The impact of climate change on smallholder and subsistence agriculture

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Edited by William Easterling, Pennsylvania State University, University Park, PA, and accepted by the Editorial Board September 26, 2007 (received for review March 2, 2007)

Some of the most important impacts of global climate change will be felt among the populations, predominantly in developing countries, referred to as ''subsistence'' or ''smallholder'' farmers. Their vulnerability to climate change comes both from being predominantly located in the tropics, and from various socioeconomic, demographic, and policy trends limiting their capacity to adapt to change. However, these impacts will be difficult to model or predict because of (*i*) the lack of standardised definitions of these sorts of farming system, and therefore of standard data above the national level, (*ii*) intrinsic characteristics of these systems, particularly their complexity, their location-specificity, and their integration of agricultural and nonagricultural livelihood strategies, and (*iii*) their vulnerability to a range of climate-related and other stressors. Some recent work relevant to these farming systems is reviewed, a conceptual framework for understanding the diverse forms of impacts in an integrated manner is proposed, and future research needs are identified.

developing countries | subsistence farmers | vulnerability | livelihoods

Although both are widely used terms, there are surprisingly few published definitions of either ''subsistence agriculture'' or ''smallholder agriculture.'' Subsistence farming has been defined by Barnett *et al.* (1) as ''farming and associated activities which together form a livelihood strategy where the main output is consumed directly, where there are few if any purchased inputs and where only a minor proportion of output is marketed.'' However, the term is also sometimes used to denote the activity of self-provisioning with agricultural produce or a relative move toward such activity, as in developments in Eastern Europe following the end of the planned economies (2). It is also frequently used in a nontechnical sense to describe the rural poor of developing countries.[†] Such a usage diverts attention from the fact that market relations have entered deeply into agriculture in virtually all parts of the world, and that many of these farmers' most important problems stem from the terms of their inclusion in the market (3).

''Smallholder agriculture'' is used more generally to describe rural producers, predominantly in developing countries, who farm using mainly family labor and for whom the farm provides the principal source of income (4). Definition of ''peasants,'' for example as given by Ellis (3), are similar but give more emphasis to inclusion in wider economic systems and imperfect markets. ''Smallholder and subsistence farmers'' is used here to denote these farmers, who can be found on a continuum between subsistence production and concentration on crop production for the market. Definitions by scale are relative to national contexts, and ''smallholders'' in transitional or developed countries may have farms (and incomes) many times larger than those in developing countries.

Pastoralists, who almost all depend on the sale of livestock and livestock products to buy staple foods and other necessities (5) and people dependent on artisanal fisheries and aquaculture enterprises (6) are also included in this category. All suffer, in varying degrees, similar problems associated with isolation and low levels of technology, but also unpredictable exposure to world markets.

These systems have been characterized as ''complex, diverse and risk-prone'' (7). Farms are generally small, often held under traditional or informal tenure, and are in marginal or risk-prone environments. Soil-related constraints to productivity are widespread, severe, and increasing (8), although diversity of soils and farmer soil management strategies is also important (9). Production systems are complex and diverse in the combinations of plant and animal species exploited, the types of integration between them, the production objectives and the institutional arrangements for managing natural resources. Risks (10) are also various—drought and flood, crop and animal disease, and market shocks—and may be felt by individual households or entire communities. Smallholder and subsistence farmers and pastoralists often practice hunting/gathering of wild resources as well as crop and livestock production to fulfil energy, clothing, health, and cash income needs as well as direct food requirements (11). They also widely participate in off-farm and/or nonfarm employment (12). Beyond these points, smallholder agriculture is subject to what has been called ''the centrality of the social:'' its grounding in social relations within households (particularly gender relations) and between households, profoundly affecting the negotiation of production decisions, management of knowledge, and marketing (13).

