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AN INNOVATION SYSTEMS APPROACH TO ENHANCED FARMER ADOPTION OF CLIMATE-READY GERMPLASM AND AGRONOMIC PRACTICES

Jon Hellin, International Maize and Wheat Improvement Center (CIMMYT)
Tina Beuchelt, International Maize and Wheat Improvement Center (CIMMYT)
Carolina Camacho, International Maize and Wheat Improvement Center (CIMMYT)
Lone Badstue, International Maize and Wheat Improvement Center (CIMMYT)
Bram Govaerts, International Maize and Wheat Improvement Center (CIMMYT)
Laura Donnet, International Maize and Wheat Improvement Center (CIMMYT)
Jens Riis-Jacobsen, International Maize and Wheat Improvement Center (CIMMYT)

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CGIAR Systemwide Program on Collective Action and Property Rights (CAPRi)
C/- International Food Policy Research Institute, 2033 K Street NW, Washington, DC 20006-1002 USA
T +1 202.862.5600 • F +1 202.467.4439 • www.capri.cgiar.org

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ABSTRACT

By 2050, climate change is likely to reduce maize production globally by 3–10 percent and wheat production in developing countries by 29–34 percent. Even without climate change, the real costs of wheat and maize will increase by 60 percent between 2000 and 2050; climate change could make the figure substantially greater. Food security, despite the above, may be possible if agricultural systems are transformed through improved seed, fertilizer, land use, and governance. Cross-disciplinary research by the International Maize and Wheat Improvement Center (CIMMYT) and partners in Sub-Saharan Africa, South Asia, and Mesoamerica aims to enhance farmer uptake of climate-smart agricultural technologies and practices. Key technologies include maize and wheat varieties with tolerance to heat and drought stress and low-nitrogen conditions, together with greater nitrogen-use efficiency. Agronomic practices involve reduced or zero tillage, enhanced surface retention of crop residues, and economically viable crop rotations and diversification, to ensure cropping environments that maximize expression of crop genetic potential, buffer crops against erratic weather, and contribute to climate change mitigation.

We report on the Sustainable Modernization of Traditional Agriculture (MasAgro) initiative in Mexico that uses an agricultural innovation systems approach to enhance uptake of climate-smart technologies and practices. We trace the antecedents of innovation system theory and practice in Mexican agriculture; the institutionalization of the approach in MasAgro; and CIMMYT's role as a network broker, facilitating the establishment of linkages amongst different actors including researchers, seed companies, farmers, agro-processors, and policymakers. In order to be an effective network broker changes are required within CIMMYT; ones that provide an institutional environment encompassing both the "traditional" technology-generation research approach with one that places more emphasis on outcomes and impacts. The innovation systems approach adopted by MasAgro suggests that innovation systems theory and practice can contribute substantially to the scaling-out of climate-smart agriculture.

Keywords: climate smart agriculture, climate adaptation, innovation systems, Mexico, maize

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AN INNOVATION SYSTEMS APPROACH TO ENHANCED FARMER ADOPTION OF CLIMATE-READY GERMPLASM AND AGRONOMIC PRACTICES

Jon Hellin[1], Tina Beuchelt, Carolina Camacho, Lone Badstue, Bram Govaerts, Laura Donnet, Jens Riis-Jacobsen

1. **INTRODUCTION**

Climate change is likely to lead to increased water scarcity in the coming decades (Lobell et al. 2008) and to changes in patterns of precipitation. This will lead to more short-term crop failures and long-term production declines. Climate change is also likely to lead to an increase in temperature. Climate models show a high probability (greater than 90 percent) that by the end of this century growing season temperatures will exceed the most extreme seasonal temperatures recorded in the past century (Battisti and Naylor 2009). While an increase in temperature of a few degrees is likely to increase crop yields in temperate areas, in many tropical areas even minimal increases in temperature may be detrimental to food production.

The resulting decline in global per capita food production will threaten future food security (Brown and Funk 2008). This is especially the case with maize and wheat. These are two of the most important food crops worldwide. Together with rice, they provide 30 percent of the food calories to 4.5 billion people in almost 100 developing countries. Maize and wheat are very vulnerable to climatic variability and change. Climate changes will also influence the development of maize and wheat diseases, with increasing temperatures and incidents of drought exacerbating plant stress and increasing plant susceptibility (Garrett et al. 2011; Savary et al. 2011). Predictions suggest that climate change will reduce maize production globally by 3 percent to 10 percent by 2050 (Rosegrant et al. 2009) and wheat production in developing countries by 29 percent to 34 percent. This will coincide with a substantial increase in demand for maize and wheat due to rising populations.

There are gloomy predictions of how environmental crises will affect global security (Paskal 2010, for example). Through direct effects on livelihoods and indirect effects on state functions, climate change may in certain circumstances increase the risk of violent conflict. The environmental problems associated with climate change could, in turn, play a role in stimulating greater migration leading to conflict in receiving areas: the arrival of “environmental migrants” can burden the economic and resource base of the receiving area, promoting native-migrant contest over resources such as cropland and freshwater (Warner 2010). Crop yield declines in Mexico caused by climate change are predicted to lead to increased migration to the United States (Feng et al. 2010).

While it is true that farmers have a long record of adapting to the impacts of climate variability, predicted climate change represents an enormous challenge that will test farmers’ ability to adapt and improve their livelihoods (Adger et al. 2007). There is an urgent need to identify priorities for future research. Maize and wheat

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[1] Corresponding author: j.hellin@cgiar.org

research, therefore, has a critical role to play in enabling adaptation to and mitigation of climate change. The concern is very high on the agenda in Mexico because it is expected to be among the most negatively affected countries. Agricultural output in Mexico could decrease by 25.7 percent by 2080 due to climate change (Cline 2007). Climate-smart agricultural technologies and practices are available but the challenge remains to enhance farmer adoption and adaptation.

