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Opinion paper

Soil and water conservation on Central American hillsides: if more technologies is the answer, what is the question?

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Abstract: Climate change is likely to lead to increased water scarcity in the coming decades and to changes in patterns of precipitation. The result will be more short-term crop failures and long-term production declines. Improved soil management is key to climate change adaptation and mitigation efforts. There is growing interest in the promotion of climate smart agricultural practices. Many of these are the same practices that were promoted in the 1980s and 1990s under the guise of soil and water conservation. Farmer non-adoption of soil conservation technologies was rife and suggests that different approaches are needed today. Much can be learnt from these past endeavors to ensure that current efforts are better designed and implemented. We use the example of Central America to highlight some of these lessons and suggest alternative ways forward. Technology per se is not the limiting factor; many suitable technologies and practices are extant. What is required is a more nuanced approach to soil conservation efforts. There is a need to focus less on capturing soil once it has been eroded, via the use of cross-slope soil conservation practices, and more on improving soil quality of the soil that remains through improved soil cover. It is also critical to understand farming systems as a whole i.e. the full range of interlinked activities and the multiplicity of goals that farm households pursue. Furthermore, it is important to engage farmers as active players in conservation efforts rather than passive adopters of technologies, and to adopt a board value chain approach and engage a plethora of value chain actors (researchers, extension agents, equipment manufacturers, input suppliers, farmers, traders, and processors) in an agricultural innovation system.

Keywords: Central America; soil conservation; climate change; farming systems; farmer participation; agricultural innovation systems

1. Introduction

Climate change is likely to lead to increased water scarcity in the coming decades [1] and to changes in patterns of precipitation. This will lead to more short-term crop failures and long-term production declines. The resulting decline in global per capita food production will threaten future food security [2]. Environmental problems associated with climate change could, in turn, play a role in stimulating greater migration. 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 [3].

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 [4]. There is, hence, growing interest in soil management and conservation practices that can contribute to climate change adaptation and mitigation and, by so doing, play a critical role in meeting the challenge of increasing food production in the face of climate change. The challenges of ensuring food and livelihood security of millions of people is accentuated by the fact that agricultural production increase will need to take place with less land available per capita [5].

Many regions of the world are predicted to be affected adversely by climate change. Central America is one such region. Climate change adaptation and mitigation approaches in Central America, and other parts of the world, are re-discovering technologies and practices that were promoted in the region in the 1980s and 1990s under the guise of "soil and water conservation" [6,7]. There is nothing wrong with these technologies and practices per se, but a new approach to soil management and conservation is required, one that better accounts for soil-climate interactions, addresses the socio-economic conditions that smallholder farmers face, and that takes on board lessons from the often disappointing outcomes of previous soil and water conservation endeavors. We outline the rationale for such as approach based on the authors' experience of land management in the region over the last two decades.

This paper is structured as follows: Section 1, the Introduction is followed by in Section 2, where we outline why Central America is vulnerable to climate change and some of the predictions based on climate models. In Section 3, we outline soil and water conservation approaches in the 1980s and 1990s and why these were less successful than had been anticipated. Based on extensive research in the region, we identify some of the reasons why farmers did not readily adopt soil conservation technologies. Section 4 draws on lessons from the soil and water conservation initiatives in the 1980s and 1990s in Central America to outline alternative approaches to pathways of knowledge transfer and successful implementation of soil conservation approaches. The section highlights the need to i) focus more on improving soil quality, ii) capture the complexity of farming systems and identify the main trade-offs and synergies associated with the implementation of soil conservation technologies, iii) encourage active farmer participation in technology development, and iv) foster agricultural innovation systems in place of top-down extension approaches.

2. Central America and climate change

Central America has long-been recognized as a region prone to soil and land degradation [8]. The main cause of this soil degradation is two-fold: much of Central America is steep hillsides and inequalities in land distribution have forced many resource-poor farmers to seek out some degree of livelihood security by farming these marginal areas [9]. The encroachment onto hillsides represents a move to an area of lower resilience (the resistance to degradation) and higher sensitivity (the 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 [10].

