Coping with changes in cropping systems: plant pests and seeds

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INTRODUCTION

The evidence for climate change is overwhelming, with the poorest countries and people most vulnerable who will suffer the most from its negative impacts. Maintaining food security is already critical for smallholder farms, and minimizing vulnerability in the face of change is becoming even more of a challenge. Increased variability due to different aspects of climate change results in greater exposure of marginal areas and small farmers to new risks.

Climate change causes highly variable environmental conditions, including:

- higher temperatures and shift of seasons;
- changes in rainfall and subsequent variation in water availability;
- extreme natural events, causing disasters;
- change in atmospheric gas composition.

Such changes generate variations in biological cycles – phenological phases of crops, timing of cropping seasons, agro-ecological zones and population dynamics of living organisms (including pests and invasive alien species) are all affected. The rate of climate change might possibly exceed the rate of adaptation of ecosystems, including cropping systems, creating many concerns on how to cope with such changes, particularly in relation to food production and availability.

Credible and scientifically robust studies on various cause–effect relationships of climate change are under current research, while the impacts of climate change are tangible, and negatively affect crop productivity and livelihoods of marginal rural communities. It is imperative to develop a sound understanding of these dynamics, and learn from previous experiences on coping with emerging changes and challenges.

The sustainable production intensification (SPI) is one of FAO's strategic objectives. SPI is promoted through the concept of *Save and Grow*[1] to increase production efficiency and to achieve sustainability in agricultural production, with a special focus on small farmers. The concept builds on local biodiversity and ecosystem functions to enhance productivity, and aims to increase efficiency in the use of agricultural inputs. Essential elements of *Save and Grow* are soil health and proper fertilizer management, conservation agriculture, management

[1] http://www.fao.org/ag/save-and-grow/

of genetic resources and improved seed systems, integrated pest management (IPM), proper water management, enhanced pollination services and knowledge of local agro-ecosystems.

This paper focuses on IPM and seed systems as two key pillars of *Save and Grow*. We propose to learn from experiences on strengthening seed systems, and closely monitor the dynamics of plant pests and diseases to establish effective ecosystem approaches for management using environmentally acceptable science based tools.

CHALLENGES

Agro-ecosystems are in a dynamic state. Many insects, diseases and weeds, generally defined as crop 'pests', are an integral component of agro-ecosystems. In naturally established agricultural systems, 'pest' species are in a shifting balance with other species (including those of their own natural enemies – parasites and predators) and crops, as components of local food webs. Their presence in any specific field varies in time, population level and relationship with other species as does their role (as pests or defenders). Such variations may depend on crop phenology, environmental conditions **and** agricultural management practices in the specific field (or area). Under certain circumstances, populations of such species may reach a level resulting in significant damage to crops, and thus become 'pests'. This change of status is often related to local management practices, including cropping patterns, host genotypes, and use of chemical fertilizers and pesticides that may have adverse effects if improperly used. In order to assess and manage decisions for minimizing disruption to the local ecological balance properly, it is essential to have a good understanding of existing species in the field and their role in the local agro-ecosystem. Understanding the local agro-ecological balance is at the core of good farming practices that farmers have been mastering for millennia, to provide food successfully for their communities.

Agricultural intensification over the last 50 years has focused on the introduction of new inputs and practices in traditional agro-ecosystems, which has led to higher productivity, but at the same time to increased vulnerability in agricultural systems, reducing their resilience and production sustainability.

Recent outbreaks of brown planthopper (*Nilaparvata lugens*) in rice in Southeast Asia represent a typical case of disruption of ecological balance by misuse of pesticides. This is now a common scenario in agricultural intensification: if pest management decisions are not supported by appropriate knowledge and understanding of ecosystem balance and their variations, both at field and at policy level, the whole agricultural system is at risk.

Based on such experiences related to agricultural intensification, new causes of vulnerability in agro-ecosystems caused by climate change can be looked at, in particular, focusing on the natural life cycles of different kinds of pests.

