Climate Smart Agriculture in Latin America:

Learning from Existing Research to Increase the Adoption of Climate Change Adaptation Technologies in the Future

Abstract/Summary:

Climate change threatens to have grave effects on agricultural production worldwide and particularly in Latin America, increasing the incidence of drought in some regions and flooding in others, and raising climate volatility and thus yield variance in all regions. A number of technologies and agronomic techniques have been developed which can reduce the effects of climate change by keeping yields high and stable. This paper will outline four of these key "climate smart agriculture" techniques: conservation agriculture (tillage, cover crops, rotation), irrigation, agroforestry, and soil conservation structures, covering the existing research on their effects and adoption levels in Latin America. For each type of these technologies, the results of the current research, as well as analysis of its gaps and limitations, will then be used to make suggestions on how to better design projects promoting climate smart agriculture and assess their impact on Latin American farmers in the future.

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Section 1: Climate Change and Agricultural Households in Latin America

1.1: Expected Impacts of Climate Change in LAC

Global average surface temperatures have increased by 0.74°C over the past 100 years, with the biggest increase, of 0.55°C in only the past 30 years (Mertz 2009). Temperatures worldwide are projected to increase by a further 1.5-5.8°C by the end of the 21st century (Rosenzweig et al. 2001). Climate change is expected to have a range of consequences on agriculture, chief among them yield declines and higher yield variability. This is a huge challenge considering that the global population is expected to increase to 9.1 billion by 2050, meaning that global agriculture will need to feed over 2 billion additional people (UNFPA 2011). Because of climate change, it is estimated that the number of people at-risk of hunger will increase by 40 million by 2020, an additional 24 million by 2050, and a further 55 million by 2080 (Parry et al. 1999). Currently, 75% of the 925 million food-insecure individuals in the world live in rural areas and earn incomes either directly or indirectly from agriculture (FAO 2010). Thus, efforts to ensure food security despite climate change must focus on the livelihoods of these developing-country farmers, improving the resiliency of farming systems and the capacity to adopt technologies which both help farmers to adapt to and mitigate the effects of climate change (Parry et al. 1999).

In Latin America and the Caribbean (LAC) an estimated 100 million people live in environments particularly at risk from climate change, and Central America, Brazil, and the Andean region alone account for 7% of the world's malnourished (Lobell et al. 2008). Many parts of LAC are particularly vulnerable to the effects of climate change, because soil and water resources are already limited. Poverty-driven degradation and deforestation is most severe in the Andean region of South America and in Mexico and Central America, where one-quarter of the vegetated land is degraded (Redclift 1989, Pichón and Uquillas 1997). The rate of deforestation in Latin America is also very high, at over 4.1 million ha/year in 1989, which takes a heavy toll on the ecosystem and increases vulnerability to climate change (Altieri 1992). About 17 million small farming households operate on 60.5 million hectares in LAC, or 34.5% of the total cultivated land, producing 51% of the maize, 77% of the beans, and 61% of the potatoes for domestic consumption (Altieri 2008). Thus, a focus on smallholder adaptation to climate change in Latin America is crucial if we hope to address food insecurity.

The Intergovernmental Panel on Climate Change forecasted an increase in temperatures in LAC of 0.4-1.8°C by 2020 (IPCC 2007), while four different models cited by Schimmelpfennig et al. (1996) predicted temperature increases by 2100 in LAC of 2.6-4.7°C. This presents a huge problem for crops that are already being grown close to the highest temperature tolerance threshold; yield declines have already been observed in several systems where this is the case, including Sonora, Mexico and mango and cotton in coastal areas of Peru (IPCC 2007). Temperature increases stimulate respiration, which can increase growth (though this "carbon fertilization" is low in cereal crops), but this is off-set in many cases by increased disease prevalence, as pathogens are able to survive warmer winters, and lower available water under higher temperatures (Rosenzweig et al. 2001, Baez and Mazon 2008). Perhaps even more grave than the projected average temperature increases is the fact that climate change is expected to increase interannual and seasonal climate variability, making it difficult to make management decisions (IPCC 2001, Rosenzweig and Tubiello 2007).