There is also the challenge of enhancing adaptive capacity to climate change. Eakin and Lemos (2006) posit that the high uncertainties in climate change scenarios mean that there is growing interest in improving adaptive capacity rather than the promotion of specific adaptation options per se. There is an expectation that nation-states will improve their capacity and that of their citizens to adapt to climatic change (Eakin and Lemos 2006). Hence, while specific adaptation technologies and practices are critical, there is a need to direct more attention at the institutional changes that empower states to design and implement policy to increase adaptive capacity. Furthermore, the adaptive capacity of nation-states is linked to the complex relationships that exist between the state and private sector and civil society. As we will see below, the Mexican government is strengthening adaptive capacity by embedding the promotion of climate-smart technologies in an innovation systems framework.

2. CLIMATE-SMART AGRICULTURAL TECHNOLOGIES AND PRACTICES

Climate-smart agricultural technologies and practices contribute to i) an increase in global food security; ii) an enhancement of farmers' ability to adapt to a changing climate; and iii) the mitigation of emissions of greenhouse gases. In the context of Mexico, key technologies include climate-adapted germplasm and more sustainable land management practices.

Germplasm Technology

Improved crop varieties are a key output of agricultural research and have contributed to significant increases in agricultural production and productivity (Evenson and Gollin 2003). Communities may adapt to climate change in different ways, including switching to water efficient or drought and heat tolerant crops better suited to a warmer and drier climate (Lobell et al. 2008). Scientific crop breeding will continue to play a critical role in meeting the challenge of increasing food production in the face of climate change. The development and dissemination of improved germplasm has the potential to offset some of the yield losses linked to climate change. Crop varieties with increased tolerance to heat and drought stress and resistance to pests and diseases are critical for managing current climatic variability and for adaptation to progressive climate change.

The development of climate-adapted germplasm is possible through a combination of conventional, molecular, and in some cases transgenic breeding approaches. In conventional breeding for tropical maize, the application of proven drought breeding methodologies in managed stress screening has resulted in significant grain yield increases under drought stress (Bänziger et al. 2006). However, further yield gains will be required to offset the potential effects of climate change on maize. In particular, research is required into the identification of traits associated with combined heat and drought tolerance, and the development of improved germplasm for high temperature, water-limited environments.

Despite decades of maize breeding and the promotion of improved maize varieties, the majority of Mexican maize farmers continue to use local maize varieties (Barkin 2002). There are many reasons for this. First, market-related issues in both input and output chains can influence farmers' propensity to adopt improved maize varieties. On the input side, bottlenecks exist in the value chains and impede farmers' access to seed. On the output side, quality and scale-related barriers also exist, inhibiting the acceptance of farmers' maize in industrial maize markets (Keleman et al. 2013). Second, farmers may prefer local maize varieties for culinary (Tuxill et al. 2010) and cultural reasons (Perales et al. 2005). These are also differences in preferences between women and men due to their reproductive and productive roles; women set priorities towards food security and thus tend to favor varieties that are palatable, nutritious, and meet processing and storing requirements. Women can also generate income from the artisanal processing and sale of traditional maize products (Beuchelt and Badstue 2013). Third, improved maize varieties, often developed on research stations, do not necessarily perform well under farmers' conditions. Further, Mexican farmers frequently cite the variable performance of hybrids and their "dependency" on fertilizers or other chemical inputs to explain their reluctance to adopt them at a larger scale (Keleman et al. 2013).

The maintenance of local maize varieties may, however, have a very important role to play in climate change adaptation in Mexico (Bellon et al. 2011). In some parts of Mexico, crop germplasm that is appropriate for predicted climates may already exist in the form of farmers' local maize varieties (Mercer et al. 2012). Furthermore, within the primary maize and wild relatives gene pool there exists unexploited genetic diversity for novel traits and alleles (Ortiz et al. 2009) that can be used for breeding new high yielding and stress tolerant cultivars using conventional approaches. Farmers' local maize varieties should be part of the arsenal of climate-smart technologies and practices.

Wheat yields decline at supra-optimal temperatures (Reynolds et al. 1994) and significant breeding effort will be required to maintain productivity in regions, such as Mexico, that are closer to the equator. Wheat breeding has had considerable impact in marginal environments, for example, analysis of CIMMYT international nursery data shows clear and steady progress in the performance of both bread and durum wheat under drought (Braun et al. 2010). One of the most effective research strategies for wheat has been, and will continue to be, to change the phenological pattern of the crop so that critical growth stages do not coincide with stressful conditions or simply to finish the life cycle early before severe stress conditions occur.

Conservation Agriculture

Climate change will be especially detrimental to crop production in cropping systems where soils have degraded to an extent that they no longer provide adequate water-holding capacity to buffer crops against drought and heat stress. These effects will be most severe if irrigation is not available to compensate for decreased rainfall or to mitigate the effects of higher temperature. Improving genetic adaptation to heat or drought stress alone will not address these problems;

there is also a need for complementary agronomic interventions (Hobbs and Govaerts 2010). Scientists are developing improved cropping systems and management practices known as conservation agriculture (CA) as part of climate change adaptation options.