Given the lack of clear and standardized definitions of these categories, there are few informed estimates of world or regional population of smallholder or subsistence farmers (14). The United Nations Food and Agriculture Organization (FAO), for example, does not publish data disaggregated to these categories. Although not all smallholders, even in developing countries, are poor, data published by international agencies concerned with rural poverty give some idea of the scale of these livelihood systems. According to The International Fund for Agricultural Development (IFAD), 75% of the world's 1.2 billion poor (defined as consuming less than one purchasing-power adjusted dollar per day) live and work in rural areas (15). Earlier IFAD figures (16) suggest that ≈50% of the developing-country rural population were smallholders (farming 3 ha or less of crop land), and ≈25% were landless, which may have included some agricultural laborers, nonpastoralist livestock keepers, and poor people not engaged in agriculture. The proportion of smallholders in sub-Saharan Africa was higher at 73%.[‡] Smallholders are responsible for cultivating a hugely variable proportion of land across developing countries, with figures of >70% of arable and

Author contributions: J.F.M. designed research, performed research, analyzed data, and wrote the paper.

The author declares no conflict of interest.

This article is a PNAS Direct Submission. W.E. is a guest editor invited by the Editorial Board.

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[†]One suspects that it was in this sense that the Intergovernmental Panel on Climate Change mandated specific inclusion of ''subsistence agriculture'' in the Fourth Assessment Report.

[‡]There appears to be some inconsistency between tables in the 1992 IFAD figures, but they do not significantly affect the argument here.

Table 1. Nonclimate stressors affecting smallholder and subsistence agriculture

Stressors	Source
Population increase driving fragmentation of landholding.	17
Environmental degradation caused by population, poverty and ill-defined and insecure property rights, including widespread soil degradation.	8,18
Regionalized and globalized markets, and regulatory regimes, increasingly concerned with issues of food quality and food safety.	19
Market failures in product marketing and input supply, following withdrawal of governments, leading to decreased market access for smallholders.	20
Protectionist agricultural policies in developed countries, declines and unpredictability in the world prices of many major agricultural commodities, macro-economic shocks.	21
HIV/AIDS pandemic, reducing household labor supply, eroding household assets, disrupting knowledge transmission and agricultural services.	22
Threats of panzootics (e.g., avian influenza) attacking livelihoods and constraining trade.	23
State fragility and armed conflict in some regions.	24

permanent cropland in several West and Southern African and Pacific countries. They are responsible in many countries for very high proportions of food and cash crop production, for example, 90% of rice, wheat, other food crops, cocoa, and cotton in Nigeria (16).

Non-Climate-Related Stressors and Trends

Subsistence and smallholder livelihood systems currently experience a number of interlocking stressors, other than climate change and climate variability, as outlined in Table 1.

The complex interaction of such stressors in increasing vulnerability can be illustrated with reference to pastoralists of the Horn of Africa and elsewhere. There are debates on whether environmental degradation in such tropical dryland areas is widespread, irreversible or appropriately referred to as "desertification" (25, 26), but there are, at the least, important processes of localized environmental degradation around small towns that are driven by the sedentarization of destitute pastoralists but also further weaken their livelihoods (27). Enclosure of land for farming by outsiders (28) and by pastoralists themselves (29) and demarcation of rangelands as Protected Areas has also been an issue: at the basis of all of these is a lack of government recognition of communal ownership of rangelands and traditional natural resource management (30). Human population increase, long neglected in pastoral studies, has been given new prominence by Sandford (31), who argues that its recognition, alongside other stressors, necessitates a major shift in views on pastoral development, with greater emphasis on diversification away from pastoralism and out-migration from the rangelands. Pastoralists are also subject to market-related stressors: the rapid withdrawal of government and parastatals from direct involvement in livestock purchasing and meat processing in Kenya in the 1980s is still lamented by Kenyan pastoralists (32). Although Horn of Africa pastoralists do not trade directly with Europe or North America, they are heavily involved in trade with Middle Eastern countries, in which they have been highly vulnerable to abrupt import bans on meat and livestock on veterinary grounds (33), in some cases with disputed scientific justification, but also seen as an indicator of a general trend to greater concern of Arab markets with meat quality and safety (34). Although there is a serious lack of information, but some concern, about the impact of HIV/AIDS on these pastoral populations (35), the impacts of armed conflicts, from international wars to quasitraditional raiding, on pastoralists throughout the region are now well known (36). All these, and other stressors, are seen as contributing to an increased vulnerability to drought, which in turn feeds back in to environmental degradation, conflict and underdevelopment of markets (37, 38).