Arthropods. Life cycles and population levels of insects and spiders are sensitive to changes in temperatures as they are poikilothermic (organisms whose internal temperatures vary, often matching the temperature of the immediate environment). For these cold-blooded organisms, temperature is the single most important environmental factor influencing behaviour, distribution, development, survival and reproduction. Effects of temperature increase on these species have been studied by Kiritani in Japan (2006), based on a 1 °C increase in mean annual temperature over the last 40 years. This increase has resulted in a shift in species distribution range, reduction of winter mortality, earlier occurrence in spring and increased number of annual generations.

The same study also indicated that with present trends in increasing temperature, tropical and subtropical insect species may advance continuously poleward (as far as their cold hardiness allows) because they lack diapause in their lifecycles. Temperate species will expand stepwise, as they need to reach the required temperature to allow them to develop one additional generation before reaching the diapause stage. In fact, diapause introduction is driven by photoperiodic cues (Tobin *et al.*, 2008).

Differences in patterns of response to temperature change among insect species do affect relationships within food webs (host, pest, natural enemy) owing to changing phenology and their synchronization. This may result in the emergence of new pests as species may be released from natural control factors (predation/parasitization). Conversely, the new balance may also work in favour of the buildup in populations of natural enemies such as *Trichogramma* and egg parasitoids (*Apanteles*, *Cyrtorhinus*). These may be able to increase the number of generations per year earlier than their host species as a result of their lower thermal constant. Both possibilities demand good understanding to support development of new management strategies – defining the essential role of stakeholders and decision-makers at different levels: policy-makers, researchers, extension workers and farmers.

Interestingly, Kiritani also suggested that greenhouse culture represents a model of a temperate agro-ecosystem after global warming: most greenhouse pests are invasive species from subtropical or tropical origins and thus lack diapause. In the last 30 years, new pests, such as *Trialeurodes vaporariorum*, as well as another ten species, have invaded greenhouse cultures in Japan, and have been combated with increases of insecticide application on tomato (X4), eggplant (X7) and cucumber (X8). Without the identification/introduction/survival of natural enemies of these pests, global warming may result in a prevalence of invasive pest species and consequent increase in insecticide use. Similarly, insect-borne diseases, mainly viruses (CuYV, TYLCV, TSWV, etc.) may become important with global warming.

Global warming is also related to increased concentrations of greenhouse gases, such as CO_2, that will affect crop pests indirectly through changes in plants and vegetation composition, quantity and quality. Studies have been conducted on the impact of increased CO_2 and O_2 concentration levels (free-air gas concentration enrichment – FACE) to the level estimated for predictions for the mid-twenty-first century, demonstrating higher insect pressure (of Japanese beetle, potato leafhopper, western corn rootworm, Mexican bean beetle) requiring additional insecticide usage (Hamilton *et al.*, 2005).

Pathogens are sensitive to temperature changes and atmospheric gas composition, as these changes affect host plant growth and canopy shape/density and cause a change in microclimatic conditions in favour of disease spread and virulence. Plant disease agents will respond to climate change, but such responses will be difficult to predict owing to the complex relationship between host and pathogen mediated by local environment and management