CA involves significant reductions in tillage, such as a permanent soil cover through enhanced surface retention of crop residues, and diversified, economically viable crop rotations. This has contributed to productivity growth, reduced burning of crop residues, and efficient utilization of water, soil nutrients, as well as savings in cost of fuel and labor (Govaerts et al., 2009). CA is particularly important in rainfed areas where it helps in retaining water and improving yields (Verhulst et al., 2011). Furthermore, sustainable agronomic and resource management practices, such as CA and improved nitrogen management, can contribute to climate change mitigation. CA also enhances soil carbon sequestration and cuts CO2 emissions by reducing tillage (and hence use of fossil fuels) and by reducing or eliminating the burning of crop residues. At the same time, trade-offs exist, for example, due to the use of crop residues for feed or fuel (Hellin et al. 2013). These trade-offs need to be addressed and if necessary, appropriate context-specific solutions have to be developed to be not only environmentally, but also socially and economically sustainable (Baudron et al., 2013) .

3. FARMER (NON) ADOPTION OF CLIMATE-SMART TECHNOLOGIES

Farmers will not be able to benefit from existing and future technology options if they are unable to access the improved seed and other technological innovations. The benefits from advances in plant breeding and research into improved land management have often not reached the majority of poor farmers cultivating marginal lands. The reasons behind farmer adoption of climate smart technologies are complex but we can learn much from previous research on farmers' reluctance to adopt soil and water technologies (see Hudson 1991).

Farmers base their adoption decision on the profitability, that is, the expectation of marginal gains, and risks associated with the new technology or practice (Kaliba et al. 2000). Adoption studies related to smallholder production systems have shown that risk is an important component in farmers' decision-making. Thus, farmers tend first to adopt simple technologies or components and then progressively move to more complex and more costly technologies. To reduce risk further, they tend to experiment first on rented or low quality land (Ramírez-López et al. 2013). In terms of the adoption of seeds of improved varieties risk is also linked to the fact that improved varieties that crop breeders identify as superior to landraces under experimental conditions may actually yield substantially less under farmers' conditions due to genotype-by-environment interactions that remain undetected in the data from experimental plots (Keleman et al. 2013) and the fact that farmers' management is not optimal in terms, for example, of the use of fertilizer. The result is that farmers often trust local varieties, considering farmer-saved seed to be a "known quantity" while fearing that unfamiliar seed will perform in unexpected ways (Arellano Hernández and Arraiga Jordán 2001).

An important factor in the nonadoption of climate-smart technologies has been rural labor shortages (Zimmerer 1993). Many farmers depend both upon production from their land and upon off-farm income-generating activities. This has far reaching implications for the availability of labor at different times of year and can determine farmers' acceptance of practices such as CA systems especially if farmers are unable to purchase labor-saving technologies such as herbicides to control weeds (Giller et al. 2009).

CA and high-input agriculture based on improved seeds, fertilization, and agronomic management, are complex technologies linked to complex social processes (Wall 2007). A major challenge to farmer acceptance of CA and other climate-smart technologies is that they are knowledge-intensive (Kassam et al. 2009). While agricultural extension, education, and training can help many farmers maximize the potential of their productive assets through adoption of climate-smart technologies, the promotion of these technologies has coincided with deep cuts to publicly funded extension services in the developing world (Ajieh et al. 2008).

The breakdown of classical publicly funded agricultural research and extension services means that these services are now unable to address the needs of farmers living in marginal environments. In the majority of cases, the private sector has proven incapable of replacing previous state services due to high transaction costs, dispersed clientele, and low (or nonexistent) profits (Muyanga and Jayne 2008). In the absence of relevant and competent extension provision, one can expect lower adoption rates of knowledge-intensive technologies. There is a need for new approaches to extension provision along with a new consensus on the role of the public and private sectors and how extension for resource-poor farmers can be provided on a more sustainable basis.

Public- and private-supported extension programs can play a key role in information sharing by transferring technology, facilitating interaction, building capacity among farmers, and encouraging farmers to form their own networks. Extension services that specifically address climate change adaptation include disseminating local cultivars of drought-resistant crop varieties, teaching improved management systems, and gathering information to facilitate national research work. The breeding and agronomic research work needs to be supported by other factors including complementary investments in climate-responsive information and input delivery systems and strengthening of institutions to coordinate grain marketing with seed, fertilizer, and credit delivery. The development of reliable seasonal weather forecasts, reliable records of weather, and strengthening of early warning systems are also crucial for facilitation of adaption to climate change.

The above can best be achieved via a judicious mix of public and private service provision in the agricultural sector that also address multiple market and government failures in the delivery of technologies, inputs, and services (Cooper et al. 2008). This requires new institutional arrangements and policy instruments to enhance local capacity and stimulate the adoption of improved technologies for adaptation, management of risks, and protection of vulnerable livelihoods. This requires novel, flexible research and extension approaches that differ from those more commonly used by policy makers, donors, researchers, and extension agents (Ekboir et al. 2009). Enhancing the productivity and profitability in marginal areas will require approaches that promote the translation of innovations in plant science into concrete benefits for poor farmers and in ways that support the emergence of agricultural innovation systems.

4. AGRICULTURAL INNOVATION SYSTEMS

Agricultural development is an immensely complex process characterized by a high degree of nonlinearity. Farmers participate in social change not as passive subjects, but rather as social actors. Their strategies and interactions shape the outcome of development within the limits of the information and resources available (Sumberg et al. 2003). Agriculture can be viewed as an integrated social-technical system in which farmers and service providers create solutions to production and livelihood problems, often taking advantage of new opportunities through the modification of new technologies and existing production systems (Hall et al. 2005). In the agricultural sector, innovation is a central strategy to achieve economic, social, and environmental goals.

