FEED THE FUTURE
The U.S. Government's Global Hunger & Food Security Initiative

A guide to

scaling soil and water conservation

in the Western Highlands of Guatemala

Buena Milpa Project

Jon Hellin, Santiago Lopez-Ridaura, Kai Sonder,
Carolina Camacho and Andrea Gardeazabal Monsalue

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FROM THE AMERICAN PEOPLE

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CIMMYT – the International Maize and Wheat Improvement Center – is the global leader in publicly-funded maize and wheat research and related farming systems. Headquartered near Mexico City, CIMMYT works with hundreds of partners throughout the developing world to sustainably increase the productivity of maize and wheat cropping systems, thus improving global food security and reducing poverty. CIMMYT is a member of the CGIAR System and leads the CGIAR Research Programs on Maize and Wheat and the Excellence in Breeding Platform. The Center receives support from national governments, foundations, development banks and other public and private agencies.

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1. Introduction

Central America has long-been recognized as a region prone to soil and land degradation (e.g., Scherr and Yadav (1996:21). The main cause of this soil degradation is twofold: much of Central America consists of steep hillsides and unequal land distribution that has forced many resource-poor farmers to farm these marginal areas (Hellin et al. 2017). The encroachment onto hillsides represents a move to an area of lower resilience (resistance to degradation) and higher sensitivity (degree to which soils degrade when subjected to degradation processes). Sloping lands are very susceptible to rapid soil degradation caused by physical, chemical and biological processes (Stocking, 1995). Central America's mountains and heavy rainfall, as well as poor land management, make much of the region particularly vulnerable to soil degradation. In addition, the widespread conversion of forests to agriculture has created serious soil erosion problems in the region. In response, there are growing efforts directed at the promotion of soil and water conservation (SWC) technologies (Hellin and Schrader, 2003).

Climate change is likely to lead to increased water scarcity in the coming decades (Lobell et al. 2008) and to changes in precipitation patterns. This will lead to more short-term crop failures and long-term production declines. Farmers have a long record of adapting to the impacts of climate variability, but predicted climate change represents an enormous challenge that will test farmers' ability to adapt and improve their livelihoods (Adger et al. 2007). The fifth assessment report (AR5) of the Intergovernmental Panel on Climate Change (IPCC) for Central and South America concludes that farmers in Central America are particularly vulnerable to the effects of climate change. An increasing body of scientific evidence points to the negative impacts on Central American agriculture of changing temperature and rainfall patterns. Lobell et al. (2008) looked at the combined outputs of 20 of the latest GCM models for 2030 under three different emission scenarios and reported median precipitation declines of approximately -5% for Central America in both the winter (December-February) and summer (June-August) seasons. This is of concern due to the fact that smallholder farming in Central America is predominantly rainfed.

There is a need to work with farmers to develop climate change adaptation and mitigation strategies and to increase the countries' capacity to adapt to climate change. Thus, climate smart agricultural practices have often been promoted. These are practices that contribute to: (1) increasing global food security; (2) enhancing farmers' ability to adapt to a changing climate; and (3) mitigating greenhouse gas emissions. Many of these same practices were promoted in the 1980s and 1990s under the guise of SWC, but farmer non-adoption was far too common. Much can be learned from these past endeavors to ensure that current efforts are better designed, implemented and adopted.

This manual suggests new approaches to SWC in Central America and describes tools and strategies to achieve them. The new approaches include: exploring other soil conservation options besides erosion control, examining the spatial context, examining farming systems as a whole, encouraging active farmer participation, and monitoring and evaluating the effects of the adopted technologies. The Buena Milpa project in Guatemala is presented as a case study that used these approaches, described in three separate boxes showing the scaling of soil conservation practices in the study area, its agricultural innovation system, and its monitoring and evaluation strategies.

2. Past soil and water conservation approaches

For many years, soil conservation programs were based on the assumption that runoff is the main cause of erosion, and that runoff and erosion are inevitable consequences of farming and the principle causes of land degradation. The main objective of soil conservation programs was often to control runoff on agricultural lands in order to prevent loss of soil through accelerated erosion (Douglas, 1993). To combat the perceived threat to soil productivity, and backed by a large amount of field and laboratory research data, soil conservation specialists provided farmers with technical advice, assistance and technologies designed to control runoff and restrict soil losses.

The conventional approach to soil conservation involved cross-slope technologies such as live barriers, rock walls, terraces, and/or earth bunds, along with other physical structures such as drainage channels and vegetated waterways. Soil erosion control methods usually combine practices that do one or more of the following:

- Reduce the susceptibility of the soil surface to detachment
- Reduce the application of detaching forces to erodible surfaces by providing soil cover
- Reduce the ability of erosion processes to transport detached materials
- Induce deposition of transported materials

Erosion control measures can be divided into two categories: mechanical and biological. Mechanical protection includes all those practices that involve moving earth, including digging drains and building terraces. All other practices, such as live barriers, are known as biological methods. More attention is also being directed to the use of cover crops to protect the soil surface from the impact of high-intensity raindrops (Bunch 2012).

Soil conservation initiatives have generally adopted a 'top-down' physical planning approach. Government and non-governmental organizations often implement national and regional soil conservation programs. In general, their work aims to educate and involve uninformed farming communities (Norman and Douglas, 1994:55). The focus has often been on the concept of technology transfer, where a small array of soil conservation techniques are seen as having universal application, including practices such as conservation agriculture (Thierfelder et al., 2013).

3. Farmer non-adoption

The benefits of research into improved land management in Central America have often not reached the majority of poor farmers cultivating marginal lands largely because the promotion of soil conservation practices in Central America has met limited farmer response (Hellin and Schrader, 2003). For the most part, the establishment and maintenance costs of soil conservation technologies can be high. Many farmers depend both upon production from their land and off-farm income-generating activities. Based on research in Central America (including Guatemala), Hellin (2006: 54-55) documented a number of reasons for farmers' non-adoption of SWC technologies, some of which are listed in **Box 1.**

An important factor in the non-adoption of SWC technologies has been rural labor shortages (Zimmerer, 1993). Resource-poor farmers often find that they need to divert labor that is essential for improving soils or maintaining conservation structures, to the immediate goal of primary production or off-farm activities. This has far-reaching implications for the availability of labor at different times of year and can determine farmers' acceptance, or non-acceptance, of labor-intensive soil conservation technologies such as terraces.

Box 1. Reasons for farmer reluctance to adopt SWC technologies (based on Hellin, 2006).

- Farmers do not feel that they reap expected benefits because of a lack of secure access to land.
- Labor costs involved in establishing and maintaining SWC technologies are too high, especially if farmers periodically work off-farm.
- Farmers believe that the economic contribution of their plots to their livelihoods is so small that it is not worth investing time and money in 'improving' the plots.
- Physical earthwork technologies and cross-slope barriers do not, of themselves, lead to improvements in productivity, and even if they do, farmers expect low economic returns from the technologies available.
- Technologies often require farmers to take land out of agricultural production.
- Farmers do not rate soil erosion as a key problem that needs to be addressed and so soil conservation recommendations are seen as a waste of time and effort.
- There is resistance by local peoples to 'top-down' soil conservation programs.
- Technologies exacerbate other problems such as waterlogging, weeds, pests and diseases.
- Due to 'transfer-of-technology' extension approaches, farmers do not feel a sense of 'ownership' over the technologies.
- Technologies do not address, and may even increase, the risks inherent in agricultural production, especially if their implementation involves investment and additional debt.
- Farmers do not have access to the capital necessary to establish and maintain soil conservation technologies.
- Soil conservation practices require changes in farming systems that do not suit the economic or cultural realities of those systems.

Another issue for farmers is that recommended soil conservation technologies often require taking land out of agricultural production. In the case of cross-slope soil conservation technologies, extrapolation of the slope/horizontal spacing relationships from flatter lands to steep hillsides often results in unacceptably close spacing between the technologies and the loss of about 20% of arable land (Shaxson, 1999:87). In many parts of Central America there are severe land shortages. For farmers in the Western Highlands of Guatemala (WHG), losing land for crop cultivation in order to establish a SWC technology may not be an attractive proposition.

Agricultural extension, education, and training can help many farmers maximize the potential of their productive assets by adopting conservation practices. Promotion of these practices, however, has coincided with deep cuts to publicly funded extension services in the developing world and this has meant that fewer farmers have access to important extension messages and information. Rather than repeat the 'mistakes' of the 1980s and 1990s, alternative approaches to improved land management are needed as part of climate change adaptation and mitigation strategies in Guatemala and the rest of Central America.