Central America's mountains and heavy rainfall, as well as poor land management, make much of the region particularly vulnerable to soil degradation. The widespread conversion of forests to agriculture has created serious soil erosion problems in the region. In the early 1990s, an estimated 75% of Central America's agricultural land classified as degraded [11]. In the 1980s and 1990s, concerns were raised by reports that highlighted high erosion rates in Central America [12,13]. In response, much effort was directed at controlling soil and land degradation via the promotion of soil and water conservation technologies [9], an approach that was mirrored in many other parts of the world [14].

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 negative impacts on Central American agriculture due to changing temperature and rainfall patterns. An average temperature increase of nearly 1 °C in Mesoamerica has already been observed since the mid-1990s [15] and projected temperature increases for Central America in the wet season are +0.5 to +1.7 °C by 2020, and +1.0 to +4.0 °C by 2050 [15]. The concern raised by the IPCC AR5 surrounding drought in Central America is supported by several independent studies. Both actual precipitation data and future predictive models are now highlighting negative precipitation trends in the Central America region.

Neelin et al. examined global tropical precipitation trends predicted by 10 of the latest generation of General Circulation Models (GCM) using the IPCC emissions scenario A2 (a business as usual scenario, regarded by many as a likely future scenario) [16]. Despite considerable model differences, the study highlighted one significant drying trend—during June-August (wet season) in the Central America/Caribbean region by the end of this Century—as the most consistent and likely change with seven or more of the GCM models being in agreement. This is important because smallholder farming in Central America is predominantly rain-fed.

Lobell et al. 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 [1]. In terms of future extreme events, few studies currently exist but Jones and Thornton investigated potential effects of climate change on maize production in 2055 using crop simulation models [17]. Decreases in yield were predicted for all of the Central American countries.

The challenge of improving land management in Central America, hence, remains. There is a need to work with farmers to develop climate change adaptation and mitigation strategies and to increase the countries' adaptive capacity to climate change. There is, hence, much interest in the promotion of climate smart agricultural practices. These are practices that 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. Many of these are the same practices that were promoted in the 1980s and 1990s under the guise of soil and water conservation. Farmer non-adoption of soil conservation technologies was rife and much can be learnt from these past endeavors to ensure that current efforts are better designed and implemented.

3. Past soil and water conservation initiatives and farmer non-adoption

The benefits from 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 met with limited farmer response [9]. The experience in Central America has been mirrored worldwide and is not confined to soil conservation technologies per se. There is growing interest in conservation agriculture as a key climate change adaptation and mitigation response. Conservation agriculture involves significant reductions in tillage, such as a permanent soil cover through enhanced surface retention of crop residues, and diversified, economically viable crop rotations. Despite wide promotion, different adoption rates have been observed world-wide. In Sub-Saharan Africa, farmer adoption rates have been very variable [18,19], while in parts of Latin America, notably Argentina, Brazil and Chile, they have been more pronounced [20,21].

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 [22]. In order to combat the perceived threat to soil productivity, and backed up by a huge 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 take the form of some combination of 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 protection describes all those practices that involve moving earth and includes digging drains and building terraces. All other practices, such as live barriers, are known as biological methods. More attention is also being directed at the use of cover crops to protect the surface of soil from the impact of high-intensity raindrops [23].

Furthermore, 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 [24] and the focus has often been on the concept of transfer of technology where a small array of soil conservation techniques is seen as having universal application, including practices such as conservation agriculture [25].

The reasons behind farmer adoption of soil and water conservation technologies are complex but we can learn much from experiences in the 1980s and 1990s when soil and water conservation technologies were heavily promoted in Central America. Based on research on soil and water conservation in Central America, Hellin documented a plethora of reasons for farmer non-adoption and adaptation of soil conservation technologies [9]. These include:

- Farmers do not feel that they reap expected benefits because of a lack of secure access to land
- Labor costs involved in establishment and maintenance of 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
- Technologies of physical earthworks 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
- Technologies exacerbate other problems such as water-logging, 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, or 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 that system

An important factor in the non-adoption soil and water conservation practices has been rural labor shortages [26]. 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 labor-intensive soil conservation technologies such as terraces especially if farmers are unable to purchase labor-saving technologies such as herbicides to control weeds [27]. A major challenge to farmer acceptance of many practices, for example, conservation agriculture is that they are knowledge-intensive [28]. Agricultural extension, education, and training can help many farmers maximize the potential of their productive assets through adoption of conservation practices. The 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.