A systems approach is needed in which innovation is the result of a process of networking, interactive learning, and negotiation among a heterogeneous set of actors (Klerkx et al. 2009). This very much applies to climate change adaptation because "the effectiveness of these adaptations for mitigating future sensitivity to climatic risk will be strongly influenced by the ways in which policy enables or inhibits households' capacity to address climatic challenges" (Eakin 2005). This is largely because a household's management of climatic risk is a function of numerous factors including education, wealth, natural resources, social organization, and institutional relationships (Eakin 2005). This has led to increased interest in agricultural innovation systems.

An innovation system is a network of organizations and individuals focused on bringing new products, new processes, and new forms of organization into social and economic use. The institutions and policies that affect their behavior and performance is also part of the innovation system. Innovation systems depend on learning processes, feedback loops, and iterative interactions that are decidedly non-linear (Spielman et al. 2008; Davis et al. 2008). An innovation system consists of a web of dynamic interactions among researchers, extension agents, equipment manufacturers, input suppliers, farmers, traders, and processors (Hall et al. 2005). Innovations systems have emerged around conservation agricultural practices across the developing world (Erenstein et al. 2008; Dixon et al. 2008) and well as in market access (Devaux et al. 2009) and rural development (Hellin 2012).

The purpose of an agricultural innovation system is to strengthen the innovative and adaptive capacity of all actors throughout the agricultural production and marketing system. In a vibrant innovation system, agricultural development results from efforts to combine technological improvements in production, processing, and distribution with organizational improvements in how various actors in these systems exchange information and knowledge in these systems, along with policy changes that create favorable incentives and institutions to promote change (Davis et al. 2008). Agricultural innovation systems, therefore, include both users and producers of information, and must link them in a dynamic process that needs to be supported by appropriate framework conditions—not just policies but also financial, business, and educational systems (Spielman et al. 2008).

There is a link between innovations systems and collective action even though the role of collective action in innovation processes has received little attention to date. As Devaux et al. (2009) comment, the literature on collective action emphasizes its role among individuals with common interests, in managing common pool resources, reducing transaction costs, gaining economies of scale, and improving the bargaining power of small farmers. The innovation literature, meanwhile, highlights the importance of interactive, social learning among individuals with different perspectives and interests. Neither discusses the use of collective action in fostering innovation, a topic that is becoming more topical in the context of pluralistic and diversified extension systems.

Most cases of successful agricultural innovation systems highlight the importance of collective action and the crucial role of a facilitator or network broker who catalyzes this collective action, enhances farmers' access to information and technical assistance, and builds the capacity of a group to engage effectively in production and marketing activities. The network broker is an internal or external "facilitator" who catalyzes collective action (Best et al. 2006). The key is that they need to be catalysts or knowledge brokers rather than instructors, working with actors in the innovation system to achieve the same communities' defined and perceived goals (Anandajayasekeram et al. 2008). As Klerkx et al. (2009) point out, different actors can take on the role of network or innovation brokers including NGOs and even research organizations.

It takes several years for large-scale innovation networks to become fully functional and institutionalized; constant reflection on failures and success as well as adjustment of strategies is necessary. Thus, organizational and institutional learning capacities need to be developed by all network actors, including public and private organizations. The generation of appropriate climate-smart technologies and practices, therefore, involves researchers from a broad spectrum of disciplines along with other stakeholders. There is, hence, a need for participatory and interdisciplinary research to provide farmers, policy makers, donors, and other stakeholders with the knowledge, tools and approaches required to meet the challenge of ensuring future food security. The "Sustainable Modernization of Traditional Agriculture" (MasAgro) initiative in Mexico is an example of the development of climate-smart technologies and practices within an agricultural innovation framework.

5. SUSTAINABLE MODERNIZATION OF TRADITIONAL AGRICULTURE (MASAGRO) INITIATIVE

The Evolution of Masagro

The Mexican government is seeking to boost agricultural production and productivity as well as to enhance farmers' access to markets. Despite large investments in agriculture, Mexico is not self-sufficient in the major grains and imports maize and wheat. In the face of predicted climate change and if no immediate action is taken to adapt to this change, Mexico will face declining yields and rising food prices. In response, the Mexican government has launched an agricultural initiative called "Sustainable Modernization of Traditional Agriculture" (MasAgro). The launching of MasAgro marks a new chapter in the development of Mexico's agricultural sector and specifically maize and wheat.

Until the wave of market liberalism heralded by ratification of the North American Free Trade Agreement (NAFTA) in 1994, the Mexican government was the primary provider of extension provision especially to producers of basic grains. The government was largely responsible for the provision of credit, technical assistance, storage, purchase, and marketing of agricultural products. The government also oversaw the production of improved seeds, the manufacturing of fertilizer, and the distribution of both. Since the early 1990s, successive governments introduced reforms designed to modernize the agricultural sector. The government eliminated subsidies on most agricultural inputs and directed credit at farmers with greater agricultural potential. The public extension and technical provision was dismantled and a new public/private sector extension system was introduced.

It was predicted that economic liberalization brought about by NAFTA would create substantial gains in efficiency, stimulate economic growth, and reduce rural poverty. However, it was also recognized that interventions would be required to support some smallholder farmers, who would fare less well during the adjustment process. Researchers such as de Janvry et al. (1995) predicted highly differentiated impacts caused by the reduction in maize prices associated with trade liberalization and the implementation of NAFTA. While many predicted that NAFTA would decimate smallholder maize production in Mexico, this has not happened (Bellon and Hellin 2011). Maize-producing households make complex trade-offs between maize management and other livelihood options, including shifting to alternative crops or exiting agriculture altogether. Smallholder maize production continues partly because Mexicans consume white maize while the maize imported from the United States is yellow maize, which in Mexico is used for animal feed. While other Mexican government initiatives focus on encouraging farmers to grow high value crops such as vegetables, MasAgro is especially designed to contribute and maintain national food security and counteract future yield declines due to climate change by focusing on the basic staples of maize and wheat. With that, MasAgro complements other Mexican government agricultural initiatives.