4. New approaches to soil conservation

Lessons from earlier soil and water conservation endeavors provide invaluable insights into new, alternative approaches to soil management and conservation that may be more successful in terms of farmer participation, adoption and adaptation. These are described below and summarized in **Figure 1.**

4.1. Exploring other soil conservation options

4.1.1 Preserving soil quality

Farmers are primarily concerned with attaining economic and reliable production from their land. The conventional soil conservation argument is that erosion is a threat to farmers' livelihoods and should be controlled because of the link between soil loss and productivity. There is much evidence, however, that this is not the case; often, productivity is governed more by the quality of soil

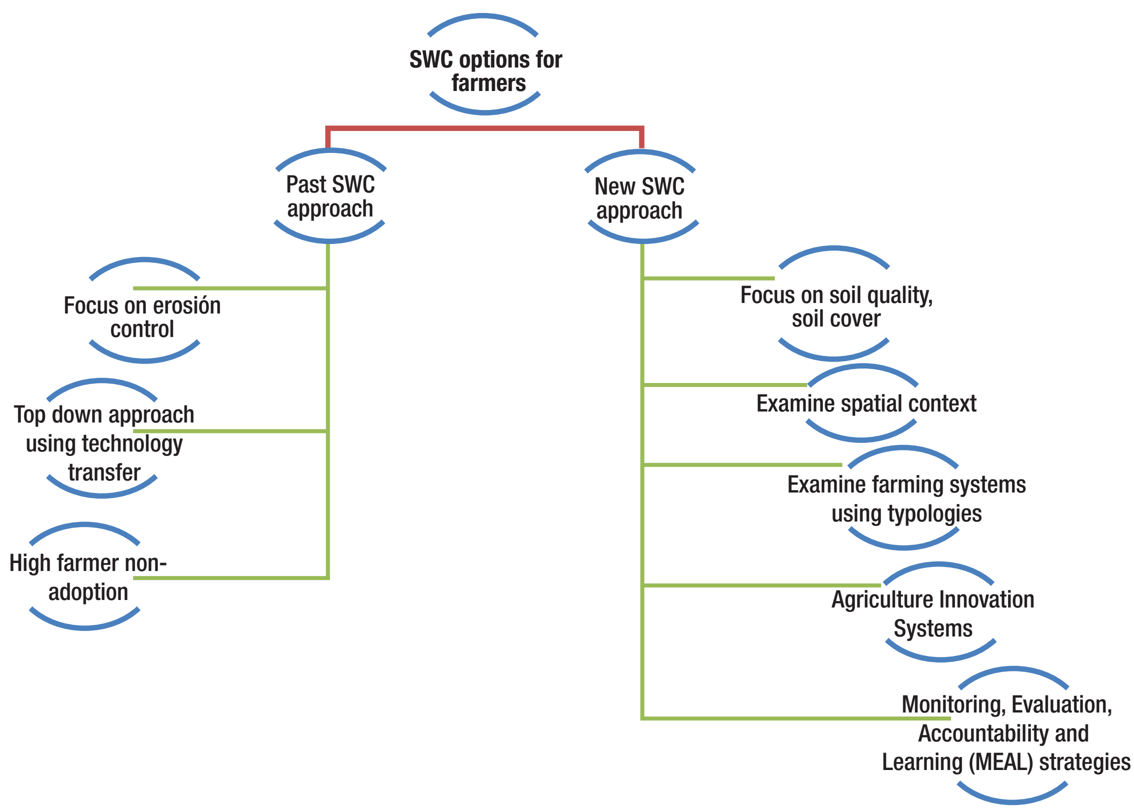


Figure 1. Comparison of past and new SWC approaches available to farmers in Central America.

remaining on the land than by the quantity lost through erosion (Shaxson et al., 1989). In some cases, post-erosion yields will be lower because plants are growing in poorer quality soil characterized by:

- Reduced depth for rooting and moisture retention
- Fewer available nutrients
- Less organic matter and reduced biological activity
- Poor soil structure leading to reduced porosity, slower gas exchange rates and less water available to plants

However, **the better the soil quality is as a rooting environment, in terms of its physical, biological and chemical status, the more productive it is, irrespective of how much has been eroded.** Actual yields are determined by a complex interaction of a number of factors including soil quality, crop and land management system, and climate. Soil conservation technologies that are designed to control soil loss seldom contribute to increased productivity because they do little to improve soil quality. The quality of the remaining soil, rather than the quantity lost, is a more important determinant of subsequent yields, and hence more attention needs to be directed at maintaining and improving soil quality (Shaxson and Barber, 2003).

A change in focus from the quantity of soil eroded to the quality of soil that remains in a farmer's field reaffirms that soil erosion is a consequence rather than a cause of soil and land degradation (Shaxson et al. 1989). The better the soil quality, the more organic matter it contains; this stabilizes the soil structure and improves its capacity to absorb rainfall and restrict runoff. In contrast, decreased cover on degraded soils allows high-energy rainfall to impact the soil surface directly. The damage caused by raindrops leads to reduced porosity in the surface layers, and in turn, less infiltration and more runoff. Alternative approaches must combine farmers' concerns about productivity with conservationists' concerns about reducing soil erosion, via practices that both enhance productivity and effectively conserve the soil.

4.1.2. Preserving soil cover

One of the critical variables under the land user's control is soil cover. The effect of soil cover is not linear, and relatively small amounts of cover have a disproportional effect on reducing splash erosion. Where low-level cover protects about 40% of the soil's surface, splash erosion may be reduced by as much as 90% (Shaxson et al., 1989:37). **Soil surface cover, either living or dead, is the single best factor for reducing erosion**. One of the most effective ways to provide additional ground cover is via the use of green manure and cover crops, including legumes that provide nitrogen to plants via nitrogen fixation. They are also of great benefit in weed control since the space, light, moisture and nutrients they need for their development reduces the growth of weeds (Erenstein, 2003).

Over the last decades, numerous farmers worldwide have used different species of leguminous green manure and cover crops in their farming systems, although there are far fewer candidate species when it comes to higher elevation areas such as the Western Highlands of Guatemala. However, improvements in crop husbandry practices such as early planting and changes in crop density can reduce splash erosion and improve water infiltration by providing more soil cover.

4.2. Examining the spatial context

One of the key factors for adoption and thus scaling out of agricultural technologies, such as crop varieties, management techniques or soil conservation and other natural resource management (NRM) measures, is to ensure that they fit a given agro-ecological target, specific local conditions and the socio-economic needs of farming communities. Geographical Information Systems (GIS) can be a powerful tool for targeting based on biophysical and/or socio-economic data. This calls for good quality recent and reliable data layers from both domains at high resolution; as is the need to geo-reference both field based activities, key locations (places where, e.g., extension agents or community workers are based, as well as input dealers, storage facilities, etc.) and areas of influence of non-governmental organizations, farmers' groups, government agencies and other relevant actors in rural development activities.

A first step is to collect basic geospatial layers such as rainfall, temperature, soils, topography, land use, road and other transport infrastructure from open sources. In some cases this has to be supplemented by mapping activities in the project areas, particularly in countries where GIS data are either scarce, costly or not in the public domain, or the areas of activities are too small to be properly represented in national datasets. This can be done directly in the field using GPS by digitizing maps, or by creating georeferenced layers from remote sensing-based data. These data may be from satellites, unmanned aerial vehicles (UAVs), plane-based or based on machine learning, such as small unpaved country roads in remote areas or field boundaries.

In the biophysical domain, there is currently free access to high quality climate data with a resolution down to 1 km. There are also global elevation models with cell sizes as small as 12 m that allow for high detail targeting, for example of NRM measures like erosion control in any given country. Together with high resolution, satellite imagery-based land-use layers, this permits the definition of development domains (Harrington and Tripp, 1984; Pender et al., 1999; Alwang et al., 2005; Chamberlin et al., 2006; Omamo et al., 2006; van de Steeg, 2014), or similar products based on combinations of layers depending on the type of technologies for scaling. In the socio-economic domain, products like open street maps, transport friction layers, night lights, poverty and other infrastructure datasets and high resolution population density datasets, e.g., Worldpop (http://www.worldpop.org.uk/) and Landscan (https://landscan.ornl.gov/), are in the public domain. These allow creating layers like market access or remoteness of any given location in a country, as well as providing information on how many people live in a given domain that can be used to represent the labor potential. Development domains as proposed by Pender et al. (1999) can be used to identify those parts of a project area, district, country or region where the potential for successfully introducing a technology is particularly high or low. Alwang et al. (2005), for example, show how to combine agricultural potential with other layers, such as poverty, road access and economic layers, to highlight those areas in Guatemala were investment in rural economic growth to reduce poverty shows the greatest promise.

Some biological options (e.g., new crop species or varieties) perform well under particular conditions of biotic and abiotic stress or introduce new specific uses into an area. Scaling out such biological options calls for geographic targeting by creating suitability maps based on basic parameters, such as temperature and rainfall (e.g., FAO Ecocrop) or minimum irrigation capacity thresholds, that represent either the optimal conditions for the biological option or indicate high risk of biotic stresses (e.g., diseases or pests).