However, even within the LAC region climate change is expected to have different effects in different geographic areas. For example, higher temperatures have already caused significant retreat of Andean glaciers over the past three decades, which is expected to cause critical water shortages in the near future in downstream areas of Bolivia, Ecuador, Colombia, Peru and Chile where some rural communities obtain up to 80% of their water from snow melt. By contrast, the Andean region is exposed to increase flooding as a result of this same phenomenon (Coudrain et al. 2005). By changing the oscillation of weather circulation patterns in the tropical Pacific, like the El Niño Southern Oscillation (ENSO), climate change is expected to increase weather variability, with dry areas becoming even drier and rainfall levels increasing where rainfall is already high (Salinger et al. 2000, Baez and Mason 2007, Candel 2007). Steady precipitation increases have already been observed in parts of southeastern Brazil, Argentina, Uruguay, Paraguay and Brazil (Schimmelpfennig et al. 1996) while steady declines have been observed in areas of southern Chile, Peru, Northeast Brazil, and most of Central America (IPCC 2007). The expected effect of climate change on precipitation in the Amazon is still highly uncertain, which makes development of adaptation strategies for that region difficult (Mertz 2009). Global warming is also expected to increase the incidence and severity of extreme weather events, which will have the highest negative effect on Central America and the Caribbean because of that region's high exposure level to hurricanes (Mirza 2003, Baez and Mason 2008). This can have a huge effect on the economy. In 1998 in Honduras alone a single storm, Hurricane Mitch, caused losses of $5 billion, or 38% of that country's capital stock (Mirza 2003).

Adams et al. (1998) reviewed a number of studies which attempted to project the yield decreases in major field crops in South and North America as a result of climate change through 2020. They reported maize yield declines of from 4-36% in Argentina, 2-25% in Brazil, and 6-61% in Mexico. The estimates for wheat had more interesting geographic variation, with an estimated decline of 30% in Uruguay and 15-50% in Brazil, but a projected yield increase in Argentina, of 3-48%, due to warmer temperatures. Jones and Thornton (2003) similarly used modeling to project a modest average yield decline of 10% for maize by 2055, but dramatic variation across more specific geographic areas. That study projected the largest yield declines in Venezuela, Uruguay, Belize, Guyana, and Brazil but found that yield of maize should actually increase in Chile and Panama by 2055 (Jones and Thornton 2003).

Yield declines are generally expected to have negative economic effects, though not in all cases. Sanghi and Mendelsohn (1999) estimated that a 2°C temperature increase would cause incomes in Brazil to drop between 5-11%, while a 3.5°C increase would decrease incomes 7-

14%. Results of modeling by Hertel et al. (2010) found that climate change would cause net welfare to decline by 1-15% in most countries in LAC, though under one scenario that study projected a 16% increase in net welfare for Chile. This is because yield is expected to decline by less in Chile than in other countries, so as agricultural commodity prices increase due to overall world quantity declines Chilean farmers should benefit greatly from these improved terms of trade.

The effects of climate change are also expected to vary by crop. For example, models estimated by Lobell et al. (2008) showed that yields of potato, maize, barley, rice and wheat in the Andean region and rice and wheat production in Central America and the Caribbean will decline significantly, but that yields of cassava, sugarcane, soybean and palm in the Andes and maize, cassava and sugarcane in Central America will increase. Detailed data is lacking on many crop-region combinations, gaps which should be filled soon to enhance adaptive capacity to climate change.