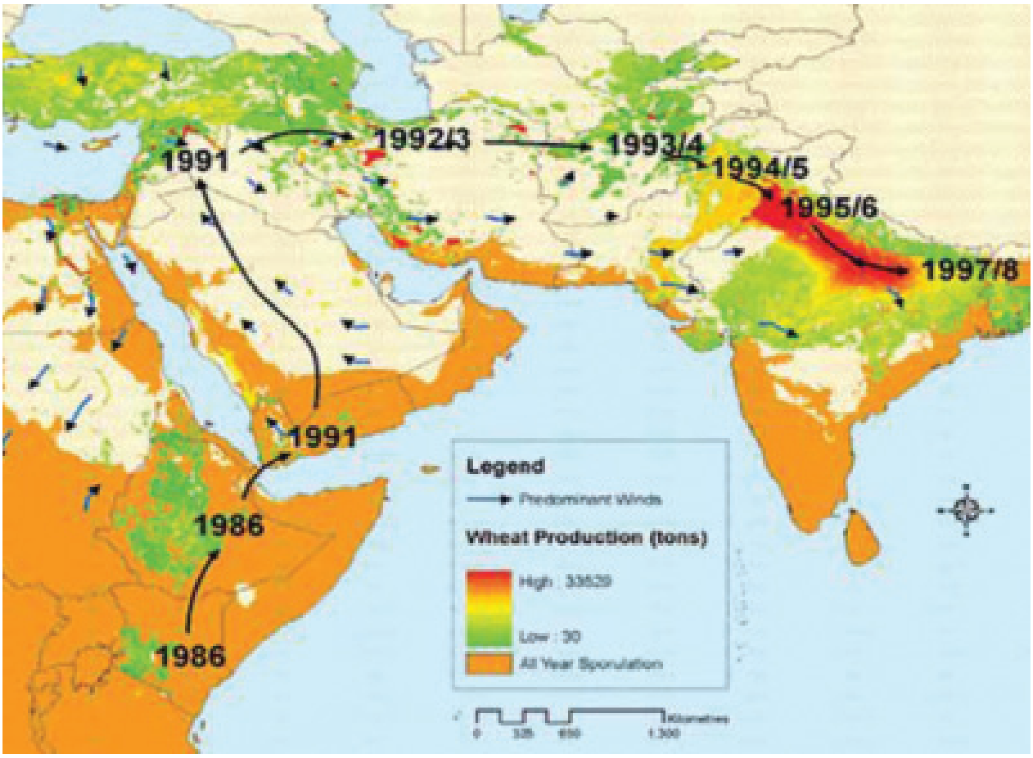

Figure 1. Yellow rust pathway (1986–1993)
Source: FAO (2008).

practices. In temperate climate zones, earlier onset of warm temperatures could result in an earlier threat from plant diseases (such as tomato late blight, *Phytophtora infestans*) with a potential for more severe epidemics and subsequent increase in fungicide applications.

A recently documented case is the spread of wheat rusts (Hodson, 2011), closely linked to conditions of temperature, rainfall distribution and relative humidity. Stem rust epidemics in the early twentieth century created a demand for studies on its spread and genetics, leading to the large breeding programmes at the core of the green revolution concept in the 1960/70s. Yellow rust emerged in the early 1990s with epidemics in North Africa, the Near East and Asia, and in the early 2000s stem rust resistance was broken by the Ug99 race lineage that emerged from East Africa and spread north and eastward. These and similar changes are linked with either continuous use of susceptible hosts or inappropriate management practices, but recently climate change is taking an increasingly important role. Studies conducted in India show increasing temperatures and relative humidity, and a decline of rainfall in Punjab. Such changes may lead to a higher incidence of pests and diseases and lower grain quality (Agarwal, Naresh Kumar and Pathak, 2009). Global initiatives were launched to mitigate the wheat rust threat, based on the need to have a sustained, collaborative, multidisciplinary effort, starting with careful monitoring and surveillance both at local and international levels. Adequate knowledge and understanding of pathogens in changing environmental conditions is required to respond effectively to these new threats.

Plant pathogen distribution and intensity will also be affected by moisture level and increased precipitation, as well as by CO_2 levels, affecting plant canopy structure and micro-environments, thus providing good shelter and higher reproduction rate for pathogen development. Finally, efficacy of fungicides may be affected by these variations causing an additional source of uncertainty and therefore vulnerability.

Distribution of diseases as well as insect pests is favoured by increased international trade and movement of plant materials. A wealth of experience and systems are in place to face this challenge. However, problems posed by intensified movement of plant materials are also increased by changes of climatic conditions. Exclusion of quarantine pests through regulatory means may become more difficult for authorities to manage as unexpected organisms may appear more frequently on imported crops.