For example, **Figure 2** shows the climatic aptitude or suitability for the fast growing cover crop canavalia (*Canavalia ensiformis*) in Guatemala based on FAO Ecocrop parameters elaborated in DIVA-GIS. Canavalia is a useful plant for erosion control, for it provides fast soil cover, improves soil through nitrogen fixation. It is also a green manure, with the additional benefit of being an animal and human food source. As the map shows, canavalia is not suitable for highland areas (gray areas) where alternatives like scarlet runner bean (*Phaseolus coccineus*) or vicia species would have to be considered. As a more complex example, the Buena Milpa project has made extensive use of suitability maps to scale soil conservation efforts (**Box 2**).

4.3. Examining farming systems as a whole

A systems perspective refers to the understanding of the farm household as a whole including the crop, livestock and forestrysub-systems and their main interactions (or competition for resources) expressed explicitly terms of flows within and through the systems (i.e., flows of agricultural production for home consumption or markets, use of crop residues and of manure, the main sources of income, or the use of labor). Farming systems are complex and diverse. Multiple natural resource management activities (e.g., livestock rearing, food and cash crop production, and forestry management) are often carried out simultaneously to satisfy multiple goals. The growing importance of off- and non-farm activities for the livelihoods of small-scale farmers further adds to the complexity (Valbuena et al. 2015). Their diversity is expressed in structural determinants such as the resources available (e.g., land, labor, and capital), as well as more functional features related to the way farmers

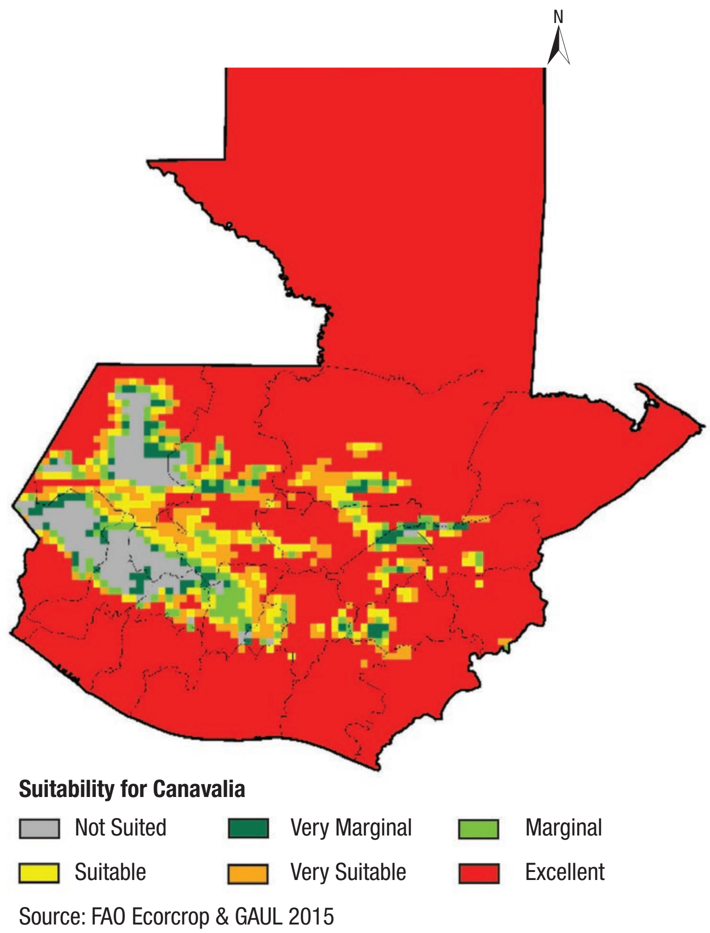
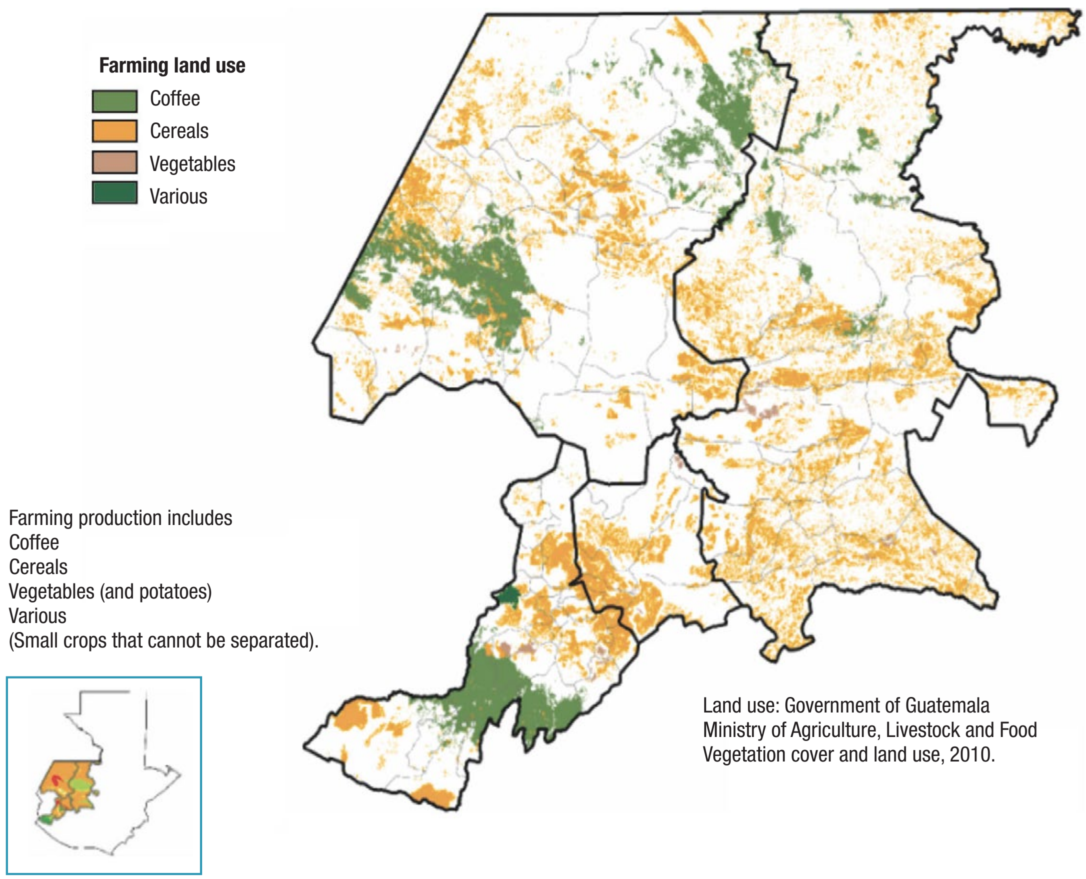


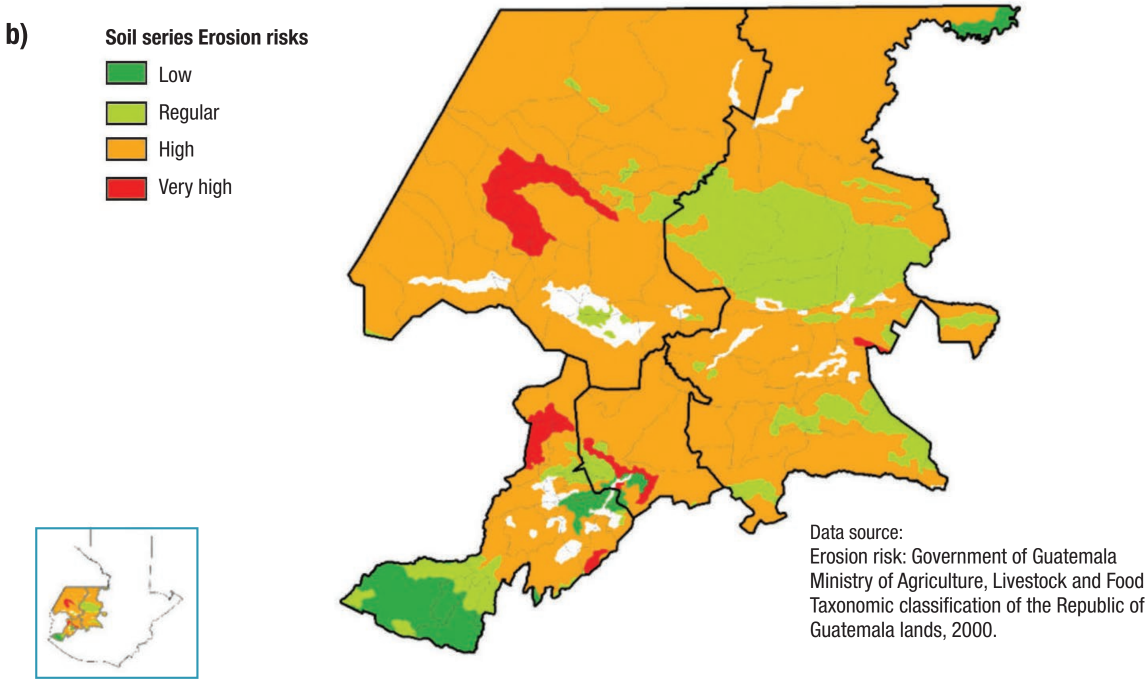
Figure 2. Suitability map for canavalia in Guatemala (based on FAO Ecocrop produced in Diva-GIS).

