of Africa (Sperling, 1987). Future livelihood transitions might be expected for agro-pastoralists in arid or semi-arid African mixed crop-livestock systems, in favor of livestock (Jones and Thornton, 2009). Recent fieldwork in marginal areas of Uganda, Tanzania and Kenya indicates that householders are attempting to diversify their livelihood systems in any way they can, to combat what they perceive as increasingly variable weather (Thornton et al., 2011). If their rangelands become increasingly fragmented and restrict mobility of livestock, and they reach limits to diversification into non-agricultural activities, there may be few options other than migration to urban areas (New et al., 2011). There is still considerable work needed to understand when such thresholds might be reached in particular regions, however, as these processes are complex and site-specific. Bottom-up assessments of vulnerability hold promise as a means of responding to local priorities and complexities (Pielke et al., 2007).

4. Mitigating agricultural greenhouse gas emissions

In 2005 agriculture contributed an estimated 10–12% of total anthropogenic emissions of greenhouse gases (GHGs). Reducing N_2O and CH_4 emissions, increasing C sequestration, or avoiding emissions through use of biomass for fuels or reduced land clearing are technical options to reduce emissions (Smith et al., 2007a). Global climate mitigation by agriculture for the period 2015–2020 could achieve approximately 1000 Mt CO_2-eq. below the business-as-usual scenario through 10% reductions in greenhouse gas emissions in concert with similar levels of improvement in the substitution of fossil fuels by biomass energy. If deforestation through agricultural expansion were reduced by 10% for the period 2015–2020 through agricultural development pathways that involve intensification, about a further 500 Mt CO_2-eq. could be stored (Smith et al., 2008). Clearly, changes in agriculture can help reduce climate change, but whether society can also meet projected food needs under mitigation regimes remains unclear. Innovation and capacity building are required for improved farming practices and measurement techniques, and for appropriate institutions and incentives.

4.1. *Agricultural intensification*

Producing more crops from less land is the single most significant means of jointly achieving mitigation and food production in agriculture, assuming that the resulting ‘spared land’ sequesters more carbon or emits fewer GHGs than farm land (Robertson et al., 2000). The crop area in low-income countries is expected to expand 2–49% (Balmford et al., 2005), and avoided land conversions in the moist tropics are the most critical for mitigation (West et al., 2010). Agricultural intensification (or the increase of yields per unit land area) is widely assumed necessary to meet projected food needs, given current economic and dietary trends (Gregory et al., 2005). Yield gaps still exist for rice and maize (Tilman et al., 2002). Burney et al. (2010) demonstrated that increases in crop productivity from 1961 to 2005 helped to avoid up to 161 Gt of carbon emissions and were a relatively cost-effective intervention for mitigation, despite use of inputs that increased emissions. But this ‘land sparing’ effect of intensification is uneven in practice and requires policies and price incentives to strengthen its impacts (Angelsen and Kaimowitz, 2001). Investing in agricultural technologies to increase yields may have perverse effects, for example that farmers tend to expand land areas with intensification (Rudel et al., 2009). Future intensification will require more attention to the efficiency of inputs and their environmental costs (Gregory et al., 2002). More efficient use of fertilizers, pesticides and fossil fuels, more sustainable alternatives, and breeding for efficiency will be required to reduce the carbon intensity (emissions per unit yield) of products, as well as reduce land areas and inputs that damage environmental health.

4.2. *Technical compatibility*

The other major option is to farm in ways that reduce GHG emissions or sequester more carbon without reducing food production. The potential trade-offs and synergies between mitigation practices and food production have been well reviewed (FAO, 2009b). Enhancement of soil carbon through, for example, conservation tillage or management of crop residues (Lal, 2004), and to a lesser extent agroforestry (Verchot et al., 2007) or high productive grassland restoration (Smith et al., 2008), are expected to have significant impacts on climate without compromising food production. Enhancing soil carbon also has important environmental benefits in terms of water storage, soil biodiversity, and soil aggregate stability. Sustainable agricultural land management (SALM) is an umbrella term for practices expected to enhance productivity and mitigation. SALM should also enhance agroecosystem resilience and adaptation to climate change (Smith and Olesen, 2010). Soil carbon sequestration is estimated to have the highest economic mitigation potential (Smith et al., 2007a), although incentives for its adoption, as well as permanence, variability and monitoring, need to be addressed. FAO has shown that areas with large food-insecure populations also tend to have soils lacking carbon (FAO, 2009b), suggesting that these locations would be suitable for SALM approaches to mitigation.

