Climate risk assessment and management in agriculture

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INTRODUCTION

Climate risk in agriculture represents the probability of a defined hydro-meteorological hazard affecting the livelihood of farmers, livestock herders, fishers and forest dwellers. Risk refers to a probability that can be estimated from prior information, while uncertainty applies to situations in which probability cannot be estimated. Both risks and uncertainties contribute to choice of appropriate management practices by the decision-makers in agriculture. Farmers to some extent understand the risks and uncertainties of climate at their location and optimize the management practices based on years of experience. However, growing demand, changing climatic conditions, intensification and spread of agriculture to marginal production environments warrants improved climate risk management and decision support systems to enable appropriate choice of practices and strategies to match the current and future climate risks.

According to the International Research Institute for Climate and Society (IRI)[1] , climate risk management (CRM) refers to the use of climate information in a multidisciplinary scientific context to cope with climate's impacts on development and resource management problems. Further, IRI's definition elaborates that climate risk management covers a broad range of potential actions, including early- response systems, strategic diversification, dynamic resource-allocation rules, financial instruments, infrastructure design and capacity building. CRM is the use of climate information to cope with possible impacts of climate change on development and resource management (African Development Forum, 2010).

According to the World Meteorological Organization (WMO)[2], climate-related risk management refers to appropriate climate information distribution through an efficient delivery system that can alert food officials to assure food and water security long before the actual natural hazard sets in. WMO has initiated development of a concept of CRM and is developing examples of best practices already in use in different parts of the world, especially in water and agriculture sectors. According to the United Nations Framework Convention on Climate Change (2011) CRM refers to different aspects of the risk management process, including: (a) risk assessments for informed decision-making; (b) risk reduction: planning and preparation; and (c) risk sharing, pooling and transfer in the context of adaptation. The World Bank (2006) defines CRM as assessment of threats and

[1] http://portal.iri.columbia.edu/portal/server.pt
[2] http://www.wmo.int/pages/themes/climate/risk_management_overview.php

opportunities arising from existing and future climate variability, including those deriving from climate change and, where necessary, incorporated into the design of projects and plans.

It is widely recognized that CRM revolves around the use of climate information and focuses on better management of climate variability as a starting point to determine vulnerability to the current climate conditions, including variability and weather extremes and then to assess how vulnerabilities might change as a result of climate change. In this way, CRM highlights the current pressing issues while factoring in projected future changes. In the agriculture sector, the approach is considered as valid as many developing countries are only partly adapted to current climate conditions. The CRM approach is of immediate relevance and benefit to smallholder farmers. The approach focuses on a coordinated response for addressing climate risks with committed engagement of farmers, herders, fishers, agricultural support services, institutions and enabling policy to build sustainable livelihoods resilient to climate risks (Figure 1).

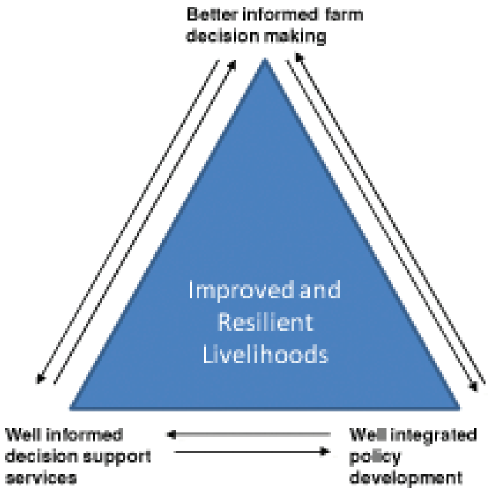

Figure 1. Coordinated response for assessment and management of climate risks in agriculture

In this paper, CRM is defined as a systematic process of identifying, analysing and responding to hydro-meteorological risks at varying temporal and spatial scales. The approach brings together the synergies of adaptation to climate change and disaster risk reduction (climate-related) by focusing on actions that can be taken now to improve adaptive capacity and preparedness to cope with the current climate variability and to build resilience to better respond to the impacts of climate change. This covers a broad range of potential actions including early warning systems, weather and climate information application for risk and opportunity management, optimization of farm management practices for sustainable production, communication to the end-users of climate information and institutional-level decision-support systems such as medium-term warning systems, early warning systems and humanitarian response, crop monitoring and yield forecasting, agricultural insurance,, and development and application of data, tools and methods. Capacity building, gender considerations, cooperation and collaboration, and mainstreaming into plans, programmes and policies are integral to the overall CRM approach.

CLIMATE RISKS IN AGRICULTURE

Agriculture is deeply interconnected with weather and climate, the main drivers of agricultural production, but also the dominant factors in the overall variability of food production (Selvaraju, Gommes and Bernardi, 2011) and a continuing source of disruption to ecosystem services (Howden *et al.*, 2007). Rainfall quantity and its distribution are key factors determining the rainy season characteristics, farming systems, field crop production and livestock rearing. Both interannual and intraseasonal rainfall variability constrains crop production in the tropics and subtropics.

In semi-arid tropics, unreliable rainfall combined with high evaporative demand and soils with low water-holding capacity and high run-off potential result in a high risk of water deficit at any stage of crop growth (Muchow and Bellamy, 1991). Frequent soil water deficit during early plant development, resulting in seedling mortality, retarded development and reduced yield, are very common. There are many instances where water deficit during the later stages of crop development is apparent. The wet spells and excessive rainfall events during the rainy season create waterlogging in the root zone, reduce plant growth and hinder field operations.