Box 2. Steps towards SWC in Guatemala: the Buena Milpa project.

The goal of the Buena Milpa project (http://www.cimmyt.org/project-profile/buena-milpa/) is to reduce food insecurity and malnutrition by promoting sustainable, resilient, and innovative maize-based farming systems in the WHG. *Milpa* refers to the traditional slash-and-burn system used in the region for food production. For the project area, the scaling of soil conservation interventions was observed by combining three maps to produce one suitability map: (1) a land-use map to identify crop production areas as opposed to other land uses such as forests or cities (**Figure 3a**), (2) an erosion risk map based both on soil parameters and slopes (**Figure 3b**), and (3) a rainfall erosion map (**Figure 3c**).

a)





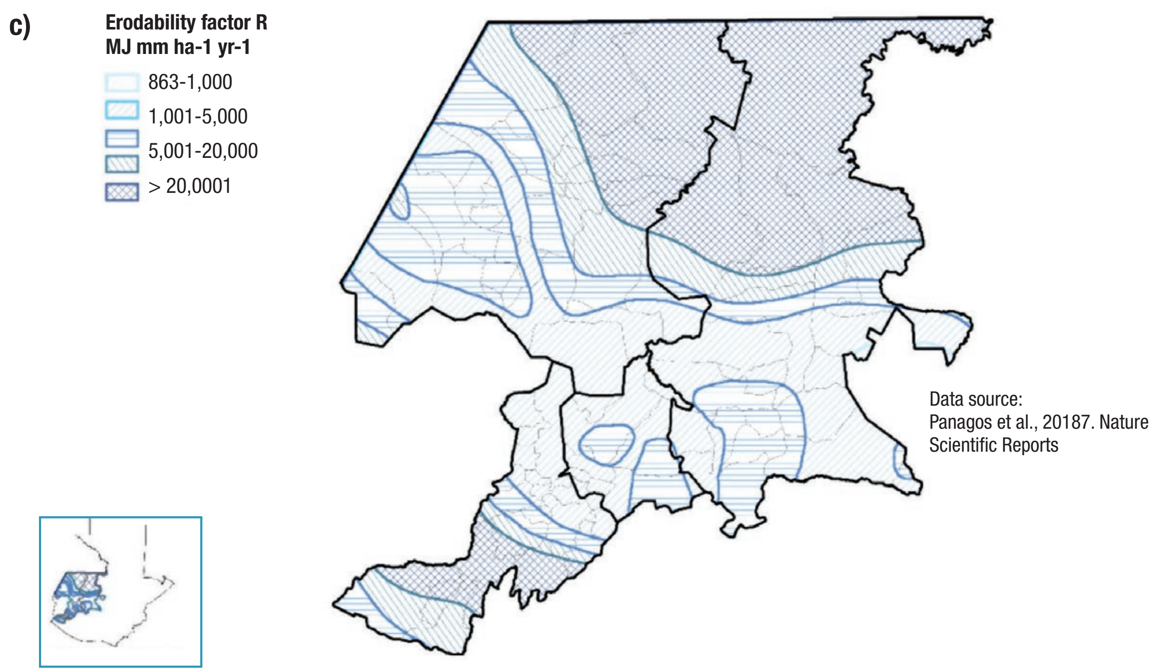


Figure 3. Land-use, b) soil erosion risk, and c) rainfall erosion maps for the Buena Milpa Project area, western Guatemala.

The three layers were combined to highlight croplands at different risk levels and to target the respective erosion control measures (**Figure 4**).

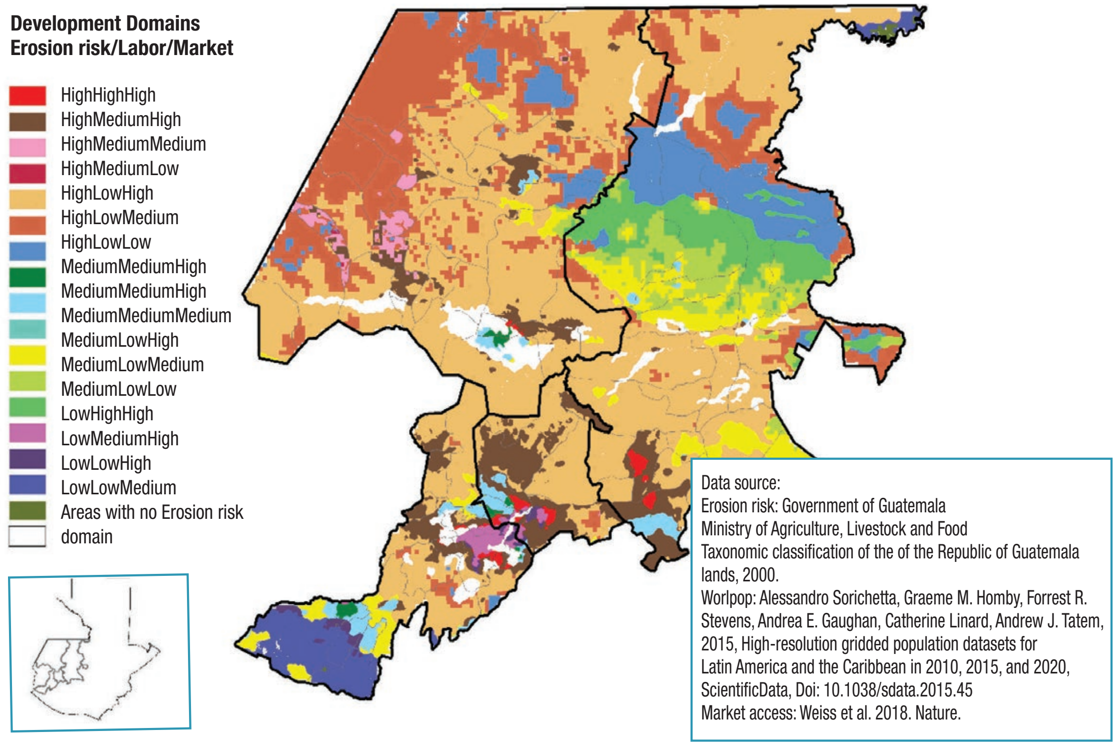
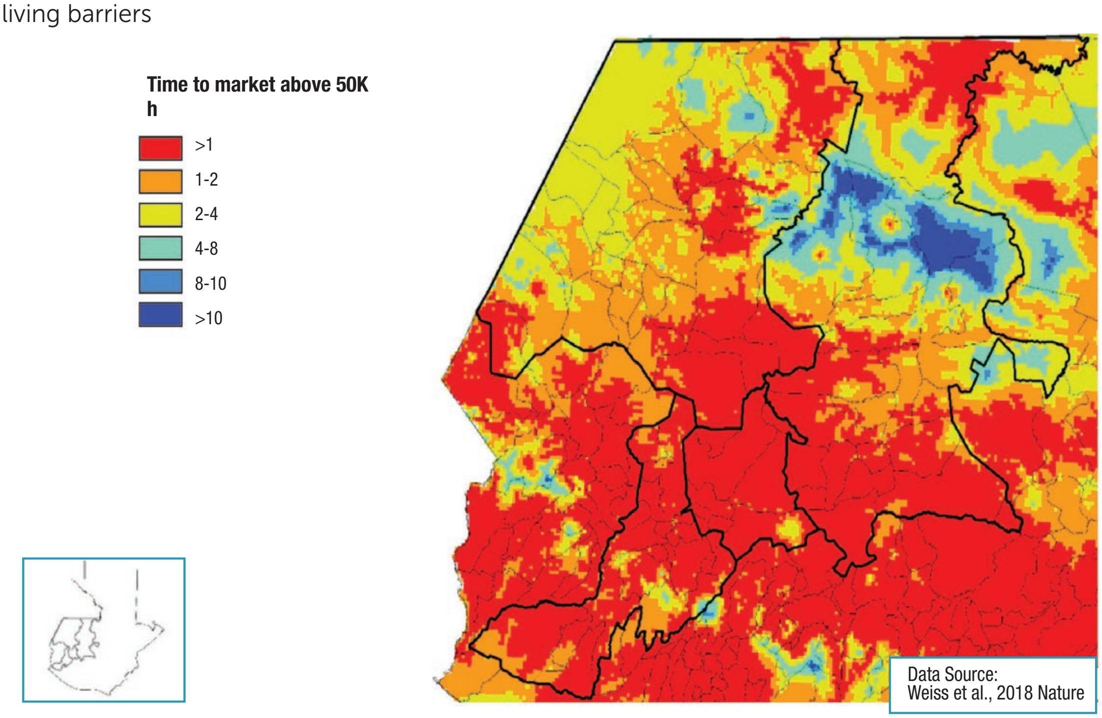


Figure 4. Development domains for the Buena Milpa Project area, western Guatemala (based on soil erosion risk, labor potential and market access).