A report presented by Brasier (2010) at CPM5 of the International Plant Protection Convention argues that current sanitary and phytosanitary (SPS) protocols are not appropriate in global market conditions, possibly also due to climate change conditions, and need some revision. *Phytophthora* spp., reported to be one of the most damaging genus among plant pathogens (such as potato blight), threatening natural forests and fruit trees, are increasingly transmitted via international trade and spreading worldwide through local adaptation and development of new species by hybridization. Pest risk assessment (PRA) procedures should be adapted for new conditions including consideration of climate change. Moreover, deeper knowledge at the local level, including by nursery operators, is proposed as a better solution to identify and to avoid the spread of diseases from the point of source in support of better diagnostics at the port of entry. Again, a more responsible and informed discussion on recent developments, including aspects of climate change, involving all relevant stakeholders and not limited to scientists and regulators, would address this problem more effectively in the future.

Weeds: Climate change induces changes in plant-growth-determining factors such as temperature and solar radiation. It also affects availability of growth-limiting factors (e.g. water) to plants and modifies the interaction between plants and growth-reducing factors such as insect pests. Beneficial insects foraging on weeds are also affected by climate change. Altogether, climate change may favour the spread of many weed species into new areas. This is illustrated by the examples reported below.

Red rice, a weedy relative of cultivated rice, can constrain production of rice grown for food. It has been reported that elevated CO_2 levels increased growth in both types of rice but more so in red rice. Aggressive weeds such as cheatgrass (*Bromus tectorum*) and Canada thistle (*Cirsium arvense*) flourish when CO_2 levels rise.

In India, *Prosopis juliflora* has invaded nearly 5.55 million hectares of land, constituting 1.8 percent of the geographical area of the country. The most potential invasive feature of the species is typically a greater assimilate partitioning towards roots leading to extraordinary enlargement in root mass with rich food reserves. This aids rapid and robust regeneration after mechanical lopping or after revival of ecological stress conditions such as drought or inundation. The increase in root biomass largely contributes to the weed's ability to tolerate climatic extremes such as peak summer associated with high temperatures and water scarcity, and peak monsoon winter with water inundation and flooding (Kathiresan, 2006).

Solanum elaeagnifolium, commonly called silverleaf nightshade, has been introduced from North America to Africa, Asia, Australia, Europe and South America, where it is an important weed of croplands and pastures. The invasiveness is aggravated by high seed production and an extensive root system that promotes vegetative multiplication and renders conventional control methods very difficult. Other negative effects include hindering commercial cropping activities, harbouring agricultural pests, being toxic to livestock and reducing land values. The plant is officially declared as a noxious weed in several countries. This weed prefers high summer temperatures and lower annual rainfall (Heap, Honan and Smith, 1997). Lower temperatures and high rainfall are the limiting factors that restrict range expansion (Heap and Carter, 1999). While the weed is drought and saline tolerant, it is highly sensitive to waterlogging and frost. Accordingly, increasing temperatures, alternating periods of soil moisture deficit and surplus periods in the semi-arid tropics caused by climate change could prove to be an inducing factor for invasive behaviour of *S. elaeagnifolium.*

As illustrated above, climate change will favour the spread of a number of invasive plant species, especially in a context where globalization of trade and exchange of germplasm worldwide represent pathways of introduction of exotic species. To cope with this new threat, vigilance is needed at community, national, regional and international levels. At a community level, vigilance is needed to detect and report emerging weed problems related to climate change and design appropriate management strategies. At a national level, enabling policy and institutional environments must be created to promote integrated weed management options at the community level. At regional and international levels, common regulations and strategic frameworks are needed to limit the impact of invasive plants.