Agricultural reform in Mexico faced two challenges: first, different agricultural actors and interventions were poorly linked. Research and development activities were only weakly connected with the on-the-ground reality. Second, technology options still tended to be promoted via linear extension models within a weakly functional extension system. Agricultural development in Mexico also has to take into account that the country is composed of 32 states with varying agroecological areas. This heterogeneity presents a challenge for the development and extension of suitable climate-smart technologies and practices, particularly if these have to be adapted to local conditions.

It was clear that complex, multicomponent technologies such as CA-based cropping systems and use of improved germplasm could not be successfully scaled out through traditional linear models of research and extension. What was needed was a change towards more dynamic agricultural innovation systems, systems that reconnected research for development with on-the-ground needs, generated information that helps to align public policies, and stimulated further innovations that solve farmers' problems.

In light of the geophysical and socioeconomic complexity of the country, the level of current and projected agricultural production as well as climatic, environmental, and economic challenges, the government acknowledged that an innovation network approach integrating the agricultural production with federal and state authorities, research organizations, and the private sector was greatly needed. The International Maize and Wheat Improvement Center (CIMMYT) was chosen to become a network broker and to develop the concept of innovation networks in dialogue with public and private sector players in Mexico, whereby research for development, strong local partnerships, and clear generation of ownership of the process of change were central. The Mexican federal government launched the ambitious MasAgro initiative in 2011 targeting maize and small cereals (wheat-barley) systems.

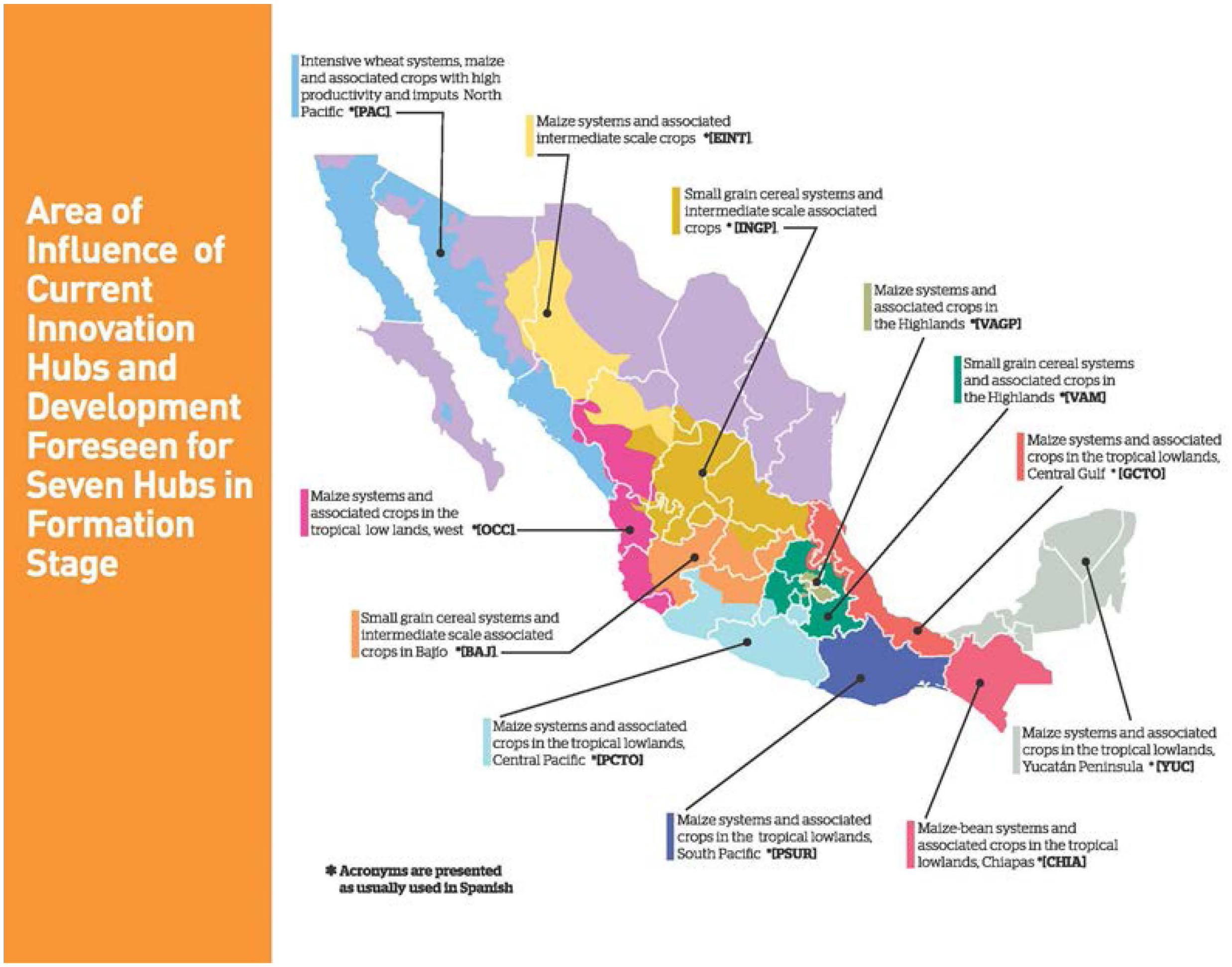
CIMMYT is well placed to play the role of a network broker as it is an international nonprofit research and training organization headquartered in Mexico. It is a respected and neutral research institution in Mexico. CIMMYT's mission is "to sustainably increase the productivity of maize and wheat systems to ensure global food security and reduce poverty". CIMMYT applies the best science to develop and freely share high-yielding, stress-tolerant maize and wheat varieties; large, unique collections of maize and wheat genetic resources; productivity-enhancing and resource-conserving farming practices; and training and information related to the above.