Additional layers, such as population density (**Figure 5a**) and market access (**Figure 5b**), can be used to further refine intervention areas or specific requirements, such as labor availability for making terraces or markets for products coming out of soil protection measures like fruit trees in living barriers

a)



b)

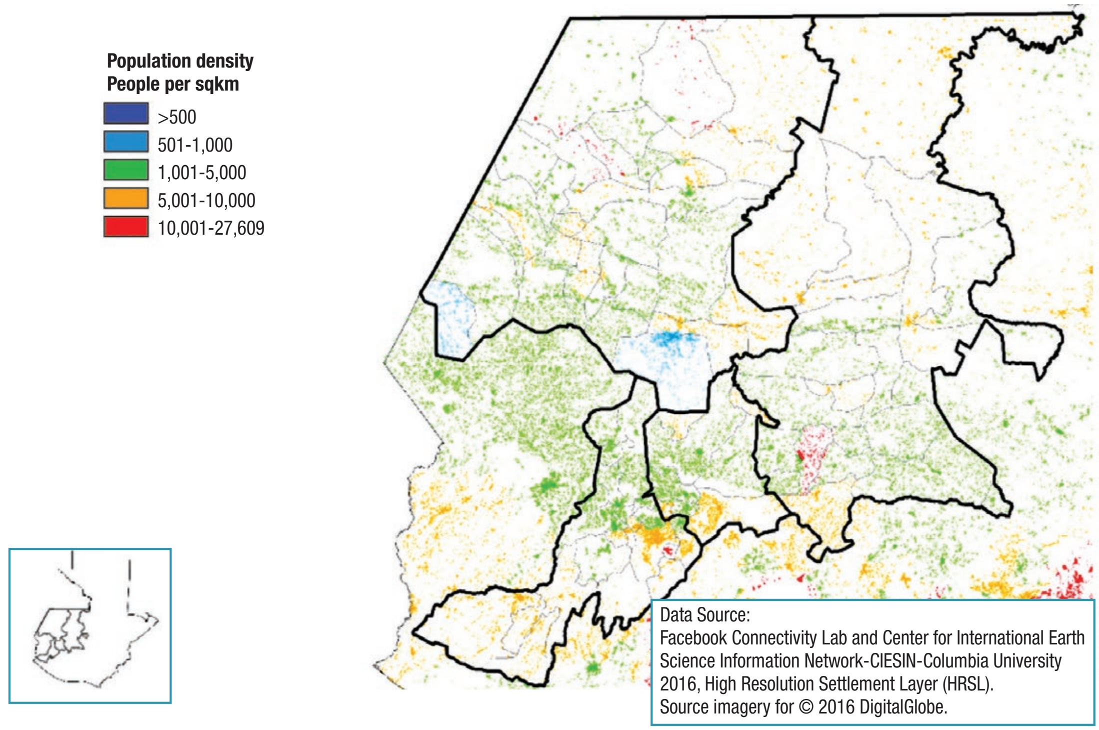


Figure 5. a) Population density and b) market access (based on travel time in hours to a market of 50,000 people or more) for the Buena Milpa Project area, western Guatemala.

For example, an initial system proposed by Pender et al. (1999) was combined with the soil erosion risk map with classified population density and market access (**Figure 6**). Each layer was classified by high, medium and low, the thresholds for population density being < 300, 300-1,000 and above 1,000 people per km². For market access, < 2 h hours to a market of 50,000 people was considered high market access potential, 2-4 h was medium, and > 4 h was low. The resulting matrix shows 17 possible combinations for development domains (**Table 1**). These can be used to define soil conservation measures with potential for generating marketable products, specific needs for labor inputs for each specific domain, and the mapped domains used for scaling these.

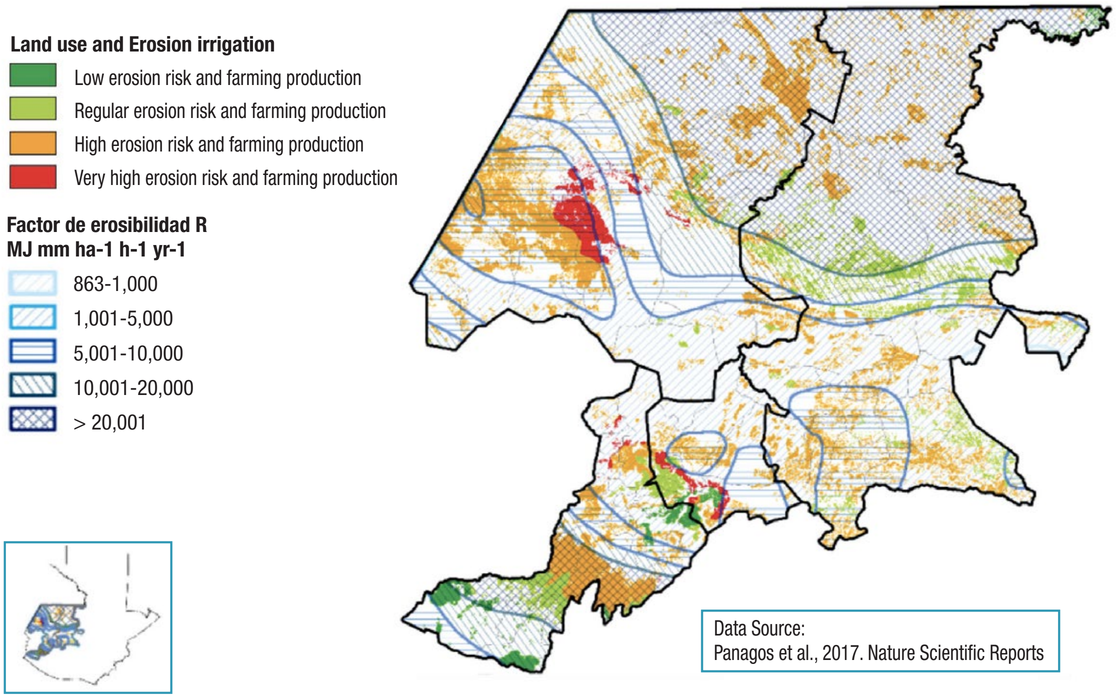


Figure 6. Map of erosion risk in agricultural lands for the Buena Milpa Project area, western Guatemala.

Table 1. Development domain matrix based on soil erosion risk, labor potential and market access.

Erosion risk	Population (labor potential)	Market access	Development domain
High	High	High	HighHighHigh
High	Medium	High	HighMediumHigh
High	Medium	Medium	HighMediumMedium
High	Medium	Low	HighMediumLow
High	Low	High	HighLowHIgh
High	Low	Medium	HighLowMedium
High	Low	Low	HighLowLow
Medium	High	High	MediumHighHigh
Medium	Medium	High	MediumMediumHigh
Medium	Medium	Medium	MediumMediumMedium
Medium	Low	High	MediumLowHigh
Medium	Low	Medium	MediumLowMedium
Medium	Low	Low	MediumLowLow
Low	High	High	LowHighHigh
Low	Medium	High	LowMediumHigh
Low	Low	High	LowLowHigh
Low	Low	Medium	LowLowMedium

use these resources (e.g., crop choice and management techniques, labor allocation, and production objectives) (Tittonell et al. 2010, Berre et al. 2019)).

Soil conservation technologies and practices need to be adapted to the complexity and diversity of small-scale farming systems. This is often best achieved via a systems approach that includes a co-innovation process where farmers adopt and adapt specific technologies in coherence with their farming systems as a whole. **One of the key factors for adoption and thus scaling up of technologies, be it crop varieties or soil conservation and other NRM measures, is to ensure that they fit a given target agroecology or the socio-economic realities of the farming communities**.

Typologies are often used to capture the diversity of farming systems. Typologies are groups of relatively homogeneous farmers to which the fitting of a technology or the expected impact can be assessed. A key feature of typologies is that processes are not linear; instead, they represent the circumstances of a household at a given point in time. Farmers can move from:

- 'hanging in' (where farmers engage in activities to maintain current levels of wealth and welfare) to
- 'stepping up' (where farmers engage in current activities, but make investments to expand them), or
- 'stepping out' (where farmers engage in activities to accumulate assets and move into different activities) and can also fall back into a less desired state (Dorward, 2009).