The establishment and maintenance costs of soil conservation technologies can be high. Resource-poor farmers often find that labor, essential for investment in soil improvement or maintenance of conservation structures, needs to be diverted to the immediate goal of primary production or off-farm activities. Faced with these labor constraints and given the importance of cash in fulfilling household requirements, it is not surprising that farmers often chose not to engage in labor intensive conservation measures but decide to invest their labor in off-farm activities, such as working in nearby cities on construction projects and/or emigrating to another country e.g. Central Americans moving to the United States. These off-farm activities can lead to short-term increases in income.

There are severe land shortages in many parts of Central America. An 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 gives unacceptably close-spacing between the technologies and the loss of about 20% of the cultivable area [29].

Rather than repeat the “mistakes” from the 1980s and 1990s, alternative approaches to improved land management are needed as part of climate change adaptation and mitigation strategies in Central America and worldwide.

4. New approaches to soil conservation in Central America

Faced with the threat of climate change, there is growing interest in climate smart agriculture. In the context of Central America, many of the climate smart agricultural practices being promoted today include many that farmers were encouraged to adopt in the 1990s as part of soil and water conservation efforts, such as live barriers, dead barriers and cover crops. It is all too common to disregard the past, reinvent the wheel and by doing so commit the same mistakes as the past, or worse still not heed important lessons from the past.

Many mistakes can be avoided and more progress achieved if researchers and development practitioners learn from the past. A development practitioner with decades of experience of soil and water conservation in Central America wrote:

> *"Agricultural improvement will always be more of an art than a science… Though general guidelines for programs can be established, the final outcome will depend more upon good judgement and understanding than strict adherence to a set of guidelines. The success of programs depends on an understanding of people's needs, motivations, values and viewpoints and of the possible consequences of the social pressures that programs are setting in motion"* [30].

We argue that the lessons from earlier soil and water conservation endeavors provide invaluable insights on alternative approaches to soil management and conservation that are likely to be more successful in terms of farmer participation, adoption and adaptation. We outline the main lessons below.

4.1. Stronger focus on soil quality

Farmers' unwillingness to follow recommendations probably stems more from the fact that soil conservation technologies devised by outsiders do not accord with farmers' resources, needs and priorities [30]. 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 the relationship between soil loss and productivity is elusive at best [31]. The reason is that productivity is governed more by the quality of soil remaining on the land than by the quantity lost through erosion [32]. In some cases post-erosion yields will be lower because plants are growing in a poorer quality soil characterized by:

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

However, the better the quality of soil 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, however, contribute to increased productivity because they do little to improve soil quality. The quality of the soil remaining, 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 [33].

A change in focus from the quantity of soil eroded to the quality of soil that remains in a farmer's field, also aids the understanding that soil erosion is a consequence rather than a cause of soil and land degradation [32]. The better the quality of a soil, the more organic matter it contains, the more stable its structure, and the greater its capacity to absorb rainfall and restrict runoff. The onset of soil erosion is actually a consequence and not a cause of soil degradation. Decreased cover of the soil subsequently allows high-energy rainfall to impact the soil surface directly. The damage caused by raindrops leads to reduced porosity in the surface layers. This in turn causes more runoff. As the soil becomes more degraded, there is less infiltration and more runoff.

Conventional soil conservation programs that focus on controlling soil erosion rather than maintaining or improving the quality of soil that remains in farmers' fields, address the symptoms of soil degradation rather than its causes. Alternative approaches are needed, ones that combine farmers' concerns about productivity with conservationists' concerns about reducing soil erosion via practices that are both productivity-enhancing and conservation-effective. Shaxson urges practitioners to *think like a root* [34]. From the viewpoint of a root, the quantity and quality of the root-environment that remains behind is of far greater significance for its future growth and development than the quality and quantity of that which has been eroded away. Progress may be made, first by identifying in what conditions of the soil plant roots function optimally, and then taking measures to improve the state of the roots' habitat. Secondly, attention can be directed at reducing soil loss as inevitably this will contribute to soil and land degradation.

4.2. More emphasis on soil cover

One of the critical variables under control of the land user is cover. The effect of cover is not linear and relatively small amounts of cover have a disproportional effect on reducing splash erosion [35]. Where low-level cover protects about 40% of the soil's surface, splash erosion may be reduced by as much as 90% [32]. For this reason another way to reduce the trade-off between feed demands and soil cover is to focus on partial residue retention (while still leaving adequate amounts of crop residue in the field).