The rainy season duration is one of the primary factors affecting crop production prospects. Within a specific location, rainy season onset and final rain date are varying greatly from one cropping season to another. The variation of onset explains the significant variation in season duration since the onset date is more variable than the end date of the rains. Early onset of rains, relative to the mean date of onset for a given location, results in a longer growing season (Sivakumar, 1988). However, the relationship between onset date and seasonal rainfall duration is not always linear as rainy season characteristics are uncertain.

In addition to seasonal rainfall variability, higher growing season temperatures can have dramatic impacts on agricultural productivity, farm incomes and food security (Battisti and Naylor, 2009). Temperature during the cropping season often exceeds the optimum for physiological processes such as phenology, leaf area development, assimilate accumulation and grain filling. High air temperature around flowering can reduce pollen viability and grain set in major cereals of the tropics (rice, maize, sorghum, etc.). The incidence of high soil temperature during crop establishment is also a threat in semi-arid and arid environments. Soil surface temperature greater than 60 °C is common in Africa, India and Australian semi-arid tropics, and seedling mortality or thermal injuries are frequent.

Intraseasonal variability leads to extreme climate events that have direct impact on crop production and livelihood opportunities in the agriculture sector. For example, an unprecedented deficit of 49 percent in the all-India average rainfall in July 2002 led to a major drought, while rainfall was close to normal during all the other months of the rainy season. This led to a decline in farm-level crop productivity especially due to mid-season breaks in the monsoon activity. Farmers and herders often lose all the investment made during the season until the occurrence of climate extremes. Extreme climate events during the cropping season are posing a major threat to the agriculture sector. FAO's global information and early warning system on food and agriculture indicates that sudden-onset disasters – especially floods – have increased from 14 percent of all natural disasters in the 1980s to 20 percent in the 1990s and 27 percent since 2000 (FAO, 2008).

Risk of climate variability affects dairy, meat and wool production, mainly arising from its impact on grassland and rangeland productivity. Heat distress suffered by animals reduces the rate of animal feed intake and results in poor growth performance (Rowlinson, 2008). Multiple climate-related risks cause far-reaching consequences for the livestock sector. For example, "dzud" in Mongolia – a multiple natural disaster consisting of a summer drought resulting in inadequate pasture and production of hay, followed by very heavy winter snow, winds and lower-than-normal temperatures – prevent livestock from accessing pasture or from receiving adequate hay and fodder. During 1999–2001, Mongolian herders in particular experienced the worst "dzud" in the last 30 years, where they lost more than 25 percent of the total number of their livestock, which was ten times higher than the normal year (AIACC, 2006).

Climate variability and climate extremes are already having impacts on agricultural production systems. Future changes associated with climate change will present additional challenges (Karl *et al*., 2008). The intensity of tropical cyclones (Knutson *et al.,* 2010) and frequency of heavy precipitation events are very likely to increase over many areas during the twenty-first century. At the same time, the proportions of arid land are projected to increase, in addition to a tendency for drying during summer, especially in the subtropics, low and mid latitudes (Bates *et al*., 2008). According to IPCC (2012), it is likely that the frequency of heavy precipitation or the proportion of total rainfall from heavy falls will increase in the twenty-first century over many areas of the globe; and there is medium confidence that droughts will intensify in the twenty-first century in some seasons and areas, due to reduced precipitation and/or increased evapotranspiration.

Climate change threatens agriculture biodiversity; IPCC (2007) projected that approximately 20–30 percent of plant and animal species assessed so far are likely to be at increased risk of extinction if increases in global average temperature exceed 1.5–2.5 °C over 1980–1999 levels. The range of crop weeds, insects and diseases is projected to expand to higher latitudes (Rosenzweig *et al*., 2001). Coastal zones and fisheries are particularly prone to risks associated with rising sea levels, changes in ocean salinity, cyclones, and a decrease in fish stocks and availability due to increasing water temperature (Hall-Spencer, Rodolfo-Metalpa and Martin, 2008).

Lobell *et al*. (2008) conducted an analysis of climate risks for crops in 12 food-insecure regions to identify adaptation priorities, based on statistical crop models and climate projections for 2030 from 20 general circulation models. Results indicated South Asia and Southern Africa as two regions that, without sufficient adaptation measures, will likely suffer negative impacts on several crops that are important to large food-insecure human populations. Battisti and Naylor (2009) used observational data and output from 23 global climate models to show a high probability (>90 percent) that growing season temperatures in the tropics and subtropics by the end of the twenty-first century will exceed the most extreme seasonal temperatures recorded from 1900 to 2006. In temperate regions, the hottest seasons on record will represent the future norm in many locations.

MANAGING CLIMATE RISKS TO ADVANCE ADAPTATION TO CLIMATE CHANGE

Climate risk management (CRM) in the context of climate variability is integral to a long-term strategy for adapting agriculture to climate change. Effective climate change adaptation requires spatially and temporally downscaled climate change projections. Climate change projections are the key to impact assessment and direct adaptation planning, but are often seen to be a major constraint in transforming them into locally relevant adaptation actions owing to broader spatial scale and uncertainties. Nonetheless, countless studies have highlighted the issues of uncertainty and stressed that these uncertainties are not an excuse for inaction. Climate uncertainties present an additional challenge, but should not be a stumbling block for designing adaptation actions focusing on baseline issues and more towards longer-term resilient adaptation.