Typologies for socio-economic characteristics can build on GIS work (Dorward, 2009) and be linked to existing farmer typologies (Lopez-Ridaura et al., 2018). When developing and scaling alternatives for SWC, it is important to understand that farmers are all different and therefore the same technology will not necessarily be relevant or coherent for all farmers. Thus, the main concern of typology delineation in highly unstable environments (economic and environmental) is that typologies are only a 'snapshot' of the diversity of farming systems, which are highly dynamic in such environments (e.g., 'moving targets') (Valbuena et al., 2015). Understanding the diversity of farming systems is needed to make a scaling plan, identify the most likely group to adopt/adapt a given technology, and develop differentiated scaling pathways for different technologies.

Typologies have been used in agricultural research for more than two decades and different techniques have been developed based, among others, on quantitative multivariate analysis, participatory approaches, or simply on expert knowledge. Each of these techniques has advantages and disadvantages and is appropriate for different purposes and scales.

4.2.1 Multivariate analysis-based typologies

One of the most common techniques for making typologies is the use of multivariate analysis (MVA), more specifically principal component analysis (PCA) followed by hierarchical clustering. The PCA reduces data into dimensionless values and the hierarchical clustering defines groups in which the internal variation is less than the intergroup variation. Alvarez et al. (2014) provide a simple, yet robust guide to typology-making through MVA. In the WHG, for example, there are several databases from the surveys that have been done. When selecting variables, two important rules need to be followed: (1) the number of variables needs to be at least four to five times lower than the number of households to be grouped, and (2) when variables are strongly correlated (e.g., land size and land sown to maize), it is important to use only one so as to not add too much weight to that specific feature. **Figure 7** shows an example of farm types identified after PCA-clustering analysis, that are sufficiently distinct from each other mainly in relation to land available and the share of the land sown to maize or coffee. Lopez-Ridaura et al. (2019) show the methods used for this typology, as well as the descriptions of the most important maize-based systems.

4.3.2. Typologies with a participatory approach

Typologies with a participatory approach are commonly done on a small scale (i.e., within a village or a group of farmers) in which the main differences among farming systems can be elucidated together with farmers and technicians. **A good practice when using participatory approaches to build typologies is to ask farmers and technicians what are the main features that differentiate farmers and then make a frequency analysis to highlight the most important characteristics.** For example, in the WHG, a group of technicians were asked to mention the two or three most important determinants of farming systems diversity in the region. **Figure 8** shows how land size, access to roads and transportation, access to credit, and livestock determine farming systems diversity.

4.4. Active farmer participation

Agricultural development is a 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). The rule in many soil conservation programs has been to plan from the top down (Douglas, 1993); yet there is strong evidence that soil conservation projects work best when there is strong farmer participation. This should be the guiding force in future soil conservation initiatives.

4.4.1 Moving away from top-down extension

The success of a soil conservation program in terms of farmer adoption rests partly on the credibility of extension agents and their ability to communicate with farmers. The breakdown of classic publicly funded

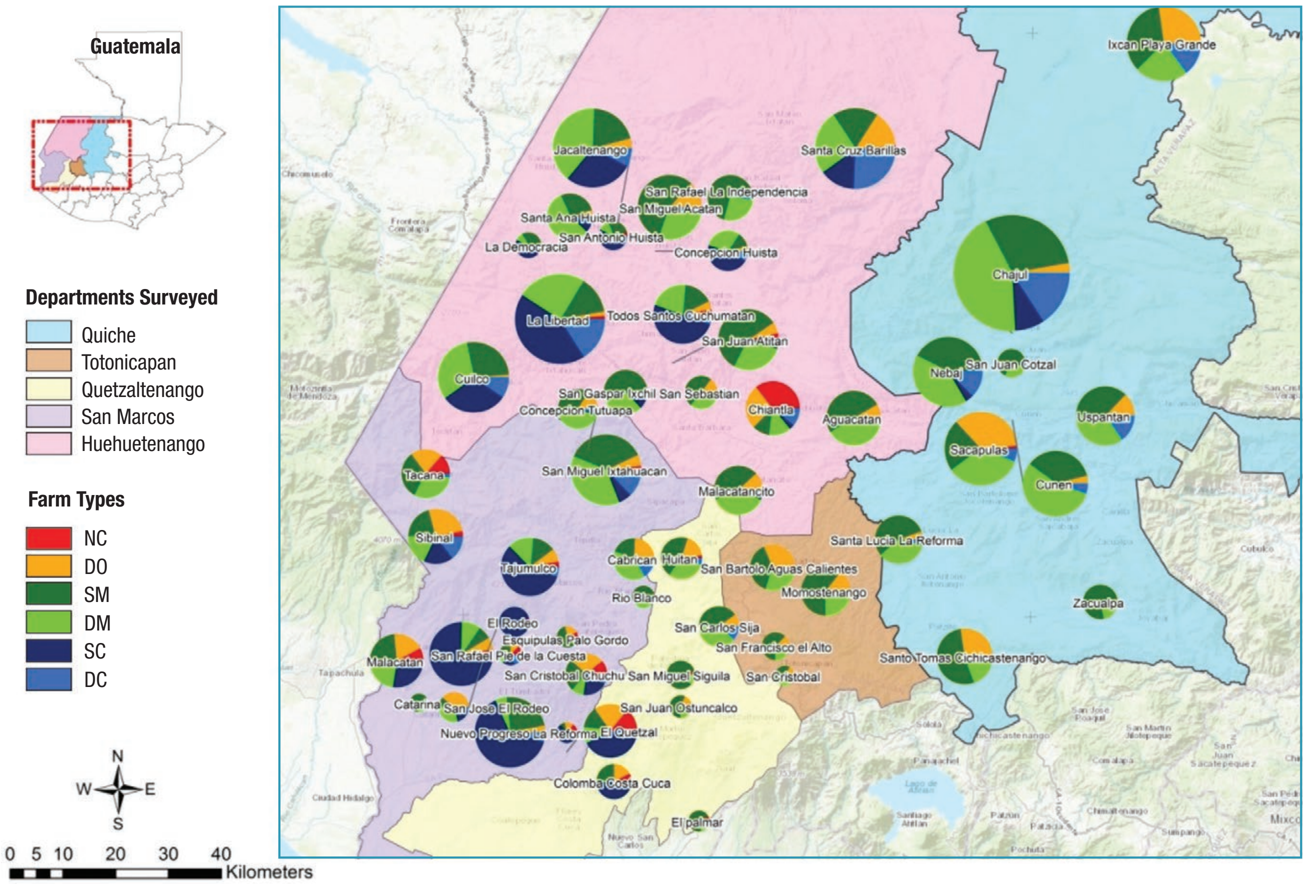


Figure 7. Abundance of farm types among municipalities in the WHG. NC: non-crop farm households; DO: diversified with other crop households; SM: Specialized maize farm households; DM: diversified maize farm households; SC: specialized coffee farms; DC: diversified coffee farms.

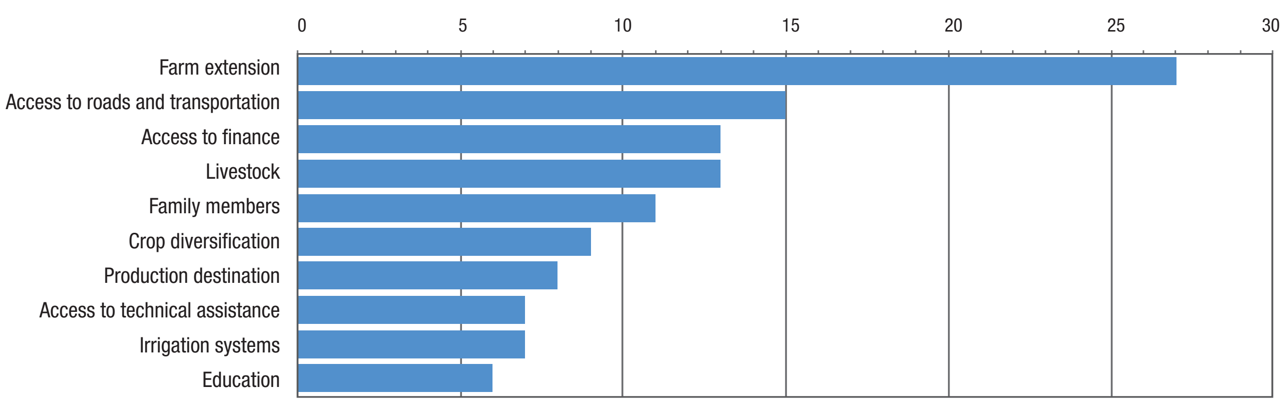


Figure 8. Main determinants of farming systems diversity in the Western Highlands of Guatemala.

agricultural research and extension services means that these services now do not address the needs of marginal farmers. In many 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 of knowledge-intensive technologies.

Furthermore, high uncertainties in climate change scenarios mean that there is growing interest in improving farmers' adaptive capacity rather than focusing on the promotion of specific adaptation options *per se* (Eakin and Lemos, 2006). Instead of defining large development domains for identifying and implementing adaptation options, what is needed are localized, community-based efforts to increase local adaptive capacity (Thornton et al., 2009). Hence, 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, including farmers (Klerkx et al. 2009)**.