Wheat is one of the crops on which the most long-term research exists in Latin America. A long-term study of wheat in Yaqui Valley, Mexico (Ortiz et al. 2008) has shown that in some years, particularly 1991, wheat yields were very low because of high minimum temperatures, high rainfall, and low solar radiation levels caused by a severe ENSO event. This study provides good data for projections of the effect of climate change on wheat yields in Mexico and gives an idea of the strategies which would help to minimize the effects of climate variation: growing varieties that can tolerate warmer temperatures, incorporating agroforestry to reduce temperatures, shifting cultivation to other regions. Unfortunately, this type of detailed long-term data is currently lacking for many other crops and in other regions of Latin America.

Mean estimates aggregated by country also hide important variation across different groups. Smallholder farmers in developing countries are the most at risk to the negative effects of climate change (Eakin 2005, Morton 2007, Smit and Pilifosova 2003, Hertel et al. 2010). Vulnerability to the effects of climate change, and thus food insecurity, are highest for groups which cultivate the most marginalized land, those with the lowest level of assets (and thus resources for adaptation), those with low access to technology and training, and those with low market power who are already vulnerable to input and output price volatility (Smit and Pilifosova 2003, Mertz 2009). Projects which help to increase the adaptive capacity of smallholder farmers to climate change, particularly those which simultaneously work to mitigate the causes of climate change, are critical (Smit and Pilifosova 2003, Branca et al. 2011, McCarthy et al. 2011).

1.2: Climate change adaptation and mitigation strategies

Throughout history farmers have had to deal with climate variability through various coping strategies; in fact, adaptation can be considered the “norm rather than the exception in agriculture" (Rosenzweig and Tubiello 2007). However, although farmers left to their own devices will find ways to adapt to climate change, this process is not instantaneous and often still entails huge losses, so efforts should be made to enhance adaptive capacity (Smit and Pilifosova 2003). This section will cover both existing, autonomous adaptation strategies and those which can be promoted and encouraged by outside initiatives in the future. The same strategies which allow individuals to adapt to the effects of climate change in many cases also help to mitigate the causes, by promoting carbon sequestration and decreasing emissions, so it is in fact in the interest of public institutions to support farmers in implementing these strategies (Delgado et al. 2011).

Cooper et al. (2008) classify strategies for adapting to climate variability into three categories: ex-ante risk management options, in-season adjustment of management options in response to specific climate shocks, and ex-post risk management options that minimize the impacts of adverse climate shocks to one's livelihood. Ex-ante strategies include the choice of risk-tolerant varieties, crop diversification, investment in irrigation and other water management techniques, the use of terraces, cover-crops and other techniques to reduce erosion, and engaging in off-farm employment. This category could also include data gathering to develop new calendars for planting and harvesting in response to a shifting hydraulic cycle (Valdivia et al. 2010, Delgado et al. 2011). Options during the season include adjusting labor for weeding and other inputs to yield expectations and replanting failed plants with early-maturing varieties. One extreme version of in-season adaptation is known as "response farming" and entails altering crop patterns in response to seasonal fluctuations in weather predicted by climate models; unfortunately, though it is under study in some areas (Blench and Marriage 1998, Van Viet 2001, Lemos et al.), its potential is limited because it requires a great deal of data and knowledge on the relevant farming system. Ex-post options include grazing animals on failed fields, distress sales of assets, borrowing, and reducing expenditures.

Another obvious measure to better control and increase yields in the face of climate change is the application of chemical fertilizer; however, this strategy has several disadvantages which lead us to leave it out of our broader analysis: rather than mitigating climate change, it contributes to the problem (Salinger et al. 2005), and it is prohibitively expensive for many poor smallholder farmers.