However, all of the populations grouped as smallholder and subsistence farmers, including pastoralists and artisanal fisherfolk, also possess certain important resilience factors: efficiencies associated with the use of family labor (14), livelihood diversity allowing spreading of risks (12), and indigenous knowledge (39) allowing exploitation of risky environmental niches and coping with crises. The combinations of stressors and resilience factors give rise to complex positive and negative livelihood trends, envisaged differently by different authors, and depending largely on policy environments. Rural–urban migration will continue to be important; urban population growth in many large developing country cities is >4% per annum, and rural migrants account for between 35% and 60% of recorded urban population growth (40). Within rural areas, there will be continued diversification away from agriculture (41): nonfarm activities already account for 30–50% of rural income in developing countries (42). Although Vorley (43), Hazell (44), Lipton (14), and Toulmin and Gueye (45) see the possibility, given appropriate policies, of pro-poor growth based on the efficiency and employment generation associated with family farms, it is overall likely that smallholder and subsistence households will decline in numbers, as they are pulled or pushed into other livelihoods, with those that remain suffering increased vulnerability and increased poverty. The decline in numbers and qualitative changes in livelihoods mean that global and regional projections made for the category of smallholder and subsistence farmers will be progressively less meaningful over the medium- and long-term time scales associated with research and modeling on climate change.

Coping and Adaptation

Smallholder, subsistence, and pastoral systems, especially those located in marginal environments, areas of high variability of rainfall or high risks of natural hazards, are often characterized by livelihood strategies that that have been evolved (*i*) to reduce overall vulnerability to climate shocks ("adaptive strategies"), and (*ii*) to manage their impacts *ex-post* ("coping strategies"). The distinction between these two categories is however frequently blurred (46): what start as coping strategies in exceptional years can become adaptations for households or whole communities.

Many defining features of dryland livelihoods in Africa and elsewhere can be regarded as adaptive strategies to climate variability. For example, Mortimore and Adams (47) for Northern Nigeria mention five major elements of adaptation:

- Allocating farm labor across the season in ways that follow unpredictable intra-season rainfall variations: "negotiating the rain."
- Making use of biodiversity in cultivated crops and wild plants.
- Increasing integration of livestock into farming systems (at a cost of increased labor demands).
- Working land harder, in terms of labor input per hectare, without increasing external non-labor inputs.
- Diversifying livelihoods.

Other authors have mentioned on-farm storage of food and feed, strategic use of fallow, and late planting of legume crops when cereals fail as drought responses—examples from rain-fed areas of Morocco (48).

African pastoralism has evolved in adaptation to harsh environments with very high spatial and temporal variability of rainfall (49).

Several recent studies on Northern Kenya and Southern Ethiopia (50–53) reviewed by Morton (54) have focused on the coping strategies used by pastoralists during recent droughts and the longer-term adaptations that underlie them

- *Mobility* remains the most important pastoralist adaptation to spatial and temporal variations in rainfall, and in drought years many communities make use of fall-back grazing areas unused in "normal" dry seasons because of distance, land tenure constraints, animal disease problems, or conflict. However, encroachment on and individuation of communal grazing lands and the desire to settle to access human services and food aid have severely limited pastoral mobility.
- Pastoralists engage in *herd accumulation*, and most evidence now suggests that this is a rational form of insurance against drought. There is considerable debate on the extent to which pastoralists cope by systematically selling livestock during drought or drought-onset, and why they might not do this, but some evidence that they would sell more stock if markets were more efficient.
- Pastoralists classically keep multispecies herds to take advantage of different ecological niches and the labor of men, women, and children. Shifts in the balance of species can occur as responses to climate variability and changes in the environment, market conditions, and availability of labor.
- A small proportion of pastoralists now hold some wealth in bank accounts, and others use informal savings and credit mechanisms through shopkeepers.
- Pastoralists also use *supplementary feed* for livestock, purchased or lopped from trees, as a coping strategy, they intensify *animal disease management* through indigenous and scientific techniques, and they increasingly *pay for water* from powered boreholes.
- *Livelihood diversification* away from pastoralism in this region predominantly takes the form of shifts into low-income or environmentally unsustainable occupations such as charcoal production, rather than an adaptive strategy to reduce *ex-ante* vulnerability.
- There are a number of *intracommunity mechanisms*, to distribute both livestock products and the use of live animals to the destitute, but these appear to be breaking down due to high levels of covariate risk within communities.