MasAgro focuses on developing, improving, and spreading climate-smart technologies and practices including CA and the use of high yielding maize and wheat germplasm. Many of the proposed technologies have been promoted in the past but adoption rates have been low (Ardila 2010). MasAgro aims to build a constant communication flow through different channels, thereby clearly establishing shared goals and efficient coordination between all the actors involved in the agricultural production chain. MasAgro is a network of value chain actors that includes the private sector, international and national research centers, universities, farmers, extension workers, input suppliers, and of course decision makers at all the levels, from the very local to the national ones.

The Structure of the Masagro Innovation Network

The MasAgro project works in the major maize and wheat producing regions in Mexico. In total seven regions of similar ecological and agricultural production characteristics have been identified and innovation systems are being established in all regions (Figure 1). The networks will focus on CA-based crop management technologies as well as improved crop varieties, postharvest technologies, and integrated soil fertility management.

Figure 1: Regions of Mexico where MasAgro is working

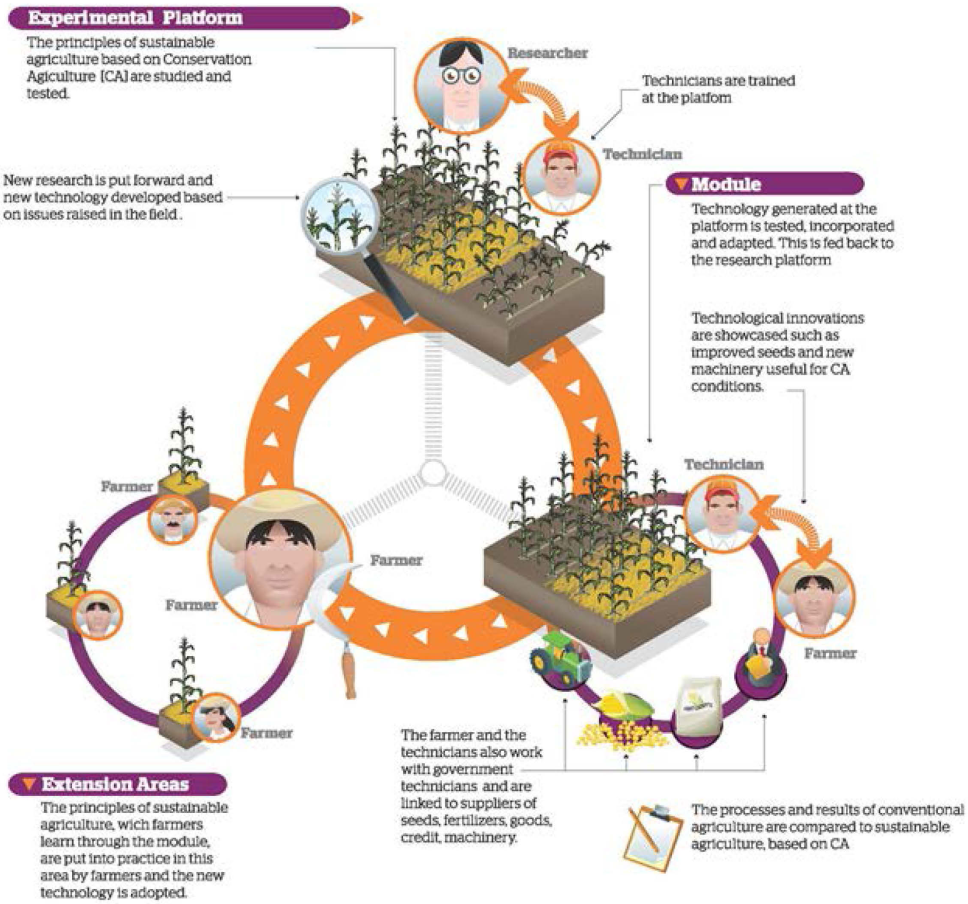


Source: MasAgro

The MasAgro initiative has established a series of hubs. The idea of a hub is to provide a space where all actors of the value chain can meet, interact, and link up to reduce information asymmetries and transaction costs as well as to create vibrant rural living spaces. The space serves also to establish strategic links between public and private institutions, be they research institutions or service providers, and to disseminate knowledge about improved agricultural systems to small and medium sized farmers. CIMMYT, as the network broker for the MasAgro innovation network, facilitates the linkages of actors.

The basic structure of a hub includes the establishment of experimental platforms, farmer modules, and extension areas (Figure 2). Experimental platforms are placed within universities, research institutes, or are newly set up with interested collaborators like farmers, producer organizations, or private industry. Research in the platforms locally adapts and improves the proposed technologies and solves problems arising from farmer trials that are specific to the local cropping systems. Additionally, the experimental platforms serve to train farmers, extension agents, researchers, and other collaborators to reach a better diffusion of the climate-smart technologies and practices.

Figure 2: General structure of a hub



Experimental Platform
The principles of sustainable agriculture based on Conservation Agiculture [CA] are studied and tested.

Technicians are trained at the platfom

New research is put forward and new technology developed based on issues raised in the field.