Adaptation to climate variability and extreme events serves as a basis for reducing vulnerability to longer-term climate change. Development of long-term adaptation strategy in agriculture depends on addressing similar issues in the short-term, recognizing the fundamental understanding that adaptation is a location-specific and continuous learning process (FAO, 2008). In addition, the action also contributes to current development priorities, reduces vulnerability (win–win opportunity) and matches with the shorter planning horizons of the farmers. CRM identifies immediate actions that are needed to manage the climate variability that is currently affecting farmers and herders. Furthermore, the impacts of possible interventions also become evident and verifiable in the short term, making them more attractive to policy- and decision-makers.

The African Development Forum (2010) proposes that better understanding of climate variability and improved management of its associated risks present a real promise to decision-makers seeking to understand how to adapt to climate change. It is understood that the patterns or trends of the past climate can tell us something about what future climate could be. Strategies developed to manage year-to-year climate variability go a long way towards building resilience and managing the risks of climate change.

COMPONENTS OF CLIMATE RISK ASSESSMENT AND MANAGEMENT

Integration of climate information in risk management and adaptation planning is one of the priorities for sustainable agriculture. The approach of climate risk assessment and management has been adapted mainly in the following domains considering recent developments in weather monitoring, climate data analysis, crop–weather relationships, seasonal forecasting and economic modelling:

- inclusion of modern methods/tools for climate data sourcing and analysis, automatic meteorological measurements (rainfall, temperature, wind, etc.) at the local level and/or satellite rainfall estimation products available on a near real-time basis and seasonal forecasts;
- analysis of climate risks and assessment of climate impacts using crop–weather interactions;
- integration of economic models, linear and non-linear optimization methods and risk perception by farmers;
- preparation of advice to farmers and access to modern information and communication technologies.

All these components contribute to provide knowledge on the full range of crops to be planted, inputs that might be used and practices to be followed, so that farmers and herders will be prepared to execute management decisions at short notice. The operational components of climate risk assessment and management include: (i) collect real-time local, weather and crop information; (ii) analyse climate risks, vulnerabilities and impacts and management options based on local conditions (e.g. soil, farming practices); (iii) develop management alternatives based on the socio-economic context of the decision-makers; (iv) communicate the management options to the decision-makers in the form of advisories. The advisory should be based on type of enterprise, historical climate risks, current season weather conditions and seasonal climate forecasts.

Establishing data and information for analysis

Data and information requirements include climate data, cropping systems, knowledge on local environmental conditions and agricultural practices, costs of inputs, market price, etc.

- Climatic data: historical rainfall, evaporation records, average and maximum/minimum temperatures and other selected climatic records and climate change scenarios.
- Knowledge of local conditions: land slopes, surface drainage, soil depth and water-holding capacities, fertility status, specific soil problems (salinity, hardpan, etc.), agroclimatic risks.
- Farming and cropping systems: crop, livestock, production systems including crop species, their specific cycle, plant population, water requirements, etc.
- Socio-economic data: socio-economic conditions (access to inputs, credit, etc.), household strategies, objectives, risk perception and technical support (institutions).

The climate risk assessment emphasizes the comparison of current quantitative data with historical information on trends and impacts. Daily rainfall records are essential in order to determine rainfall onset date and relate rainfall probabilities to crop growth stages. The key activities of the component are: analysis of decision problems; information need at the farm level; review of existing climate data availability and quality; information synthesis related to cropping pattern, soil types, natural resources and management practices; assessment of the suitability of sources of real-time weather and climate-forecast products and modern data sourcing (e.g. remote sensing).

Climate analysis and crop weather interactions

Field application of CRM involves a series of iterative analyses of the historical rainfall records, specifically oriented to crop production requirements. Subsequently, the analytical and interpretative process should consider seasonal climate forecasts and appropriate decision alternatives for response. Historical data enable risk assessment for present or planned cropping systems and quantification of risks related to actual dates when rainfall first meets crop season onset requirements. Analysing climate indices and climate/crop interactions includes assessment of historical risk patterns for crops and cropping systems, rainy season characteristics, onset, end and length of growing period, intraseasonal rainfall variations including wet and dry spells, risks for crops/varieties related to rainfall amount and duration.

Rainfall onset is the date of onset of the growing season as the key variable to which all other seasonal rainfall variables are related. However, defining onset criteria is considered important in this analysis and depends on type of crop and soil factors. Onset relations are crucial because they indicate how the seasonal rainfall is expected to behave. Rainfall probabilities should be worked out related to time periods of specific crop growing stages.

A farmer's signal for sowing may be either a fixed calendar period (window), or attainment of some arbitrarily selected buildup of stored soil water or attainment of a fixed rainfall threshold. Total seasonal soil moisture is the amount of water stored in the crop root zone at the time of germination, plus the amount that falls during the season from germination to crop maturity. Seasonal rainfall prediction provides the probabilities of exceeding a specific quantity of rainfall that poses potential risks to crop yields.

Climate risk assessment should be followed by formulation of management decisions that avoid risk to the greatest extent possible. Risk assessment is integrated into the analytical process through functional relations and crop models, which estimate potential levels of crop performance associated with different predicted levels of rainfall. Simple book-keeping procedures of water balance, water balance models and dynamic crop growth models are widely used for risk assessment. Community-based bottom-up approaches contribute to develop information on local perception of risks.

Optimization of farm management practices conditioned by climate

Crop-season-based rainfall probabilities can be made more informative with specific details on adaptive management strategies. The management strategies should be optimized for early and late onset of rainfall, good, average and bad seasons. Therefore, the optimization approach builds on the primary objective of adjusting farm management strategies based on current and future weather conditions. Modern computer technology and, in particular, decision support systems can facilitate the comparison of management strategies by simulating the crop yield and gross margins.