Crop diversification, which can include crop rotation, growing different varieties of the same crop, intercropping different species together in the same plots, and agroforestry methods can help to suppress pests and diseases and mitigate the risks from agronomic or market failure of any single crop (Zhu et al. 2000, Krupinsky et al. 2002, Tengö and Belfrage 2004, Lin 2011). Shade in agroforestry systems acts as a buffering mechanism to temperature variation and storm events (Lin 2007, Philpott et al. 2008, Lin 2011). A great deal of the staple crop production— more than 40% of cassava, 60% of maize, and 80% of beans— in Latin America is already grown in polycultures as a risk reduction measure (Altieri 1999). Other adaptive measures include early planting, switching to cultivars that mature more slowly, and adoption of cultivars with reduced vernalization requirements (Rosenzweig and Tubiello 2007).

In several cases diversification and other adaptation strategies have been proven to help farmers adapt to climate shocks. Less intensively managed, more diverse farms were found to suffer lower losses from natural disasters like Hurricane Mitch in Nicaragua and mud slides in Mexico (Holt-Gimenez 2002, Philpott et al. 2008). Seo (2010) in a survey of 2000 farmers in seven South American countries found that 42% of farmers operated mixed systems of both livestock and crops to mitigate risks, and that farmers in hotter climates with less rainfall were also more likely to have mixed systems. Economic analysis showed that in response to climate change predictions land values should fall for all three systems, but only 10% for the mixed system compared to 20% for a system with crops only (Seo 2010).

However, it is far easier for farmers to adapt to a smooth change in temperature and precipitation levels than to adapt to an increase in variability, which is predicted under several climate change models (IPCC 2001). There is currently a dearth of research on strategies to address climate and yield variation, particularly in Latin America. The research which does exist, primarily in North America and Europe, suggests that practices which can decrease the coefficient of variability (CV) of yield in the face of climatic variability include fallowing, crop rotations, integrated pest management, introducing irrigation and soil conservation (Rounsevell et al. 1999, Salinger 2000 and 2005, Rosenzweig and Tubiello 2007).

Climate change adaptation and mitigation are intimately related not only to one another, but also to soil and water conservation practices. Climate change is expected to increase potential erosion rates by 10-20% in extreme cases, as flooding increases run-off and farmers move onto marginal land with steep slopes as temperature fluctuations make some land unusable (Mendelsohn and Dinar 1999, Delgado et al. 2011). Changing rainfall patterns and increased drought mean that water conservation is ever more important, while increasing soil fertility via conservation methods is critical to maintaining yields in the face of climatic variation. Conservation methods are also crucial for mitigation of climate change, since they help to decrease the level of chemical inputs like fertilizer which generate high greenhouse gas emissions during manufacture and transport (Delgado et al. 2011).

A number of studies have investigated the determinants of the adaptive capacity of communities to climate change; key factors include economic resources, technology, information and skills, infrastructure, institutions, and equity (Bohle et al. 1994, Rayner and Malone 1998, Kelly and Adger 1999). Research conducted in the Bolivian Antiplano revealed that currently, local systems for dealing with climate fluctuations are failing or being lost due to new, unpredictable climate extremes, migration, and market integration and suggested a framework for developing a participatory early-warning system and knowledge bank to help farmers deal with climate change (Valdivia et al. 2010). This underlines the importance of outside programs to strengthen adaptive capacity and incentivize adoption of climate smart agriculture technologies.

1.3: Current Extent of Adoption of Climate Smart Agriculture

In this report we will focus on four specific climate smart agriculture (CSA) practices which have dual benefits, contributing both to adaptation and mitigation of climate change: conservation agriculture, small-scale irrigation, agroforestry, and soil conservation structures.

There has been a rapid expansion of conservation agriculture worldwide in the past decade, with acreage under reduced and no-till expanding from 45 million ha in 1999 to 105 million ha in 2008 (Derpsch and Friedrich 2009). Latin America is actually the region in the world with the highest level of adoption of conservation agriculture, with 49,586,900 ha or 47% of the world's total area under no-tillage. In 2007-20008 there were 25.5 million ha under zero tillage in Brazil alone (38% of cropped area), 19.7 million ha in Argentina (59% in cropped area), and 2.4 million ha in Paraguay (54% of cropped area, though 90% of area under tractor farming); a number of other LAC countries also had CA, accounting for 0.1-47% of cropped area(Garcia-Prechac et al. 2004, Kassam et al. 2009).