Shifting to irrigated farming is sometimes seen as a coping strategy in the face of climate variability across the developing world. Eakin (55) describes this for Mexico, but notes that the interaction of market uncertainty with climatic risk may in fact increase the vulnerability of households making this shift. In South Asia, agricultural strategies such as increasing livestock production relative to crops, and selection of crop varieties, are responses to both drought and floods, but several case studies show the importance of livelihood diversification, in the villages and in towns, and both responsively to disaster and proactively (56). These and other studies also show the importance of information and networks or social capital in coping with climate change and variability (57).

The Impacts of Climate Change on Smallholder and Subsistence Agriculture

Although there has been much recent public discussion of the effects of climate change on rural areas of developing countries, there has been little discussion that both engages with the science of climate change impact on agriculture, and with the specificities of smallholder and subsistence systems. Various tendencies are visible in the literature: firstly quantitative projections of future impacts from modeling studies, at a variety of geographical scales, focusing on key smallholder crops (58, 59) or ecosystems used by smallholder farmers (60), or reviewing data from such studies at a regional level (61). An important example is the work of Jones and Thornton (62), who find that aggregate yields of maize in smallholder rain-fed systems in Africa and Latin America are likely to show a decrease of ≈10% by 2055, but that these results hide enormous variability and give cause for concern, especially in some areas of subsistence agriculture. A development of this approach is that of ILRI (63), producing maps of vulnerability to climate change for sub-Saharan Africa, based on existing geographical data sets of current farming systems and of indicators of socioeconomic vulnerability, and projections of length of growing period, further differentiated by SRES scenario. This analysis highlights "hotspots" for vulnerability: semiarid mixed rain-fed crop-livestock systems in the Sahel, arid and semiarid grazing systems in East Africa and mixed crop-livestock and highland perennial crop systems in the Great Lakes Region.

A second tendency has focused on adaptation, often using qualitative data, and taking the characterization of impacts as a subsidiary and largely straightforward task (64, 65). Such work has often taken recent or current climate variability as a base on which to discuss adaptation, treating it largely as a proxy for future climate change, and some has emphasized the impacts of extreme events, such as tropical storms, which effect agriculture at a gross or landscape-level scale, as well as affecting livelihoods through destruction of housing and physical capital (61, 66).

A conceptual framework is now needed that can understand impacts of climate change on smallholder and subsistence agriculture (and related livelihoods like pastoralism and artisanal fishing) by harnessing the growing understanding of the biological processes involved in climate change impacts on crop and livestock production (67), to the specific features of these livelihoods.

Such a framework should

1. recognize the complexity and high location-specificity of these production systems,
2. incorporate nonclimate stressors on rural livelihoods and their contribution to vulnerability, and
3. study three different categories of climate change impact upon smallholder livelihoods:

- Biological processes affecting crops and animals at the levels of individual organisms or fields;
- Environmental and physical processes affecting production at a landscape, watershed or community level;
- Impacts of climate change on human health and on nonagricultural livelihoods.

Complexity and Location Specificity. Impacts on these systems should be considered in terms of hard to predict compound impacts highly specific to location and livelihood systems in different ecosystems and regions of the world. These livelihood systems are typically complex; they involve a number of crop and livestock species, between which there are interactions—for example, intercropping practices (39) or the use of draught animal power for cultivation (68), and potential substitutions such as alternative crops. Many smallholder livelihoods will also include use of wild resources (11), and nonagricultural strategies, such as use of remittances (12). Coping strategies for extreme climatic events such as drought (46–48, 54, 69) typically involve changes in the relative importance of crops, livestock species and nonagricultural activities, and in interactions between them. Positive and negative impacts on different crops may occur in the same farming system. Agrawala *et al.* (70) suggest that impacts on maize, the main food crop, will be strongly negative for the Tanzanian smallholder, whereas impacts on coffee and cotton, significant cash crops, may be positive.

Nonclimate Stressors and Vulnerability. The intrinsic vulnerability of smallholder and subsistence farmers has been discussed above, as have the diverse powerful nonclimate stressors to which they are currently and increasingly subject. All these contribute to a very specific context of high vulnerability and limited adaptive capacity (65). Management of nonclimate stressors, such as poor market access, by governments and development donors, would itself constitute a powerful strategy for assisting adaptation, but some stressors, particularly various forms of environmental degradation, will themselves be influenced by climate change.