4.4.2 Towards 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. It consists of a web of dynamic interactions among researchers, extension agents, equipment manufacturers, input suppliers, farmers, traders, and processors (Hall et al. 2007). **The purpose of an agricultural innovation system (AIS) is to strengthen the innovative and adaptive capacity of all actors, including farmers, 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, along with policy changes that create favorable incentives and institutions to promote change.

The operationalization of this approach happens with the implementation of more formal schemes, such as agricultural platforms (Schut et al., 2016) and hubs (Camacho-Villa et al., 2016). It has also been operationalized with more informal schemes driven by the requirements of the innovation process, as was the case of the Buena Milpa project (**Box 3**).

4.5. Monitoring and evaluation

Within the participatory research and technology-scaling context, monitoring, evaluation, accountability and learning (MEAL) strategies, including innovative data analysis methods and visualization tools, acquire significant relevance. Efficient data collection, dimensional analysis and dissemination of agri-food systems and their integrated pathways could help to overcome the challenges of the future. Since traditional MEAL systems in agricultural projects are not understood as knowledge management systems so far, they still tend to measure indicators related to increased production

Box 3. The Agricultural Innovation System of the Buena Milpa project, Guatemala

In the Buena Milpa project, strengthening the regional AIS was one of the project's lines of action. It involved different stages similar to those in the Agricultural Innovation Platforms (Nederlof, Wongtschowski, & Van Der Lee, 2011). These stages are described as follows:

a. The diagnostic stage

The first stage was the diagnostic of the regional AIS and the status of the Agricultural Extension Service. It also includes the identification of key regional actors for establishing partnerships. In this stage, different types of meetings and workshops were undertaken at regional and local levels for participatory project design and implementation. An important tool used to first identify and later facilitate the strengthening of the local and regional innovation networks was network analysis. This tool was used during all project implementation. In this first stage, it was utilized for mapping key actors of the innovation networks by identifying major players who were already working in the area for more than five years and had established relationships of trust, collaboration and cooperation with local communities. The continuity of its use reflects changes in the network during the implementation of Buena Milpa. **Figure 9** shows the evolution of the partners´ network. In 2015 education institutions (IE), international organizations (OI), and farmers´ associations (AS) were at the center of the network. This changed in 2016 when organizations (OR) and projects (PY) took their place, and by 2017, the main actors were the OR. Of special interest to the exit strategy is the fact that international organizations (e.g. CIMMYT) have not played a central role in the network since 2017.

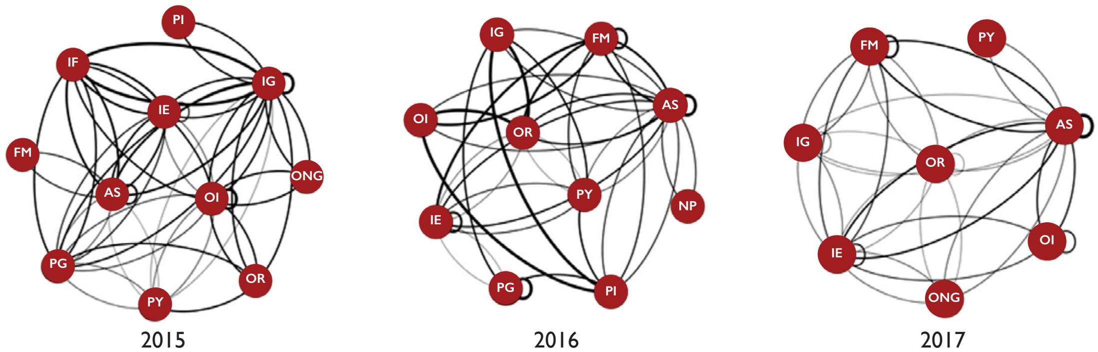


Figure 9. Evolution of the Buena Milpa partners' network. EI: educational institutions; IO: international organizations; FA: farmer associations; OR: farmer organizations; PJ: projects; MF: multiple functions; IF: financial institutions; GI: governmental instances; NGO: non-governmental organizations; GP: seed suppliers; SP input suppliers.

b. The negotiation stage

The second stage consists of negotiating with key local actors about implementing activities in specific regions and localities by means of partnerships. In that sense, there were two types of partnerships: those formalized by agreements that imply an exchange of resources (formal partnerships), and those that defined the implementation or support of specific activities (informal partnerships). Agreed activities contribute to the five thematic lines of action of Buena Milpa: (1) milpa and maize germplasm improvement, (2) natural resource conservation in farming systems, (3) farming systems diversification, (4) AIS, and (5) social inclusion. Most of the formal collaborations focused their efforts on implementing activities related to farming systems diversification (**Figure 10**). However, there have been activities associated with AIS, such as training on network analysis, and more recently, exchanging experiences between Buena Milpa partners.

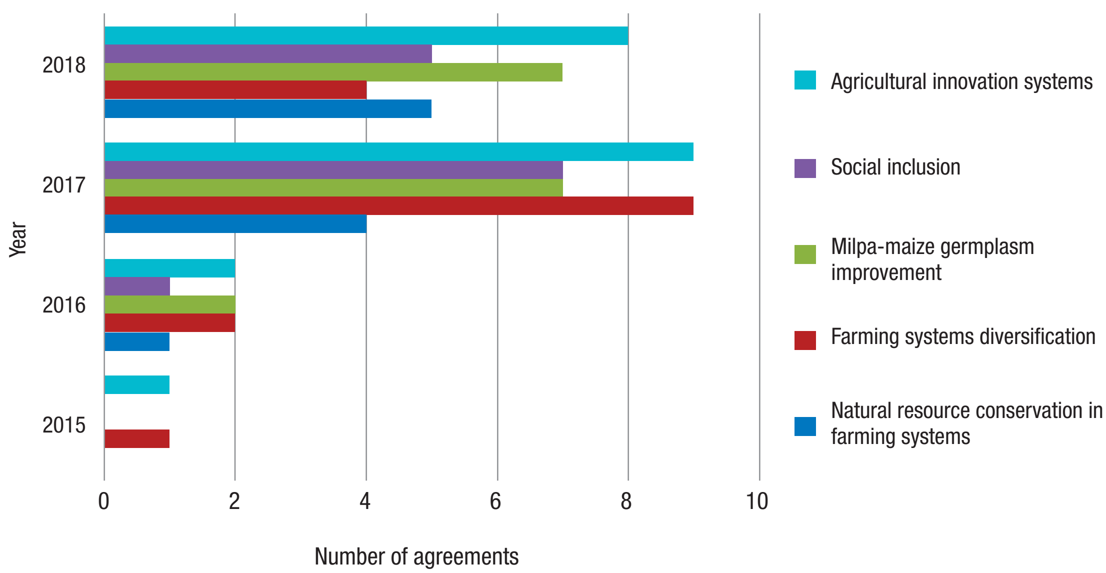


Figure 10. Partnership agreements covering the main themes.

c. The implementation stage

In the third stage, partners implemented activities with backup from the Buena Milpa team. This consisted of follow-up visits and meetings, as well as assisting, participating, supporting or co-implementing specific events. It also included different types of training that aim to develop local capacities for implementing innovations focused on extension agents from partner organizations. There were various formats for these events. In 2016, Buena Milpa organized a one-year course for strengthening extension agents' technical capacities on topics related to sustainable farming practices. In 2017, the scheme changed to specialized courses on topics such as participatory plant breeding and postharvest practices. This format continued in 2018, when specialized courses on social inclusion, sustainable technologies and innovation networks took place as part of the project's exit strategy. Local capacity development on innovation networks was key for AIS. For this reason, specific courses for project collaborators were complemented with a six-month course on innovation networks. The course aimed at developing local capacities on this topic and focused on local universities since they have a more permanent status in the region and are already working on capacity development. Thirty-seven people (professors and students) participated and presented 11 studies at the end of the course. Through this course, two bachelor's theses were developed and 11 other potential ones identified.

d. The reflection stage

The fourth stage consisted of reflecting on advancement and performance. Reflection was carried out in different ways. One way was through consistent meetings: at the end of each year, the Buena Milpa team met with each collaborator to discuss their results and challenges, and based on this, start negotiating the following year's activities. There were also events in which all project participants (collaborators and teams) met and discussed the project and how it should move forward. In addition, there were regional workshops for bringing together different stakeholders in order to discuss their contributions to strengthening the milpa system. At some of these workshops, project results were presented as discussion inputs, as was the case for the regional level results of the network analysis that contributed to discussions on how to strengthen them. A final activity carried out as part of the reflection stage was the systematization of the Buena Milpa experience. This activity consisted of interviewing key collaborators and asking them what they obtained from their participation in Buena Milpa. Some of the answers related to AIS were:

- Linkages at different levels, from internal bodies (such as different faculties within the same university) to between different actors, such as NGOs, universities, farmer organizations and government agencies.
- The multiple uses of the innovation network tool for strengthening the work of agricultural extension workers and presenting their advances; undertaking technology validation and adoption studies; and monitoring advances and presenting results on AIS strengthening.
- The use of collaborator networks for scaling experiences such as participatory plant breeding by interacting with other project collaborators who work in other regions or the scaling out of a bean variety for the milpa system.