The optimization tools are flexible, facilitate the alteration of the management practices and assess the possible consequences. Economic optimization techniques are the tools to find out the optimal management practices to reduce the impact of possible rainfall shifts from one season to another. The key activities of this component are: linking past performance of risk factors to crop performances; optimizing management practices (planting methods, cultivar selection: matching maturity to expected rain duration, crop selection: matching average daily water requirements to average seasonal rainfall patterns, optimization of plant populations, fertilizer application, weeding, intercultural operations and harvesting based on seasonal rainfall behaviour and land allocation under various crops depending on constraints, etc.) considering the farmers' objectives and adjusting cropping practices to fit selected crops and targeted rainfall.

Preparation of farmer advice and communication

Farmer advice should be based on historical weather data and risk assessment related to current weather conditions, climate forecasts and optimal management practices. The major factors to be considered for preparing advice to farmers are: (i) rainfall probability analysis; and (ii) design of optimal cropping systems and management practices related to seasonal climate forecasts. Analysis of historical rainfall, data from real-time observation and modern climate monitoring and seasonal climate impact outlooks provide guidelines for selection of suitable management options based on rainfall behaviour. Full details should be communicated to farmers, who prepare in advance to follow their preferred choice.

Farmer advice needs to be simple and targeted on key management factors, such as adapted species or matching cultivar maturity, meeting the requirements of expected duration of the rainy season. These types of targeted agro-advisories need to be prepared by Agromet or extension services and other intermediary organizations dealing with CRM. It is important to note that the advisories are not just recommendations, but are the options that may be considered by the farmers to reduce the risks of climate variability. The main activities of this component involve: preparation of advisories incorporating rainfall probabilities, optimal management strategies, identification of appropriate communication channel to deliver the information and conduct of climate workshops to enhance the decision capacity of decision-makers. The approach should facilitate interaction between providers and users of information.

CLIMATE RISK MANAGEMENT AT FARM LEVEL

The farm as a system

The farm management decisions have a significant role in deciding the productivity of the farm. The production and management systems within the farm and the economics of overall farm management and its performance depend on both on-farm and off-farm factors (Figure 2). The climatic conditions are major external factors affecting crop growth and yield at the field level. The internal factors generally relate to decisions on allocation of resources, selection of enterprises, application of inputs and management.

The CRM procedures at farm level should consider both external and internal factors of production, agronomic management practices and climate data (observed or forecast). As each type of risk poses a different type of threat to crop production, these risks must be addressed by location-specific management practices. An illustrative example of the major sources of risk, nature of threat and field level decisions and actions is provided in Table 1.

Risk management practices at farm level

At farm level, appropriate choice of management practices is the part of risk management that refers to achieving the farm household's goals as efficiently as possible in the

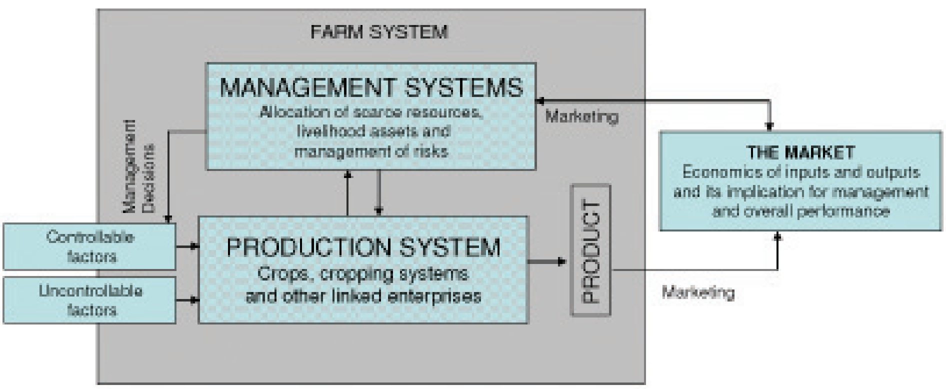

Figure 2. A simple model of the farm as a system of production and management
Source: Modified from Brennan and McCown (2001).

Table 1: Sources and nature of risks associated with seasonal rainfall behaviour and appropriate field level responses

Source of risk	Nature of threat	Field level decisions and actions
Wet spells	Waterlogging of crop root zone	Land configuration; drainage of excess water.
Dry spells	Crop water deficits	Plant population adjustment, skipping nitrogenous fertilizer application, provision of supplementary irrigation.
Early season dry spell following onset	Seedling death; low plant density	Increase onset soil water criterion and/or delay earliest planting date
Middle season drought	Crop yield loss if drought occurs at critical growth stage	Adjust ranges of planting dates to fit phenology of crops; select suitable crop types
Terminal drought and early cessation of rains	Rainy period duration inadequate for crop maturity	Select maturity classes of crops/cultivars based on rainfall analysis and expected rainfall behaviour
Deficit in seasonal rainfall amount	Crop water deficit with resultant yield loss	Select crop types with appropriate average daily water requirements; land preparation and tillage for *in-situ* moisture conservation.
High year-to-year rainfall variability	Degradation of grazing lands and poor financial performance of livestock enterprise	Adoption of safe stocking rate (livestock)

Table 2: Farmers' seasonal actions and their influence on the factors of crop and livestock production

Farmers' actions on optimal management practices	Influence on factors of crop production
Land and seedbed preparation	Imparting slopes to plant rows and modifying infiltration characteristics of the soil, thus increasing water retention and reducing run-off.
Selection of crops to be planted	Determining water requirements, potential for soil water extraction during dry periods.
Selection of cultivars	Determining length of the growing season from germination to physiological maturity
Selection of seed rates and spacing between rows	Influencing crop water requirements and pattern of soil water extraction
Selection of initial fertilizer types and rates of application	Determining potential water use efficiency and reducing the risks of extreme rainfall.
Plant population adjustments and fertilizer application after crop establishment	Conforming crop water requirements and/or potential water use efficiency based on observed early season rainfall.
Adjusting animal stocking rate	Improved carrying capacity and arresting degradation of grazing lands

face of physical, environmental, socio-cultural and other constraints. Risk management helps to optimize the farm decisions to obtain maximum possible net benefit over time. Sustainability, environment friendliness and resilience should also be explicitly considered while setting objectives for selecting optimal management practices.