SEED SYSTEMS FOR QUICK RESPONSES TO STRESSES

Seeds are a core resource of crop production systems, and carry the genetic potential for crop adaptation to changing environments. The increased abiotic and biotic stresses that have been previously mentioned (temperature, diseases, insects, salinity, etc.) will directly impact food production. The system that will provide adapted varieties to farmers has three parts: plant genetic resource (PGR) conservation and distribution, variety development and seed production and delivery. The stronger the links among these different parts, the better the whole system will function.

Conserved and improved materials need to be available for variety development to address abiotic and biotic stresses impacting on crops. New varieties have to be generated at a pace that meets changing demands and requirements. Timely delivery to farmers of suitably adapted materials, of the right quality and quantity, at an acceptable cost, is essential. To work well, the system needs an appropriate institutional framework as well as policies and practices that support its component parts and the links between them. The time required for developing and releasing new varieties is lengthy compared with the pace of environmental changes under pressure from climate change. Urgent action is therefore needed to ensure that a local genetic resource base, adequate capacities and effec-

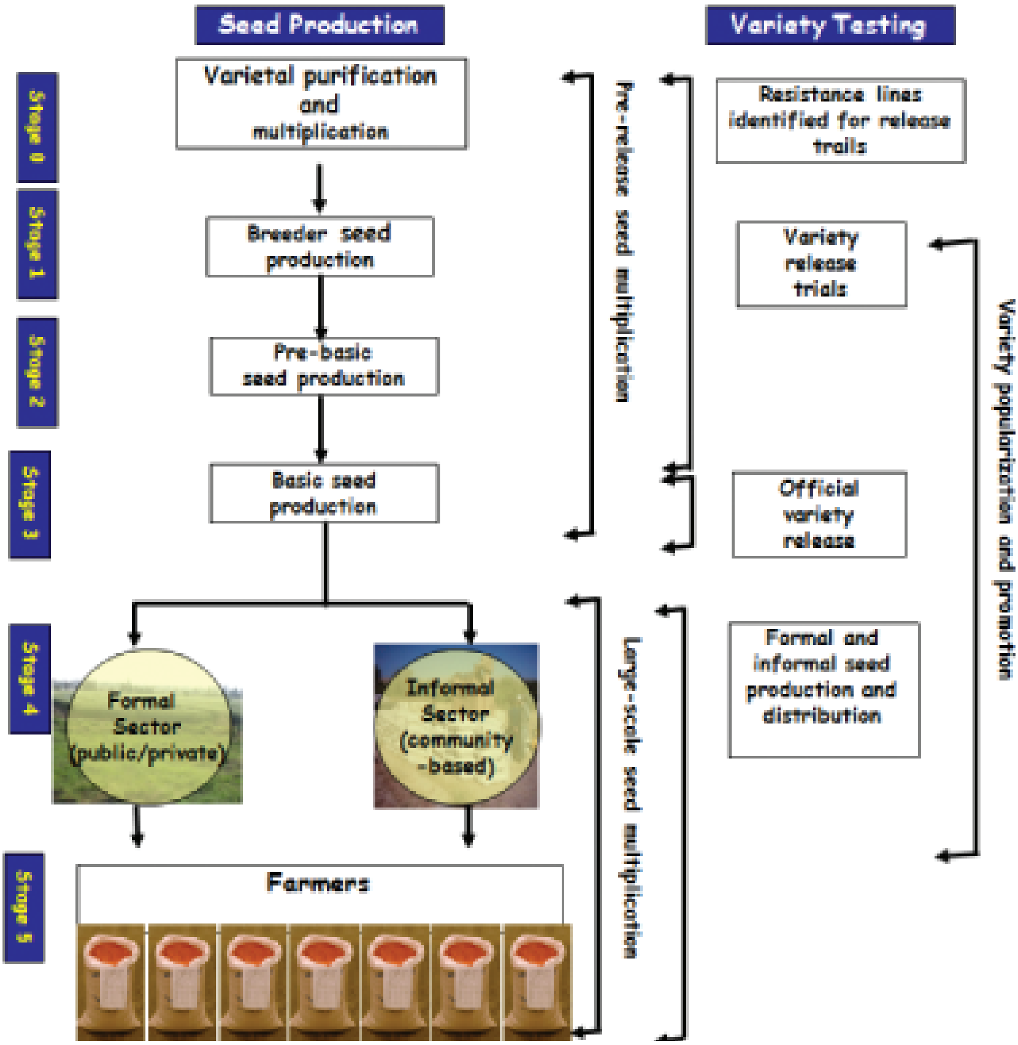

Figure 2. Accelerated variety development scheme for wheat rust resistant varieties