Soil surface cover, either living or dead, is the best single factor for reducing erosion. One of the most effective way to provide additional ground cover is via the use of green manure and cover crops. These plants can be inter-cropped maize. Cover crops and green manure crops can include 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 [36]. In zero tillage systems, the mulch that results from pruning, chemical or manual control of the cover crops can significantly reduce the weeds.

Over the last decades, numerous farmers worldwide have used different species of leguminous green manure and cover crops in their farming systems. The species are frequently food crops themselves and include cowpeas or rice bean (both *Vignas*), lablab beans (*Dolichos lablab*), scarlet runner bean (*Phaseolus coccineus*), or fava beans (*Vicia faba*). Perhaps the second most common use of green manures and cover crops is in weed control. The use of cover crops could also reduce the trade-off between biomass use for animal feed and that for soil cover. Ground cover with a high degree of contact with the soil surface can protect the soil surface from the direct impact of raindrops and reduces the velocity of overland flow. 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.

Central America has been a testing ground for the use of cover crops and green manure crops [23] and much can be learnt from previous research in terms of what might be appropriate for the region today [37]. Cover can also in some cases be provided by agroforestry systems. Several indigenous agroforestry systems found in Central America have been documented [38]. A particularly interesting one is the Quezungual System that is used by smallholder farmers in western Honduras [39]. Advantages of this system, identified by farmers, include retention of soil moisture, and increased production of crops, fruits and timber.

4.3. Looking at the farming systems as a whole

Small scale farming systems in Central America, and other parts of the world, are complex systems where multiple natural resource management activities (e.g. livestock rearing, food and cash crop production, forestry management) are often carried out simultaneously to satisfy a multiplicity of goals. Moreover, the growing importance of off- and non-farm activities in the livelihoods of small scale farmers makes the picture still more intricate [40].

Beyond productivity, the resilience and adaptability of the farming systems to climatic shocks, variability and change, as well as the conservation of the resource base, are some of the multiple objectives small scale farmers pursue when deciding on technological innovations for crop and livestock production. Trade-offs among these multiple objectives need to be understood and synergies sought when testing and adapting innovations for soil conservation [41].

Farming systems are diverse even within similar socio-economic and biophysical contexts. Such diversity is expressed in structural determinants such as the resources available (e.g. land, labor, capital) as well as more functional features related to the way that farmers use these resources (e.g. crop choice and management techniques, labor allocation, production objectives). Understanding such diversity of farming systems is essential to target and adapt soil conservation techniques [42]. For example, a farm household with an important livestock component might find a dual purpose live barrier more attractive than a farm household specializing in crop production. The latter may also be more disposed to leaving crop residues as soil cover, while the former may prefer to use crop residues as animal feed. Farm households with high pressure on labor (important migration or non/off farm activities) may well be less willing to invest in labor-demanding practices such as terraces compared to farm households with high labor availability.

Soil conservation technologies and practices need to de adapted to the complexity and diversity of small scale faming systems in specific contexts. A system approach is needed to assess the sustainability of these technologies [43], such an approach includes multiple criteria, allow identification of main trade-offs and synergies, and supports a co-innovation process where farmers adopt and adapt specific technologies in coherence with their farming systems as a whole.

4.4. Active farmer participation

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 [44]. Chambers points out that more often than not when farmers do not adopt recommended soil conservation technologies, they are accused of being ignorant, uncooperative, conservative and unwilling to change [45]. This often strengthens the resolve of researchers, development practitioners and policy-makers to "educate" farmers and to convince them of the virtue of adopting recommended soil conservation technologies.

The rule in many soil conservation programs has been to plan from the top down. Normally, the "*conservation expert identifies the problem in the field (usually perceived as loss of soil, gullying or downstream sedimentation), arrives at a solution with the aid of pre-determined technical guidelines, and only involves the farmers through an extension package at the implementation stage*" [22]. 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. Pretty identifies a seven-level typology of farmer participation that ranges from manipulative and passive participation, where people are told what is to happen and act out predetermined roles, to self-mobilization, where people take initiatives largely independent of external institutions [46].

A rich source of information on farmers' realities is indigenous and traditional knowledge. Soil conservation is a good example of the value of indigenous and traditional knowledge. There is often an assumption that soil erosion is a modern problem and that only modern techniques can be used to control soil loss. However, much can be gained by a greater appreciation of ancient techniques used to conserve soil and water and why in some cases their use has fallen into abeyance [47].