Approaches to mapping the combined vulnerability of rural populations to climate change and nonclimate stressors, have been explored for globalization by O'Brien and Leichenko (71) and for HIV/AIDS by Gommes *et al.* (72)

Biological Processes at Organism and Field Level. Easterling *et al.* (67) and relevant articles in this volume show the growing understanding of the direct impacts of changes in temperature, CO_2, and precipitation on yields of specific food and cash crops and productivity and health of livestock. In particular:

- New syntheses of the growing number of regional and global simulation studies of changes in crop yields against temperature suggest that in the tropics, even moderate temperature increases (1–2°C) are likely to have negative impacts on yields of rice, maize, and wheat (the three major cereals worldwide and among smallholder and subsistence farmers). Higher levels of warming will have serious negative impacts on yields of maize and wheat, and less so on rice. Where simulations have included the effects of agronomic adaptation strategies, trends still represent declining yields at all levels of warming.
- Increases in temperature may increase irrigation water requirements of major crops, increasing water stress, particularly in Southeast Asia.
- The conclusion of the Third Assessment Report of the IPCC (73) of likely significant negative impacts on semiarid rangelands is confirmed, although there are still very few impact studies for tropical grasslands or rangelands. There is also new knowledge on the direct negative effects of thermal stress on productivity, conception rates and health of livestock, that may be relevant to exotic (*Bos taurus*) cattle kept for small-scale dairy production in the tropics (74).
- There is evidence of increased risk of crop pests and diseases of crops under climate change, although knowledge of likely impacts in the tropics and on smallholder systems is much less developed. Modeling responses of both pathogens and (where relevant) insect vectors to rising temperatures and changing precipitation is complex, but there is cause for concern over possible spread of major diseases that attack smallholder crops in Africa: e.g., Maize Streak Virus and Cassava Mosaic Virus in areas where rainfall increases, and sorghum head smut (a fungal disease) in areas where rainfall decreases (which would be compounded by farmers switching adaptively to sorghum in areas where maize becomes marginal) (75). For diseases of livestock, modeling studies suggest overall slight declines in habitat suitable for tsetse-transmitted trypanosomiasis and East Coast Fever, although effects will be localized. Increased frequency of floods may increase outbreaks of epizootic diseases such as Rift Valley Fever and African Horse Sickness (76).

A general principle that crosscuts these projections of impacts on crops and livestock species is the increased understanding of the importance of extreme events (67). Increases in frequency of extreme events may go beyond the impacts of mean climate change in lowering long-term yields by damaging crops at particular developmental stages, making the timing of agricultural operations more difficult, and reducing incentives to cultivate (77). Increased frequency of heat waves and heavy precipitation events is regarded as very likely by IPCC Working Group 1 (78) and increased drought regarded as likely. Burke *et al.* (79) demonstrate the risk of widespread drought in many regions including Africa. Focus on extreme events in much of the literature on developing countries implicitly recognizes that their impacts are likely to be felt more strongly than the impacts of changing means in the medium-term (to 2025), a point made explicitly by Corbera *et al.* (80).

Environmental and Physical Processes. Another class of impacts is felt at the level of communities, landscapes, and watersheds, and has been less considered in literature on climate change and agriculture, although there is some overlap with consideration given to extreme events. One such impact is the effects of decreasing snowcap on major irrigation systems involving hundreds of millions of smallholders, particularly in the Indo-Gangetic plain. As a result of warming, less precipitation falling as snow, and earlier spring melting, there will be a shift in peak water supply to winter and early spring and away from the summer months when irrigation is most needed, with likely severe effects in areas where storage capacity cannot be expanded (81). Combined with increased water demand, and preexisting vulnerability of many poorer irrigated farmers, such an impact could be catastrophic.

Also to be included here are effects of climate change on soil fertility and water-holding properties. Global warming and accompanying hydrological changes are likely to affect all soil processes in complex ways, including by accelerated decomposition of organic matter and depression of nitrogen-fixing activity (82). Kundzewicz *et al.* (83) note the projected increased erosivity of rainfall, and several factors likely to increase the erodibility of soils worldwide.

Other examples of such environmental or larger-scale impacts are the effects of sea level-rise on coastal areas, increased intensity of landfall tropical storms (78), and other forms of environmental impact still being identified, such as increased forest fire risk (70) for the Mount Kilimanjaro ecosystem and remobilization of dunes for semiarid Southern Africa (84).