tive collaboration among policy, research and users are available for facing new needs. For example, the emergence and the diffusion of the new wheat rust strain UG99 has triggered an international initiative to develop and release rapidly new resistant varieties. Figure 2 shows an accelerated system whereby the seed multiplication activities start concurrently with variety release procedures being proposed in Ethiopia, with the objective of having seeds of new varieties available in farmers field in five to eight years.

Climate change will require an intensification of the **conservation of PGRs** *in situ* and *ex situ*. For example, the survival of crop wild relatives (an important source of genetic diversity for crop improvement) could be threatened. Simulations of climate change effects on wild relatives of groundnut (*Arachis*), potato (*Solanum*) and cowpea (*Vigna*) in Latin

America strongly affected all taxa, with an estimated 16–22 percent of these species predicted to become extinct and most species losing over 50 percent of their range size. While increased habitat conservation will be important to conserve most species, those that are predicted to undergo strong range size reductions should be a priority for collection and inclusion in genebanks (Jarvis, Lane and Hijmans, 2008).

Achieving adaptation to climate change will require **plant breeders to develop an increasingly diverse portfolio of varieties** of an extended range of crops. Generating these varieties will require sourcing heritable variations from the non-adapted materials that are not usually used by breeders, including crop wild relatives. Generating those intermediate materials to be used eventually in breeding would require pre-breeding, whereby germplasm curators and breeders work together to identify the carriers of sought-after traits, evaluate putative carriers and cross promising ones with elite lines to generate novel breeding materials. This will lead to larger populations of breeding materials that need to be cleared of deleterious alleles. This increased scope of work would necessitate more efficient genotyping and phenotyping platforms. There will also be a strong role for local institutions and communities to identify and select potential accessions more adaptable to climatic changes but also to local needs. Equally important attention should be given to existing materials with outstanding adaptation attributes including yield stability and nutritional values. To ensure that supply responds adequately to demand and hence ensures greater sustainability in the system, the crop and product preferences of farmers and other consumers should be taken into account. This demand-driven adaptation to climate change is not only a means of ensuring food and nutrition security but also of maintaining and improving plant genetic diversity including less profitable and neglected crop species.

Developing seed delivery systems for local and improved varieties: Seed systems are organized in different ways in different countries to ensure availability of new genetic materials, adapted to local needs, in particular changing environmental conditions. Seed systems can be very sophisticated or simple and local. Smallholder farmers around the world still rely heavily on informal seed systems (or farmer seed systems) and have little access to commercial seed systems. In some countries, well over 70 percent of seed, even of major crops, is managed within the farmer seed system. Both commercial and farmer seed systems will be essential in the distribution of climate change-adapted materials. The promotion of small-scale seed enterprises that can create the necessary link between research and local communities to bring genetic progress from test tube to the farmer's field is considered as a priority activity by the Global Plan of Action for the Conservation and Sustainable Utilization of Plant Genetic Resources for Food and Agriculture. For example, in northern Cameroon, local varieties of millet, sorghum and maize were not adapted to lower rainfall and increased drought. The agricultural research institute developed earlier maturing varieties of these crops and, with the support of FAO, farmer seed enterprises were organized to produce certified seed for sale to farmers in the surrounding villages. The new varieties produced good yields in spite of the unfavourable agro-ecology, and this has resulted in high demand and led to the creation of 68 community seed enterprises with over 1 000 members (both women and men) producing over 200 tonnes of seed per year. There are similar projects in other countries (Guei, Barra and Silué, 2011).