Although these four stages normally occur in chronological order, some of them take place continuously during project implementation. This was the case for the negotiation and implementation stages that occurred on an annual basis; however, the collaboration work plan was defined and implemented every year due to budget constraints.

and productivity with little attention to institutional, environmental, contextual and social issues, i.e., systemic questions. Therefore, **the main objective of any MEAL system in agriculture should be to bring in the latest research and technology along value chains regarding precision agriculture and conservation farming practices to farmers of all scales, and support their decision-making processes in order to achieve optimal farming systems of improved productivity, minimal use of resources and impact to the environment**. The organized data could also serve donor purposes and regional decision-making for targeting public and private efforts. **Box 4** lists the MEAL strategies carried out by the Buena Milpa project.

Box 4. MEAL strategies used in the Buena Milpa project, Guatemala.

For the Buena Milpa project, CIMMYT collected defined indicators directly from 6,284 farmers and has around 4,608 registered plots with 7,037 registered field logbooks. In addition, different tools for collecting, cleaning, analyzing and visualizing data were developed and tested to monitor and evaluate project activities and support decision-making.

Data collection: Farmer data describing crop management practices, yields, costs, dates and crop status were captured in CIMMYT-developed field books using an open-source data collection system, the Geographical Open Data Kit (GeoODK) Collect, which allows flexible question design, entry constraints (i.e., ranges in the answers-input), sub-structure repetitions and geo-referenced information. Data collectors were extension agents coordinated by CIMMYT's local partners who were able to work online and offline in the field, save submissions at any point and send them to CIMMYT servers. At present, GeoODK Collect uses an Android platform and supports a wide variety of question types, such as text, number, location, polygons, multimedia and barcodes.

Six main digital forms were developed and deployed:

- **Agronomic field logbook**
- **Participatory breeding logbook**
- **Animal breeding logbook**
- **Field visit report**
- **Training report**
- **Field day report**

Data cleaning and analytics: In order to manage data quality, two processes were put in place:

1. **Manual and dynamic data review:** Several scripts have been developed in R-language (a language for statistical computing and graphics) which automatically obtain data from an Excel file, identify and separate outliers. During the dynamic process, outliers were sent back to data collectors to distinguish mistakes from exceptional results. Once the agronomic cycle was finalized, additional automatized processes were conducted to eliminate remaining outliers and correct grammar and syntax errors.
2. **Automatic outlier identification:** several scripts have been developed in R-language (a language for statistical computing and graphics) which automatically obtain data from an Excel file, identify and separate outliers, and then make graphs, for example, of yield variation and net income per crop, region and production type.

In addition, other analytics in several projects are being tested. Farmers' data describing crop management practices, yields and crop status were pooled and combined with weather records and soil data at the field level. The data were subsequently completed by thoroughly characterizing the actual conditions in which the crops grew and relating them to the yields achieved. Empirical modelling techniques were then used to mine the databases for correlations and/or patterns of the main limiting factors and optimal management practices in each context. Typically, clustering, PCA, regressions and machine learning approaches (such as artificial neural network and classification, and regression trees) are some of the techniques that can be applied.

Visualization and dissemination: In several projects in Latin America, CIMMYT has deployed different visualization tools such GIS, dynamic analytics for visualization or SMS platforms offering free, site-specific technical advice to farmers. Particularly for Buena Milpa, a dashboard will be created with historical data from the last three years, including yield and cost variation per region, training topics and applied technologies, and characterization of the involved farmers, among others. **Figure 11** summarizes the strategies, tools and lessons learned within the project portfolio in Latin America.

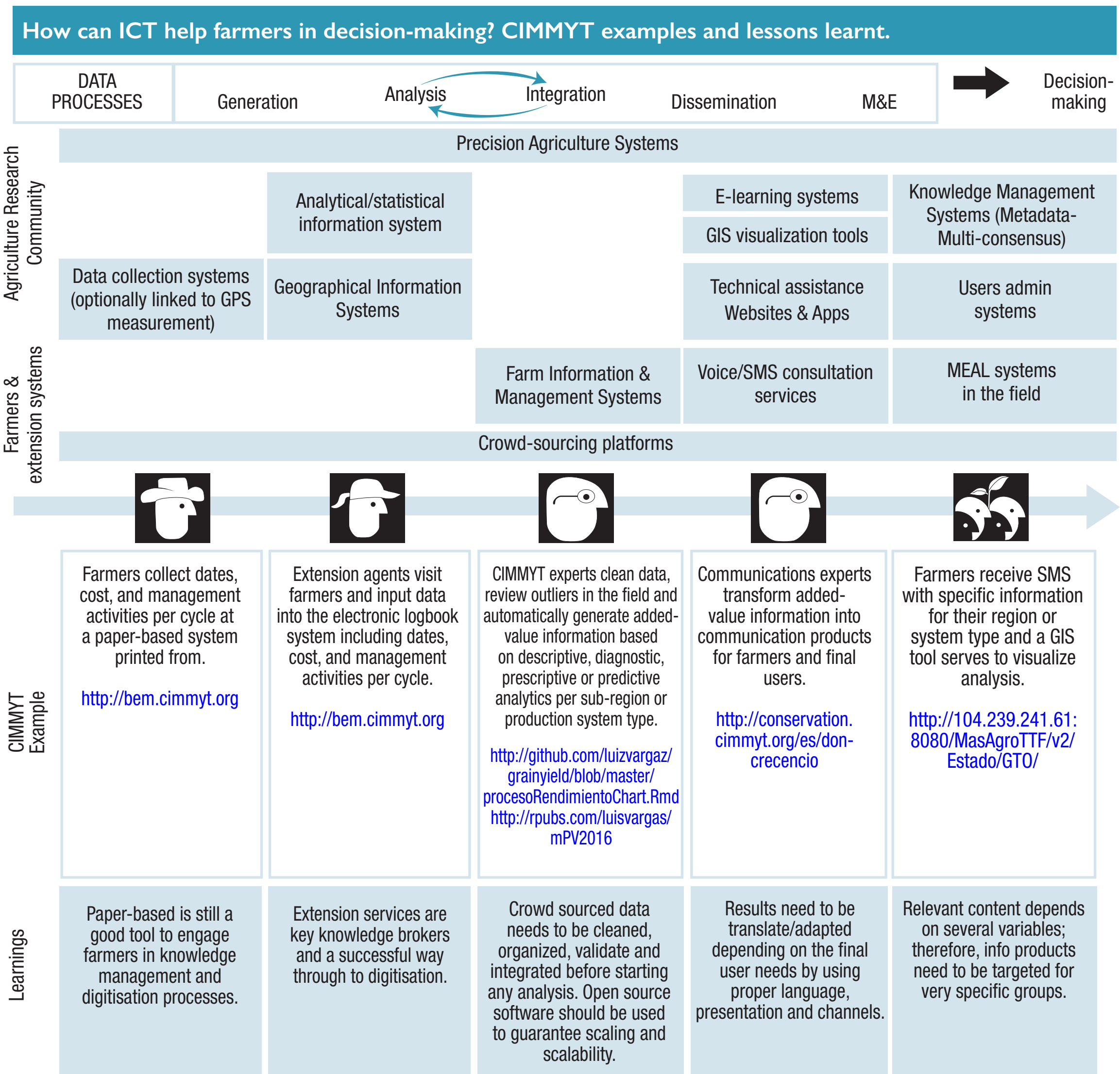


Figure 11. Examples of information and communication technologies (ICT) used by CIMMYT to assist farmers with decision-making.

5. Conclusion

There is little doubt that improved soil and water conservation and crop management practices are needed as part of climate change mitigation and adaptation strategies. It is very important to facilitate farmers' adoption of these technologies. However, adoption by smallholder farmers has often been limited. This guide suggests that more emphasis be directed at improving soil quality rather than capturing soil that has already been eroded. Furthermore, there is a need for new approaches to extension services that stimulate increased agricultural production, contribute to collective action, and foster the emergence of agricultural innovation systems. The development community is slowly trying to shift from a top-bottom technology transfer approach to one that fosters the emergence of AIS where farmers' needs are better identified and addressed. Presently, there is a risk that, as in the past, soil degradation in Central America will continue to be seen as a technical problem requiring a technical solution. Yet, a more nuanced approach is needed, one that recognizes that many proven soil conservation technologies are available, and that the obstacles to improved land management are as much social, economic and cultural as they are technological.

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Notes

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