Nonagricultural Climate Change Impacts. The above impacts on agriculture will be combined with impacts on human health and ability to provide labor for agriculture, such as increased malaria risk (85), and on important secondary nonfarm livelihood strategies for many rural people in developing countries. One such strategy involves activities connected to tourism, and some negative impacts of climate change on tourism in developing countries have already been projected (86).

The above framework shows how complex and location-specific the projection of climate change impacts on smallholder and subsistence agriculture will be. A further complexity is given by the problem of distinguishing impact and adaptation. These systems are already characterized by constant adaptation to climate variability, which is forming the basis of adaptation to climate change: there will be profound methodological problems in observing or predicting impacts that do not also involve adaptation.

In general, however, the location of a large body of smallholder and subsistence farming households in the dryland tropics gives rise to especial concern over temperature-induced decline in crop yields, and increasing frequency and severity of drought. These lead to the following generalizations:

- increased likelihood of crop failure;
- increased diseases and mortality of livestock and/or forced sales of livestock at disadvantageous prices (37);
- livelihood impacts including sale of other assets, indebtedness, out-migration and dependency on food relief.;

- possible feedbacks through unsustainable adaptation strategies into environmental degradation including loss of biodiversity (87); and
- eventual impacts on human development indicators such as health and education.

Implications for Future Research Needs

Understanding the interactions between the different forms of climate change impact will require further research on a variety of topics, and with a variety of approaches. One need is for modeling work based on a thorough understanding of the complexities of specific real-world smallholder systems. The multiagent modeling of Bharwani *et al.* is one possible approach here (88). Also important will be increased empirical research on the circumstances under which current strategies to cope with extreme events foster or constrain longer-term adaptation (46). Knowledge of crop responses to climate change also needs to be extended to more crops, livestock, and wild species of interest to smallholders and subsistence farmers, such as tropical rootcrops, sorghum and millet, beverage crops, backyard poultry and pigs, and acacia-based browse systems. A further need is for research on the impacts of climate change on the storage and marketing of smallholder crops: including losses to insect pests and pathogens of crops stored on-farm or by small traders, damage in transport (for example caused by deteriorated rural roads), and indirect costs of being less able to store on farm and more vulnerable to seasonal price swings.

Beyond these needs for research into impacts are needs for research into adaptation. Many of the potential agronomic adaptations identified (67), including improved soil and water conservation, are highly relevant to smallholder and subsistence systems, but require careful interdisciplinary and participatory research. The use of seasonal climate forecasting by smallholders needs to be carefully researched, with due emphases on farmers' ability to access, trust, and respond to forecasts (69, 89).

A further need is to broaden debate by more inclusion of literature from languages other than English, which has been markedly absent so far: the Africa chapter of the Report of the IPCC Working Group II (90), for example, contains only one non-Anglophone reference other than the official communications of Francophone governments to the United Nations Framework Convention on Climate Change (UNFCCC). This is only one aspect of a broader need to open up debates on impacts and adaptation to a wider range of stakeholders, including smallholder and subsistence farmers themselves.

Conclusion

Smallholder and subsistence farmers will suffer impacts of climate change that will be locally specific and hard to predict. The variety of crop and livestock species produced by any one household and their interactions, and the importance of nonmarket relations in production and marketing, will increase the complexity both of the impacts and of subsequent adaptations, relative to commercial farms with more restricted ranges of crops. Small farm sizes, low technology, low capitalization, and diverse nonclimate stressors will tend to increase vulnerability, but the resilience factors—family labor, existing patterns of diversification away from agriculture, and possession of a store of indigenous knowledge—should not be underestimated.

Social-scientific study of the future impacts of climate change on poor rural people in developing countries has tended to be concerned with the increased frequency of extreme events with generalized impacts. This is understandable given the short to medium term importance of extreme events, and the difficulties of predicting any trends, climate-related or otherwise, in the longer term. However, there now must also be a genuinely interdisciplinary attempt to apply the rapidly growing scientific knowledge of the effects of climate change on crops and livestock to the "complex, diverse and risk-prone" farming systems of developing countries. This will not only improve knowledge of impacts, but just as important, aid in building adaptive capacity at all levels including that of farmers themselves.

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