The discrepancies among seed regulations still remain a barrier to seed trade and exchange of varieties between countries. Climate change will impose more frequent extreme events that will increase pressure on seed security. Facilitating seed exchange among countries will be necessary to cope with situations of seed shortage in some countries. Harmonization of seed regulatory frameworks at the subregional and regional level will therefore be key to ease administrative procedures for cross-border seed trade. At the same time, the establishment of regional variety release procedures and variety catalogues will bring access to a wider diversity of varieties with the potential to adapt to climatic changes.

Agricultural diversification, crop and variety relocation based on mapping agro-ecological zones and variety characterization will be necessary to provide farmers with the germplasm (landraces and modern varieties) adapted to shifting agro-ecologies. Improved ways of transmitting information about crop variety adaptation through market and non-market channels are also needed.

COPING WITH CHANGE: A LEARNING PROCESS

In the context of climate change it is essential to develop a new and deep understanding of the practical implications of changes occurring at local and national level. To achieve this, it is essential to enhance adaptive capacities of rural communities, researchers and national policy-makers, getting all these stakeholders better connected as changes occur.

In the past, rural communities have always been working to adapt to change in climate as it gradually occurred over centuries, but now changes appear to be faster and more dramatic. Therefore, farmers in their specific agricultural systems would benefit highly from support to help develop sound and location specific adaptation strategies. Farmers with knowledge of local ecosystems, and with critical thinking skills, would stand a much better chance of coping with the effects of climate change. In countries where participatory approaches such as Farmers Field Schools (FFS) have been piloted, attempts to adapt this methodology to the new challenge of climate change have been proposed. FFS curricula could be adapted to gather and analyse information on variability and effects of climate change, and devise and locally test coping strategies towards climate-resilient farming systems.

Climate Field Schools

Following the successful experience of FFS on IPM – with a focus on field problems, starting with pests, developing field studies, using participatory methods and aiming to enhance resilience – a similar approach has been piloted in Indonesia to address new sources of variation, such as the effects of climate change. In recent years, climate change in Indonesia is increasingly a cause of concern, particularly with regard to variability in rainy seasons and rainfall intensity. Indicators of forthcoming rain – used by farmers based on local knowledge and traditions – refer to a lunar calendar (star position) and observation of falling leaves and singing birds. These signs were used as triggers to decide the appropriate planting time for rice crops.

In 2003–2007 Climate Field Schools (CFS) were established in Indonesia (Indramayu District, West Java) in collaboration with national institutions (Ministry of Agriculture, International Rice Research Institute, Indonesian Agency for Meteorology and Geophysics, Bogor Agricultural University, Asian Disaster Preparedness Center). This area is affected by drought and floods. Over 1 000 farmers worked in CFS with facilitators to understand seasonal climate forecasts as a basis for decision-making. It was intended to test coping strategies for local variations in water availability: time of planting, water capture and management, and adaption by multiple cropping. The main learning topics for the CFS were climate science, seasonal forecast and record rainfall for proper decision-making. Water management was at the core of the CFS curriculum and field studies. Critical factors emerged: local communities had limited power to adjust irrigation schemes to address water requirements, and choice of appropriate alternative crops was limited as rice remained the preferred crop for local farmers owing to reduced labour requirements compared with alternative crops. A lesson was learned showing that capacities addressed with CFS to understand and apply scientific climatological information, such as data collection and forecast interpretation, did not enable adaptive changes in management practices. Possibly a more systematic approach would have been required to mobilize collective action.

A similar experience was also conducted in mountain areas in the Andes (Bolivia, Peru and Ecuador) by the project Katalysis (Sherwood and Bentley, 2009). The overall approach and participatory training methodology built on the experience developed in these countries with FFS, aiming to cope with pest management and pesticide overuse. Also in this case, water management was the entry point for learning. Communities were suffering drought and floods at different times of the year. Learning processes focused on better observation, record keeping, developing storage methods such as increased soil organic matter or mulches, cover crops and water catchments, and testing alternative simple irrigation systems. From local field management, the attention then shifted to the watershed level: controlling goats and cattle, reforestation on slopes and windbreaks. This led to watershed 3-D maps on which management plans were built.