As a new season approaches, a number of actions should be taken by the farmers/herders, which shape the performance of the enterprise during the entire season. These actions are related to land, seedbed preparation, selection of crops and varieties, selection of seed rates and spacing, initial fertilizer application and livestock stocking rate (Hammer, Nicholls and Mitchell, 2000). An illustrative example of farmers' actions and their influence on factors of crop production is given in Table 2.

Farmers' actions on optimal management practices can influence the factors of production favourably and reduce the climate risks and uncertainties. This reiterates the importance of the need to assist farmers in supplying information that matches with existing

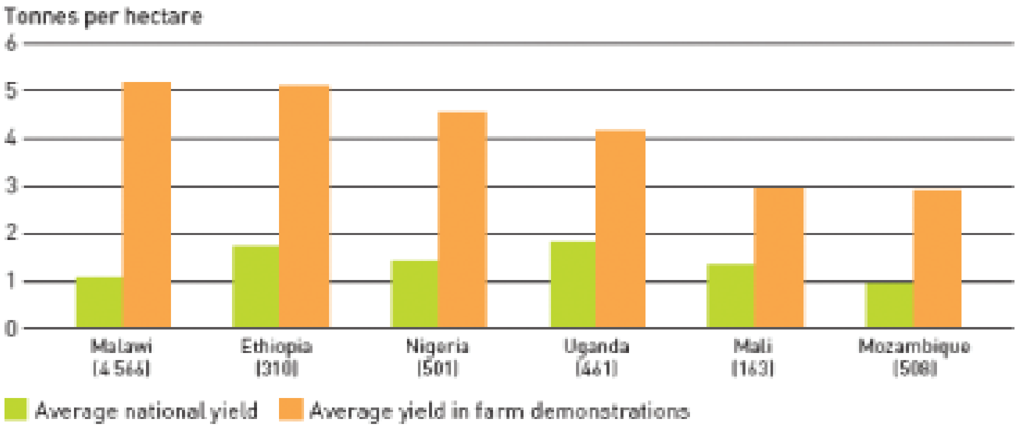

Figure 3. Exploitable yield gap for maize
Notes: Number of plots in parentheses. Open pollinated improved varieties in all cases except Nigeria, which uses hybrids. Data for 2001 for Ethiopia, Mozambique, Nigeria and Uganda; 2002 for Malawi; an average of 2001, 2002 and 2004 for Mali.
Source: World Bank (2007).

climate risks. Farmers should be able to plan/adapt their practices, given the historical and recent past climate and weather conditions, and near-term likely climate to enable pro-active management of climate risks.

The risk assessment based on seasonal and intraseasonal climate information is of a great value to promote advance planning. More efficient and relevant seasonal advisory services enable farmers to reduce the risks and stabilize their yields through optimal management of resources and inputs. The optimal management practices enhance the effectiveness of farm performance. Improving risk management approaches with concepts of farm level optimization techniques would be more suitable to manage risks of climate variability and change at farm level.

Managing full range of climate variability and bridging farm-level yield gaps

In general, decision-makers at farm level are vulnerable to climate variability for two reasons: (i) inherent variability and uncertainty associated with climate; and (ii) missed opportunities owing to risk averse conservative strategies followed by the decision-makers. Hansen *et al.* (2007) reiterated that uncertainty associated with climate variability, combined with risk aversion on the part of decision-makers, causes substantial loss of opportunity in climatically favourable and even average years. This implies that low input application during good or better than normal seasons will miss the opportunities to exploit the favourable conditions. Efforts to reduce yield gaps should consider managing full range of climate variability (good, bad and average seasons) on either side of the distribution instead of targeting only the extremes (drought, floods, etc.).

Farm yield gaps in developing countries tend to be very large (Figure 3). Improving agronomic management and input use efficiency are the most important means to reduce the yield gaps. Climate information that reduces the uncertainty that farmers face during a given season has potential to improve the effectiveness of production technologies and input use efficiency. Reducing uncertainty enables the farmers to adopt improved

Table 3; Agricultural decisions at a range of temporal and spatial scales that benefit from climate information

Farming decisions	Frequency (years)
Logistics (e.g. scheduling of planting/harvest)	Intraseasonal (>0.2)
Tactical crop management (e.g. fertilizer/pesticide use)	Intraseasonal (0.2–0.5)
Crop type (e.g. wheat or chickpea)	Seasonal (0.5–1.0)
Crop sequence (e.g. long or short fallows) or stocking rates	Interannual (0.5–2.0)
Crop rotations (e.g. winter or summer crops)	Annual/biannual (1–2)
Crop industry (e.g. grain or cotton; native or improved pastures)	Decadal (~10)
Agricultural industry (e.g. crops or pastures)	Interdecadal (10–20)
Land use (e.g. agriculture or natural systems)	Multodecadal (20+)
Land use and adaptation of current systems	Climate change

technology, intensify production during better years and reduces the risks during the bad years. Climate information services enable farmers to adopt new technology and thus sustainable intensification of production by understanding spatial and temporal climate variability.