4.3. *Measurement and monitoring*

Since mitigation measures can potentially affect the cost, yields and sustainability of food, getting more precise estimates of mitigation and its related effects on food systems is essential to assessing actual trade-offs. Mitigation potentials remain uncertain as most have been estimated through highly aggregated data (Paustian et al., 2004). At both local and national levels, greenhouse gas budgets for specific farm practices, foods and landscapes are often unavailable, especially in low-income countries. Full accounting of GHGs across all land uses will be necessary to account for leakage and to monitor the impacts of intensification. Measurement technologies are well known, but monitoring of indicators and life-cycle analysis can be expensive and interactions among farm practices difficult to assess. Current efforts of the Global Research Alliance are focused on research to measure and enhance mitigation in industrialized agriculture. These efforts are now being expanded into countries such as Ghana that have large numbers of smallholder farms, which are major contributors to emissions (Hickman et al., 2011). Comparable measurements are needed both for carbon intensity (CO_2-eq. per unit food or per tons yield) and land-based emissions (CO_2-eq. ha^{-1}) to compare efficiencies and aggregate among like units.

4.4. *Economic feasibility and incentives*

Knowledge of the economic feasibility of agricultural mitigation and its links to investments in food security needs improvement (Cannell, 2003). Smith et al. (2007b) estimate that less than 35% of the total biophysical potential for agricultural mitigation is likely to be achieved by 2030 due to economic constraints. Measurement costs and the transaction costs associated with start-up costs and aggregating among numerous smallholders are presently major barriers that require innovation. The uncertainty of carbon prices and the policies supporting them also presently limit the technical potential for implementing mitigation. Farmers and others driving the expansion of cultivated areas will require incentives to undertake mitigation practices. Lessons should be gleaned from existing national schemes for payments for environmental services programs to farmers, such as those that exist in Europe, Japan and USA (Tilman et al., 2002). International agreements that enable agricultural GHG reductions to count towards countries' commitments to emissions reductions could create an important policy incentive (Paustian et al., 2004). Understanding the potential for mitigation through alternative agricultural development pathways and the incentives driving them will be important for transforming agriculture towards more sustainable practices. Compliance with mitigation standards before receiving farm assistance, taxes on fertilizers or pesticides (or removal of subsidies), voluntary markets and consumer-related incentives related to labeling are additional options (Tilman et al., 2002). The revenues generated by even moderate levels of agricultural mitigation (USD20 per t CO_2) equivalent should yield USD30 billion in annual revenues that could also be used to encourage additional investments in mitigation or food (FAO, 2009c).

4.5. *Implications for policy support to GHG mitigation by smallholder farmers*

Smallholders should not be expected to bear costs of mitigation without compensatory benefits to incomes and livelihoods. Impacts on smallholders should be monitored. Investments in technological innovation and agricultural intensification strategies should be linked to increased efficiency of inputs, and to comprehensive land-use policies and payments for environmental services that discourage forest conversion and negative environmental impacts. Agricultural intensification will require appropriate institutional and policy support to create environmental benefits as well as increases in crop yields for smallholders (Pretty et al., 2003). Investments should also be made in technical and institutional innovations that reduce the costs of mitigation and increase incentives for the implementation of mitigation. These investments would enhance the technical biophysical potential for reducing GHGs from agriculture. Incentives for sustainable agricultural land management (SALM) are also needed, either through government programs or voluntary market payments, targeting first areas with high potential mitigation for highest impact. Technical compatibilities need to be field-tested on smallholder farms. A final priority is developing a better understanding of the GHG budgets for specific mitigation practices on farms and landscapes and for food products, alongside simple, inexpensive monitoring techniques for use in low-income countries.

5. Conclusion: broad-based action in the face of uncertainty

Significant uncertainty exists regarding the direction and magnitude of climate change, which in turn leads to uncertainty in the realm of food production and its impact on food systems and food security across complex geographies and societies. Food systems faced with climate change need urgent action in spite of uncertainties. The urgency of climate change provides a new impetus for paradigms of integrated research, policy and action. There is a pressing need to invest in databases and tools to inform policy and practice in the spheres of agricultural risk-management, adaptation and mitigation. Likewise, initiatives to develop capacity to tackle climate-change impacts on farming and food must address not only scientific capacity but also the capacity of users to demand, interpret and apply scientific outputs effectively. Decision-makers need not just a holistic view of the system but rather a strategic approach that focuses on key dependencies and processes. A key challenge in assuring future food security is to apply such approaches across the whole food system and across multi-purpose landscapes.

Action will need to move ahead of knowledge, with decisions made and reviewed on the basis of emerging research and consensus. This paper has provided a brief review of the state of knowledge in the key areas of managing climate variability and risks, accelerating adaptation to progressive climate change, and mitigating agricultural greenhouse gas emissions. We need to integrate and apply the best and most promising approaches, tools and technologies. The involvement of farmers, policy-makers, the private sector and civil society is vital. Successful mitigation and adaptation will entail changes in individual behavior, technology, institutions, agricultural systems and socio-economic systems. These changes cannot be achieved without improving interactions between scientists and decision-makers at all levels of society.

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