4.5. Incentivizing soil and water conservation

It may be that incentives are needed in order to encourage farmers to adopt recommended soil conservation practices, at least during the first few years when there may not be tangible benefits. The danger is that subsidies tend to buy short-term acquiescence and do not necessarily lead to long-term changes in attitudes and values [31]. Hence, whilst farmer implementation rates worldwide have been enhanced by these temporary subsidies, more often than not farmers abandon the technologies once external support is withdrawn. Hellin and Schrader report on a soil conservation project in Honduras that ran from 1980–1991 [9]. Soil conservation technologies were promoted from 1980 onwards, but incentives were used only from 1984 to 1991. These incentives included cash payments for farmers' labor input; free seedlings and fertilizer; and subsidized credit. The establishment and maintenance rates of the two most heavily promoted soil conservation technologies—infiltration ditches and live barriers—dropped off dramatically once incentives were withdrawn.

There is, however, a distinction between direct and indirect incentives. The former includes cash payments for labor, grants, subsidies, loans, and also in kind payments such as the provision of food aid (food-for-work) and agricultural implements. Indirect incentives include fiscal and legislative measures such as tax concessions, secure access to land, and the removal of price distortions. The provision of indirect incentives is often dependent on policy decisions made at central government level. There is evidence though that incentives such as credit can encourage farmers to invest in soil and water conservation and to continue with the practices once the incentives finish [48].

An incentive is to focus on technologies and practices that are both conservation-effective and productivity-enhancing. There are many technologies and practices to choose from. The use of different species in live barriers can often provide farmers with a *"doble proposito"* i.e. the barrier captures eroded soil and farmers also benefit from the crop used in the barrier for human and/or animal consumption, and sale. Hellin and Larrea documented in Honduras over 20 grass and fruit species being used in live barriers; similar species are being used in live barriers in the Western Highlands of Guatemala [49].

4.6. From top-down extension to agricultural innovation systems

The success of a soil conservation program in terms of farmer adoption rests partly on the credibility of the extension agents and their ability to communicate with farmers. 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 [50]. In the absence of relevant and competent extension provision, one can expect lower adoption rates of knowledge-intensive technologies.

Furthermore, high uncertainties in climate change scenarios also mean that there is also growing interest in improving farmers' adaptive capacity rather than focusing on the promotion of specific adaptation options per se [51]. Thornton et al. write that, in place of defining large development domains for identifying and implementing adaptation options, what is needed are localized, community-based efforts to increase local adaptive capacity [52]. 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.

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. An innovation system, therefore, consists of a web of dynamic interactions among researchers, extension agents, equipment manufacturers, input suppliers, farmers, traders, and processors [53]. The purpose of an agricultural innovation system 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 in these systems, along with policy changes that create favorable incentives and institutions to promote change. Innovation systems depend on learning processes, feedback loops, and iterative interactions that are non-linear [54].

5. 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 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.

Central America provides a litmus test of approaches to soil and water conservation. Farmer adoption of soil and water conservation technologies in the region in the 1980s and 1990s was disappointing. Reasons for this include a strong focus on technologies rather than on farming systems, coupled with linear extension approaches and the promotion of soil conservation technologies that did not complement farmers' agro-ecological and socio-economic realities. The same technologies are being promoted as part of climate change adaptation and mitigation approaches. Lessons from the 1980s and 1990s provide important insights into new pathways of knowledge transfer and likely more successful implementation of soil conservation approaches. It is important to heed these lessons.

More emphasis needs to be directed at improving soil quality rather than capturing soil that has already been eroded. There is also 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. These approaches depend on learning processes, feedback loops, and iterative interactions that are decidedly non-linear.

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 in which farmers' needs are better identified and addressed. In the meantime, there is a danger that, as in the past, soil degradation in Central American will continue to be seen as a technical problem requiring a technical solution. Technology per se is not the answer to the land management challenges in Central America. A more nuanced approach is needed, one that recognizes that the development community has a plethora of proven soil conservation technologies at its disposal, and that the obstacles to improved land management are as much social, economic and cultural as they are technological.

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Conflict of interest

All authors declare no conflicts of interest in this paper.

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