CLIMATE INFORMATION FOR RISK MANAGEMENT AND SUSTAINABLE PRODUCTION

Advances in climate prediction, analysis and synthesis of climate knowledge have helped improve CRM with the potential to enhance livelihood opportunities in agriculture (Selvaraju, Gommes and Bernardi, 2011). Climate information at all time scales is crucial to advance risk management and improve sustainable production. The climate information and likely decisions are: (i) climate change scenario to understand the trend and alter system-level decisions (cropping or grazing); (ii) seasonal climate information to make strategic decisions (crop type, marketing, forward selling, livestock herding rate, etc.); (iii) intraseasonal forecasts to schedule tactical operations (e.g. fertilizer, water and other adjustable inputs); and (iv) weather forecasts for the day-to-day operations. Climate information at a range of temporal scales that benefit agricultural decisions (Meinke and Stone 2005) is presented in Table 3.

Weather forecasts and early warning systems

Short- to medium-range weather forecasts and early warning systems can be useful elements of the decision-making process in CRM (Challinor, 2009). Intraseasonal to interannual climate variability impacts the agriculture sector and, therefore, many agricultural decisions can benefit from high-quality, reliable predictions. Donald *et al.* (2004) emphasized that intraseasonal forecasts are considered essential for making appropriate decisions to modify strategies that reduce vulnerability for smallholder farmers.

There are several indices and methods used to explain the intraseasonal climate variability relevant to agricultural applications. The passage of the Madden-Julian Oscillation has been described to explain patterns of suppression and/or enhancement of rainfall to be forecast beyond the synoptic scale (Bond and Vecchi, 2003). Propagation characteristics of the Monsoon Intra-Seasonal Oscillation provide indication of active and break monsoons in southern Asia (Hoyos and Webster, 2007). Tactical risk management can be improved through the application of intraseasonal forecasting capabilities that will allow farmers to assess the timing and likelihood of rainfall events and temperature fluctuations at time scales of up to six weeks.

Seasonal climate forecasts

Advanced information in the form of seasonal climate forecasts has the potential to improve farmers' decision-making, leading to reduced risks and increased opportunities. Climate information (seasonal) has the potential to improve livelihoods, enable farmers to adopt improved technology, intensify production and enhance soil fertility, and farmers are capable of investing in more profitable enterprises when conditions are favorable (Hansen *et al*., 2007). The approaches to seasonal to interannual climate predictions and sources of predictability, including ENSO (El-Nino Southern Oscillation)-related indices, offer a greater potential for risk reduction and opportunity management. These developments have the capability to improve the economic return for both smallholder farmers and rural companies, such as grain traders, sugar mills and cotton gins (Meinke *et al.*, 2006).

Addressing gaps in climate information services

Although significant developments have occurred in prediction and dissemination of weather and climate forecasts in recent decades, this information has not yet been utilized adequately and not integrated effectively into agricultural development. This is largely due to the gap between information provision (supply) and users' (demand) of the information. The demand for climate information is diverse – localized, timely and easily understandable information products are needed to translate information into actions. On the one hand, diverse cropping systems and decision cycles associated with crop and livestock activities in smallholder farming systems pose difficulties in customizing information products to match the local activities. On the other hand, inadequate access, mismatch between farmers' needs and the scale, content, format or accuracy of current operational forecasts limit the climate information use (Phillips, 2003; Ziervogel, 2004). The supply of climate information is often constrained by insufficient data and resolution. The information is often general, and technical terms are not easy to understand on several occasions and very narrow, specific information could not influence the local decisions.

To address the above gaps, the information products should be tailored to suit the user needs. The meteorological agencies, agriculture service providers, irrigation managers, input suppliers, market intermediaries, local cooperatives, microfinancing, farmers, fisherman and livestock herders need to collaborate and establish the most convenient and appropriate user interface platforms (UIPs) to share the information products and receive feedback. Strengthening/upgrading local observation networks, capacity building to understand the user needs and also to generate user relevant information products, interpretation and development of customized information products and communication of information along with associated uncertainties to end-users are essential to improve climate information services to farmers.

BETTER INFORMED INSTITUTIONAL DECISION SUPPORT SERVICES FOR CLIMATE RISK MANAGEMENT

The agricultural support services and institutions at the national and local levels need risk information for planning their activities and providing timely services to the ultimate beneficiaries. Better informed decision-support systems can be very efficient and capable of providing need-based information services to the farmers, livestock herders and fishers. Users of climate information at institutional level need historical climate information, climate monitoring products and forecasting in different time scales for institutional decisions. In most cases, effective use requires that raw climate information be translated into quantitative information (soil water status, pest and disease risk, vegetation conditions, crop yields etc.), with sufficient explanation of uncertainties.

The agriculture support institutions (extension and research) should offer and also make use of information about agriculturally relevant precipitation indices (deviation from normal, water stress, agriculture season length (beginning and end) etc.), progress of the precipitation indices from the past to current, near real-time information about the crop state and early-warning systems for humanitarian response.

Early warning systems and humanitarian response

Emergencies are on the rise – especially sudden onset disasters and series of low and high rainfall extreme events. The number of floods has increased from 14 percent of all natural disasters in the 1980s to 20 percent in the 1990s and 27 percent since 2000. Worldwide, flood occurrences have risen from about 50 floods per year in the mid-1980s to more than 200 today. Droughts followed by floods are not uncommon (e.g. Niger in 2009 and 2010). Need-based early warning systems have important implications for humanitarian response activities. Early warning systems help timely mobilization of resources needed to prepare for, and respond to, emergencies in order to save lives and protect livelihood systems. Routine climate monitoring and weather forecasting should provide necessary inputs for food security early warning and to develop scenarios for food security outlooks. Drought monitoring systems are also being used to focus emergency response and also pro-active management of impacts. Drought early warning systems can help achieve a greater level of drought preparedness and drought mitigation. These systems can be improved by integration of spatial databases, including remotely sensed data, with agronomic models.