FAO has been working for over 20 years in developing FFS and other participatory approaches to assist farmers to gather and analyse agro-ecosystem information for better decision-making. Climate change becomes just a new entry point in the process of continuous innovation/adaptation of agriculture. Strengthening local knowledge and creative adaptation, supported by scientific insight, is a realistic way to help local institutions and farmers to adapt to climate change. This requires strong facilitators – therefore investment in human resource development on participatory approaches – and flexibility in programming and funding by national institutions/local government and international donors.

CONCLUSIONS

Resilience is the ability of a system to cope with or return to balance after a stress and to regain the capacity to produce important services. Resilience is a fundamental feature of natural systems allowing them to cope with change. A number of factors pose a challenge to the continued resilience of ecosystems, including climate change. There is a need to restore and enhance resilience in agro-ecosystems, starting with an understanding of its essential features by those who make decisions, from the field to the national and global levels, which is an essential pre-requisite to management.

Understanding and managing local resilience in their own fields is the best option that farmers have to face changes and minimize vulnerabilities in their agricultural systems. At the same time, it is important that local and national institutions have a good understanding of resilience in production and food systems to support appropriate decisions on polices and research priorities.

Often the use of pesticides has been interpreted as an insurance against crop failures. During the 1960s and 1970s, the green revolution promoted input packages (fertilizers, pesticides, high-yielding varieties with narrow genetic base, etc.) to 'ensure' higher yields. This damaged agro-ecosystem resilience in several cases.

Crop intensification based on the indiscriminate use of chemical inputs resulted in major pest outbreaks in several crops. IPM emerged, with support from FAO, as a new approach to pest management. IPM requires a good understanding of local agro-ecosystems, from farmer to policy levels, to make decisions that respect ecological balance among populations of pests and their natural enemies, and to enhance system resilience.

Learning from previous experiences on coping with changes, and now facing new challenges, such as climate change, there is a need for a deep understanding of agricultural production from field to national and global levels, through a systematic approach.

Based on these experiences, it may be concluded that the synergy of challenges posed by climate change and intensification in agriculture, together with challenges posed by more frequent and intense global exchanges for increased trade and people movement, result in a demand for more concerted action among main stakeholders, both at local and global levels. This should be supported by a shift in thinking about scope and priorities to achieve sustainability in agricultural production, with a focus on stability and resilience of the agro-ecosystems.

It is urgent to understand local agro-ecosystems, their variability, modalities to develop and adapt new varieties and agricultural practices, while adjusting cropping systems. This is not only required to face the challenges posed by climate change, but also the combined effect resulting from all the drivers of change mentioned above. The essential role of national institutions, from policy to research and extension, in close collaboration with rural communities, should be recognized.

Innovative approaches should be used in agriculture, aiming not only to increase productivity expressed in tonnes/ha, but also to improve efficiencies in food production from the field agro-ecosystem – protecting resilience by enhancing ecosystem services – to the table and to national level, including social and environmental aspects, with support by adequate policies.

Similar principles would apply to seed systems and to pest management systems, aiming to achieve more resilient food production. Both these systems would benefit from a more coordinated action in crisis prevention, dealing with transboundary pests, pest outbreaks and effects of climate changes.

New learning processes and modalities for problem assessment and solving are essential at the level of farmers, extension, research and policy. At the same time, new partnerships and alliances need to be envisaged to connect main stakeholders, including farmers, at national and regional levels to address the new challenges. This may be achieved by working on experiences from field communities facing local variations to countries sharing similar problems, connecting them at regional levels, involving relevant institutions from research to extension to policy, ensuring their attention to the problems of food security at community level in a context of climatic change.

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