Module
Technology generated at the platform is tested, incorporated and adapted. This is fed back to the research platform

Technological innovations are showcased such as improved seeds and new machinery useful for CA conditions.

Extension Areas
The principles of sustainable agriculture, wich farmers learn through the module, are put into practice in this area by farmers and the new technology is adopted.

The farmer and the technicians also work with government technicians and are linked to suppliers of seeds, fertilizers, goods, credit, machinery.

The processes and results of conventional agriculture are compared to sustainable agriculture, based on CA

Source: MasAgro

The modules are placed on fields of innovative farmers who are interested in working with key agricultural technologies. The farmers are linked to an extension agent who is trained by CIMMYT and by MasAgro's scientific partners and who is supported by the MasAgro infrastructure. Together, they experiment with the chosen technologies in the farmer's field to test and further adapt the technologies. This feedback is necessary for the research platforms and other network participants to adjust the research trials and solve potential problems. Surrounding farmers, public and private extension agents, and service providers are invited to field day demonstrations.

Extension areas are also located on the fields of farmers (who are normally neighbors, relatives, friends, or other organization members) from the same or nearby communities who follow innovative farmers using new technologies. The idea behind this is that module farmers are, at the same time, promoters who convince other farmers to use the new technology via strategies such as field day demonstrations or talks. Extension areas, hence, play a key role in the upscale of new technologies. The hub assumes that platforms, modules, and extension areas are linked by actors such as extension agents and module farmers. Extension agents become the link between researchers and module farmers as they receive training from the researchers on the new technologies and they communicate their knowledge to farmers and follow up the process of adoption and adaptation. Module farmers guide farmers from extension areas in the implementation of the innovation with the support of extension agents (who in some cases also follow up in some of the extension areas).

It is also important that the networks are able to identify emergent issues and strategies so that they can adapt their interventions to new threats and opportunities. At a conceptual level, the hub allows for feedback by virtue of the links that exist between platforms, modules, and extension areas, along with the roles of actors such as extension agents and module farmers. Admittedly, explicit feedback mechanisms were not defined beforehand but much effort is directed at understanding farmers' needs, constraints, and resources for adoption of climate-smart technologies. For example, the annual hub meetings are an important feedback loop. It will take several years before the hubs have evolved to the extent that feedback mechanisms are working effectively and efficiently. The development of the MasAgro program shows that the evolution of fully functional innovation systems requires considerable efforts of all actors and that up- and out-scaling are likely to be visible only after several years. Decision makers, hence, need to understand that developing and diffusing CA and other complex technologies for small-scale farmers requires a long-term commitment and alternative, more dynamic and flexible approaches to project management, research, and extension methods.

Between 2008 and 2010, and prior to the launch of MasAgro, CIMMYT pilot-tested the innovation systems approach in the central plateau valley in Mexico. This experience showed how a complex and dynamic web of links between different actors developed in the space of a few years. Additional farmers became interested in participating and together with the existing ones were able to establish links to the research platforms as well as to technicians outside of CIMMYT. Other organizations started to play an important role, connecting agricultural research and the private sector with agricultural production. Farmers, previously not part of the network, saw the activities in the modules and decided to experiment with some of the proposed technologies. This marked the beginning of the adoption process within an innovation network and an increased connection between different stakeholders. The extension agents also had access to more and better information and were subsequently able to offer more services and information to farmers. For example, technicians became connected to national seed companies and linked them up to farmers who liked to test new varieties. Machinery producers knew that there is a certain demand and farmers knew whom to call if they needed specific machinery like direct seeders for CA. Overall, the increased network density helped the spread and adoption of new technologies and increased efficiency in the farming sector.

6. STRENGTHENING THE NETWORK BROKER

CIMMYT's coordinating role within MasAgro requires that it act as a network broker (Hellin 2012), a catalyzing agent who fosters the emergence of an agricultural innovation system in Mexico. CIMMYT is facilitating the establishment of linkages, multistakeholder interaction, and capacity building among different actors in the innovation system. A key feature of this broker role is to analyze impartially different actors' needs and to facilitate joint identification of those public and private sector actors best placed to address these needs. The Mexican government has provided an institutional environment that allows for the active participation of different actors including government, private sector, and NGOs. For example, MasAgro explicitly encourages the role of private seed companies in developing and selling improved seed varieties, as well as the role of the private sector in manufacturing of machines used sometimes in CA. MasAgro consists of a network of organizations that carry out research. The network includes national universities and local NGOs.

Being an effective player in agricultural innovation systems poses a challenge for many of the key actors involved, not least agricultural research organizations. A particular challenge is to enhance human capital development within CIMMYT in order to enable the organization to steer a steady course among MasAgro's multiple stakeholders (Donnet et al. 2012). CIMMYT scientists and the institution as a whole need a new focus in order to meet the unique opportunity of delivering technology solutions to increase food security and overcome poverty.

Crop breeding and land management research in CIMMYT has rightly focused on finding solutions to the key constraints to crop production, many of which center around abiotic and biotic stresses. In the past, the impact of an organization like CIMMYT was partly determined by the number of improved crop varieties generated. Less attention was given to whether this germplasm and land management practices were adopted by farmers and the impact of this adoption. CIMMYT, like many other nonprofit, multiple stakeholder research organizations, faces the challenge of demonstrating impact in farmers' fields. A number of factors have come together that have both encouraged and supported CIMMYT's reinvigorated focus on food security and poverty reduction, and its commitment to facilitating the emergence of agricultural innovation systems.