Crop monitoring and yield forecasting

Analysis of meteorological and climatic data allows providing near real-time information about the crop state, with the possibility of early warning. Crop monitoring and yield forecasting allow timely interventions by the government to avoid crisis. The strategies include contingency plans, alternate livelihood options and response plans for food aid. Large-scale monitoring of agriculture and crop-yield forecasting generally rely on: (i) regionalized analyses of cultivated areas, crop type distribution and crop condition based on near-real-time satellite imagery merged with available *in-situ* observations; (ii) meteorological monitoring and mid-term forecasts based on observation networks and model outputs; and (iii) regionalized knowledge of agricultural systems and their sensitiv-

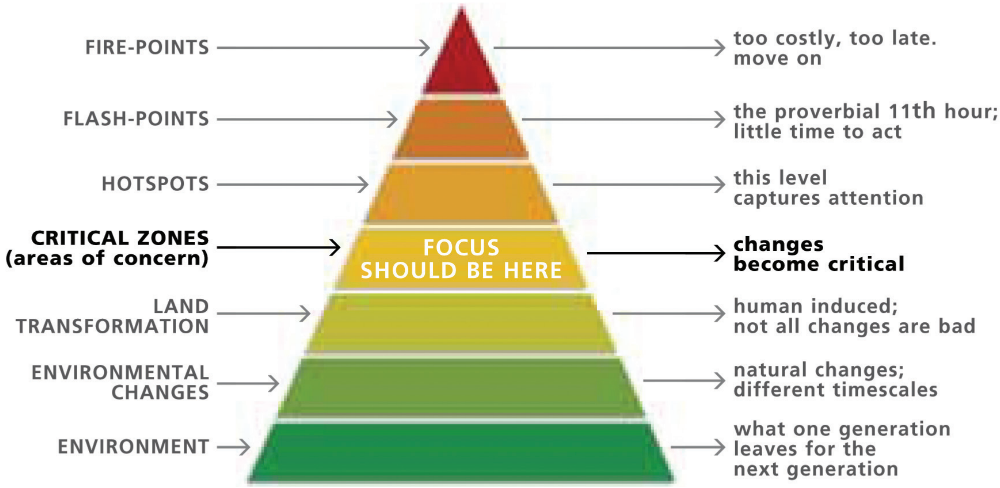

Figure 4. Hotspots pyramid showing an idealized progression of environmental change
Source: FAO (2009).

ity to meteorological conditions. The crop monitoring and yield forecasting capabilities in developing countries are weak and need strengthening at the national level with more emphasis on collection of data such as meteorological, agro-meteorological, soil, remote sensing and agricultural statistics.

Medium-term warning systems (5–10 years)

Policy-makers need advance information on likely hotspots of vulnerabilities and sensitivities. Thus a medium-term warning system (5–10 years) can fill the gap between seasonal-scale assessments and long-term impact projections. Identification of the future areas of concern and likely hotspots of vulnerabilities and sensitivities are critical to reduce the risks in a time frame of 5–10 years. The pyramid (Figure 4) shows a simplified progression of environmental changes (forests, irrigated lands, rainfed cultivated areas, fisheries, etc.) that can result from environmental interactions with human activities (FAO, 2009).

Hotspots are locations of degradation of either the managed or the unmanaged environment. They indicate situations when mitigative action remains possible at relatively higher costs and appear before conditions deteriorate further to the flashpoint stage. The flashpoint stage offers a brief, last window of opportunity for policy-makers to react before environmental collapse becomes inevitable; when (if) they do choose to react, however, the necessary measures for recovery will prove extremely costly in terms of time, money and political capital. Fire points indicate that environmental conditions have collapsed – it is too late for policy-making, as the degradation has overwhelmed all chances for recovery, and exhausted fields, for example, have to be abandoned for generations to come.

Policy-makers should focus not on hotspots but on critical zones (areas of concern) because at this stage of the continuum not only does enough scientific evidence of degradation exist but so does enough lead time to pro-actively implement relatively low-cost yet highly effective measures to arrest or reverse the devastation and avoid the negative consequences that accompany passage into the hotspots stage.

Agricultural insurance

FAO (2005) estimated that the total annual agricultural and forestry insurance premiums worldwide in 2001 amounted to some USD6.5 billion, representing just 0.4 percent of the estimated total farm-gate value of agricultural production globally. As the current insurance mechanisms do not adequately cover the millions of smallholder farmers, institutional support systems should play a major role in providing localized and needs-based climate information to farmers so as to encourage them to make use of insurance mechanisms.

Index-based insurance products for agriculture represent an attractive alternative for managing weather and climate risk (Skees, 2008). Agricultural insurance is growing as a result of increased commercialism and availability of new types of insurance products. For the government, insurance mechanisms provide some predictability to weather risk financing and offer enough lead time for emergency responses to manage livelihood crisis. This lessens the weather/climate effects by securing needed resources sooner to protect livelihoods.

Provision of localized and needs-based climate information to promote index-based weather insurance requires strengthening of weather observation networks, monitoring of extreme climate events, standardization of indices, data sharing, early warning systems and capacity building. The index-based weather insurance systems require the support of national meteorological and hydrological services to ensure high-quality weather data, monitoring instruments and procedures to downscale weather information to produce real-time crop yield indices covering a specific agro-ecological region.