In order to play an effective network brokering role, human development changes are required within CIMMYT, changes that provide an institutional environment encompassing both the "traditional" technology-generation research approach with one that places more emphasis on outcomes and impacts. Key changes have included the following:

- Connection and communication to development organizations and governmental authorities have been improved so as to enable these organizations to implement CIMMYT's research results in their work and policies.
- New staff is being recruited with different skill sets including monitoring and evaluation, systems-thinking, and broader natural and social science backgrounds. Existing staff is being offered training on project management. Training in leadership, building effective teams and facilitation skills will be needed.
- Introduction of electronic work plans and evaluation system that will develop indicators and metrics for judging the success of individuals, projects, programs, and the institution in ensuring impact.

The shift from a traditional technology-generation focus to an organization that maintains this scientific excellence while simultaneously encompassing a greater emphasis on outcomes and impacts will take time. Some existing staff may no longer have the skill sets to meet future challenges and may need to be replaced. Recruitment of new staff to cope with fast growth is time consuming and more so when it comes after several lean years when CIMMYT downsized. Furthermore, upgrading of support service partnerships are needed to complement internal capability, including information and communication technologies. Senior management has not specified the timeframe for the required institutional changes but three years is a realistic vision. In the meantime, MasAgro is a strong incentive and opportunity for CIMMYT to become a more effective player in the global agricultural community.

7. STRENGTHENING OTHER INNOVATION NETWORK STAKEHOLDERS

The government also made several changes to help foster the innovation network. The Mexican Government's Secretaría de Agricultura, Ganadería, Desarrollo Rural, Pesca y Alimentación (SAGARPA) has revised and aligned several public policies and major agricultural programs related to maize production. MasAgro has strengthened its links with 22 states of Mexico with the purpose of establishing local coordination agreements to orient state public policy towards sustainable agriculture. To date, around a third of the state governments have committed to the MasAgro strategy through coordination agreements; more states are revising the terms of the collaboration or about to sign. SAGARPA additionally supported the alignment of the national research institute for agriculture, forestry, and livestock. This means that some government research facilities have established research platforms and conduct research around the MasAgro technologies in different agroecological regions in Mexico.

In addition, the Strategic Program in Support of the Production Chain of Mexico´s Maize and Bean Farmers (PROMAF) was fully aligned with MasAgro and promotes its technologies. The extension agents had to participate in special training sessions around the technologies to ensure the quality of their advice. Furthermore, extension agents from the Strategic Food Security Program (PESA) and from Mexico's states joined the training strategy to provide better quality extension to farmers. Also the private sector showed interest and send their extension agents and sales agents to the training CIMMYT offers. MasAgro is also working with over 20 national seed companies to identify areas where the companies can expand their maize seed sales. Another feature of the collaboration with the seed companies is in business planning. The strengthening of other innovation network stakeholders is part of CIMMYT's exit strategy.

8. CONCLUSIONS

Climate change threatens current agricultural output and, hence, there is a greater need to enhance agricultural yields and resilience of agroecosystems as well as to improve the livelihoods of farmers. Despite some uncertainties on the spatially differentiated impact of climate change on agricultural production, there is little doubt that new germplasm, more suited to future climates, is critical along with improved agronomic and crop management practices. There is an urgent need to develop climate-adaptable crop varieties with improved tolerance to heat stress, and combined heat and drought stress. In addition to enhancing adaptation and reducing vulnerabilities, improved agricultural innovations such as CA may also contribute towards mitigating global warming and climate change.

The development and dissemination of climate-responsive germplasm may take several years because the process consists of several steps including breeding, on-farm testing, release of varieties, and germplasm dissemination. It is very important to facilitate farmers' adoption of these technologies. Such an effort has often been the missing link and has prevented farmers fully benefiting from investment in agricultural research. However, adoption by smallholder farmers has often been limited. Reasons for this include linear extension approaches and development practitioners underestimating the complexity of the technologies.

There is a need for new approaches to extension service delivery that stimulate increased agricultural production, contribute to collective action, and foster the emergence of agricultural innovation systems. Such matching can best be achieved through an agricultural innovation systems approach that fosters dynamic interactions among researchers, extension agents, equipment manufacturers, input suppliers, farmers, traders, and processors, and critically, depends on learning processes, feedback loops, and iterative interactions that are decidedly non-linear. MasAgro is an example of one such agricultural innovation approach with CIMMYT acting as the network broker.

There are no recipes for fostering the emergence of networks of CA or other complex technologies for small-scale farmers; even more, the network brokers have to explore alternative approaches and instruments until they find a working combination. Despite the greater recognition of the importance of agricultural innovation systems, the development community still has some way to go to achieve comprehensively the paradigm shift from a linear transfer-of-technology approach to one that fosters the emergence of agricultural innovation systems. The example of MasAgro in Mexico, however, illustrates how to foster and institutionalize the change. A less evident but no less critical change is the institutionalization of innovation systems thinking and action within CIMMYT.

Different value chain actors can assume the role of network broker. The key is that they catalyze technological and institutional innovations to address location specific challenges that adversely affect agriculture and livelihood systems. The innovation systems approach manifested in MasAgro is not a panacea to the challenge of fostering large-scale farmers' adoption and adaptation of climate-smart technologies and practices, but it suggests that a key to greater success is to catalyze technological and institutional innovations to address location-specific challenges that adversely affect agriculture and livelihood systems. Farmers' livelihood strategies, climate, and market risk management are important factors that influence the adoption of climate smart technologies by smallholders. Both factors are important during project design but also need to be revisited during project implementation as unforeseen changes may occur. Given the recent climate irregularities in Mexico and other countries, agricultural innovation networks need to focus on climate and market risk management strategies and integrate these in the breeding programs, research about agricultural cropping and livestock systems, as well as socioeconomic research.

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