Data, tools and methods

Historical climate data are the key to assist CRM efforts. But the major problem is that both synoptic and agrometeorological stations in developing countries are thin and declining in the recent decades. For example, there are just over 1 150 World Weather Watch stations in Africa giving a density of 1/26 000 km^2. Even the data collected from several existing stations are not readily available for analysis and data remain on paper and are inaccessible to users. Efforts are needed to fill the gaps and increase the resolution of spatial interpolation to fill the missing data. Proxy measurements using satellites and rainfall estimation can partially contribute to the analysis in areas where very sparse data are available.

Risk identification is often carried out through quantitative and qualitative tools and methods. Traditionally quantitative top-down approaches are used for risk identification and analysis. The community-based qualitative approaches can bring local context and traditional wisdom into the analysis. Community-based approaches provide strong, locally-relevant data and information about livelihood profiles and local vulnerability towards development of risk maps. Livelihood analysis interprets climate-related hazards and builds on local livelihood strategies. Institutional support for livelihood analysis can guide preparation of risk and vulnerability maps by dividing a region into areas with relatively homogeneous patterns of natural resources. The products can provide advance information about the livelihood baseline and vulnerability to weather and climate phenomena.

STRENGTHENING TECHNICAL AND INSTITUTIONAL CAPACITIES

Strengthening the capacity for agrometeorological observation, the development of customized forecasting products, the management of data and modelling for climate impact assessment and application of climate information at the farm level, and strengthening of decision-support systems at the institutional level are the priority (Selvaraju *et al.*, 2011). Agricultural extension services need to be strengthened in order to address climate risks and plan for adaptation if these are to provide an efficient interface between policy-makers and the farming community.

Strengthening of community networks, local institutions and norms and relationships is critical for managing climate risks. Local networks shape the farmers' social interactions leading to better participatory decisions (Meinke *et al*., 2006). Farmers' knowledge sharing mechanisms relevant to local context are the key for effective communication of value-added climate information (Selvaraju, Meinke and Hansen, 2004). Farmer participatory climate workshops, Farmer Field Schools (FFS), local climate information centres and innovative information and communication technologies (e.g. mobile networks, etc.) facilitate rapid dissemination of information products to the farmers and livestock herders.

National meteorological and hydrological services need to understand the information requirement of agriculture support services and farmers and accordingly mainstream development of weather and climate information products. Agricultural support services and community-based organizations should engage themselves in development of contingency plans incorporating new technologies, improving impact data collection, monitoring and analysis (including climate change), development of impact outlooks and management alternatives considering local needs, and facilitate communication of information to farmers/herders.

CONCLUSIONS AND RECOMMENDATIONS

The agriculture sector is highly exposed to climate risks. The majority of risks associated with production are because of adverse climatic conditions and inherent climate variability; and climate change represents an additional threat. Climate risks are often translated into poor crop yields and suboptimal performance of livestock enterprises. The climate risk is capable of altering other risks such as asset depletion (damage and loss to assets as a result of extreme climate events), price risks (risk of falling or raising prices) and financial risk (from possible increase of interest, etc.).

Farm-level CRM should focus on optimization of management practices to reduce the impacts during bad years and enhance the opportunities during better than average and average years. Management of a full range of climate variabilities is an ideal option to effectively reduce the risks and bridge the farm-level yield gaps. Recent advances in climate prediction and climate information services offer a huge potential for optimizing management practices, bridging yield gaps and sustainable production. Climate information on various time scales: (i) climate change scenario; (ii) seasonal climate information; (iii) intraseasonal forecasts; and (iv) weather forecasts and early warning systems, present immense opportunities to manage the full range of climate variability.

The agricultural support services, institutions at the national and local levels need risk information for planning their activities and to provide timely services to ultimate beneficiaries (farmers, herders, etc.). There are number of decision support systems already developed and tested in many countries. For example, advances in crop forecasting, early warning systems, humanitarian response and agriculture insurance provide decision support to the institutions to deliver timely and needs-based interventions at various spatial and temporal scales. Agricultural support services, including agricultural research and extension, national meteorological and hydrological services, community-based local institutions (e.g. farmer cooperatives) and the private sector (e.g. input suppliers, seed companies, etc.) are well placed to contribute to CRM.

A number of areas need the urgent attention of both the meteorological and agriculture community to effectively address climate risks. The priorities include: a climate monitoring and data collection network in rural areas, systematic data archival and management to characterize natural resources and provide needs-based information to research, extension agencies and farmers, ensuring the use of modern information products, forecasts from regional and international centres at the national level, strengthening livelihood-based climate impact analysis to bring down the impact outlooks to the local context, deliver improved, reliable, timely, and locally understandable information products with management options for the end-users with a view to narrowing down yield gaps. The customized climate information products should consider inputs, credit, market and financial aspects.

The role of climate services in index-based insurance, crop monitoring and yield forecasting should be enhanced in both the public and private sectors to facilitate protection of livelihoods. Mainstreaming climate information services into food security early warning and humanitarian response, agriculture and food security policies, disaster risk management plans and programmes is crucial to sustain committed support from governments. Sustained communication channels need to be established to provide needs-based information and feedback to national meteorological and hydrological services, agronomic research and extension systems. Building a local farmers' network and awareness-raising are key to enhancing trust at the community level. A number of cross-cutting elements, such as capacity building, awareness, gender and collaboration, are prerequisite in all aspects of CRM.

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