The vast majority of conservation agriculture in Latin America and in the world as a whole is on relatively large commercial farms using heavy equipment, because the most profitable conservation agriculture requires specialized machinery to prepare the field and high levels of herbicides which many smallholders cannot afford (Wall 2007). However, there are a few exceptions, including 200,000 ha land farmed by smallholders in Brazil and 480,000 ha in Paraguay; the latter is encouraged by government grants for no-till equipment provided to small farmers (Sorrenson 1998, Wall 2007, Kassam et al. 2009). Conservation agriculture is currently mostly limited to a few field crops, primarily soybean, maize, wheat, sunflower, canola, cassava, potato and leguminous cover crops, though in Latin America they have recently started applying conservation agricultural practices to some perennial and tree crops as well (Kassam et al. 2009).

Irrigation is another technology which can have a huge impact on insulating farmers from climate shocks but which also tends to be used more by larger farmers and at an industrial scale. The adoption of irrigation also varies dramatically by geographic area, depending on the availability of water and the farming system. There were 263 million hectares of land irrigated worldwide in 1996, of which only 17 million hectares were located in LAC (Howell 2001). That accounted for 11% of cropped area in the region, though the level of irrigation different by crop: 11% of wheat area, 44% of rice, 10% of maize, 19% of barley, 16% of sorghum, 35% of sorghum, and 24% of cotton were irrigated (Ringler et al. 2000). Land under agricultural irrigation increased by 72% worldwide between 1961 and 1997, with Central America and the Caribbean experiencing an 80% increase (Lin et al. 2008).

The portion of agriculture under irrigation also varies dramatically by country in LAC. For example, in 2010 Argentina had 1.55 million ha under irrigation (4.7% of "arable and permanent crop area"), Brazil had 4.45 million ha (6.8%), Chile had 1.1 million ha (140%, because they irrigate during multiple seasons), Mexico had 6.3 million ha (23%), and Peru had 1.2 million ha (27%), (ICID 2012). National differences are shaped largely by water availability and irrigation infrastructure. For example, as of 2000 there were 532 total dams in LAC built specifically for the purpose of irrigation, but 387 were located in Mexico, 48 in Brazil and, 46 in Chile (Ringler et al. 2000).

The LAC region as a whole has fairly abundant water resources, accounting for 30.8% of global available fresh water and only 8.6% of the population, but this is very unequally distributed throughout the region, with over 50% of the total found in the Amazon watershed alone (Ringler et al. 2000). In fact, 60% of the population of LAC is concentrated on only 20% of the land, with only 5% of the region's available water. The countries with the most limited water resources are Barbados, the Dominican Republic, Haiti, and Peru. On the other hand, Belize, Guyana, Nicaragua, Panama and Suriname have abundant water resources, and water available per capita is also fairly high in Brazil (Ringler et al. 2000).

Figures on the adoption of irrigation by smallholder farmers are much more difficult to find. Pretty et al. (2006) reviewed 286 sustainable agriculture projects in 57 countries and found that 12.5 million smallholder farmers practicing sustainable agriculture worldwide on 37 million hectares of land. The highest number of participating farmers was found in wetland rice, while the highest area under sustainable agriculture was in "dualistic mixed systems." Smallholder rain-fed humid agriculture had the second highest number of participants and area covered by sustainable agriculture. A survey of 2000 farmers in seven Latin American countries (Mendelsohn and Seo 2007) found that 23% of all land farmed by the survey participants was irrigated, though this varied by cropping system. Adoption of irrigation by farmers with crops only was 43%, for those with only livestock it was less than 0.5%, and for those with mixed livestock and crops it was 16%.

Three separate studies have estimated that the land under agroforestry worldwide is approximately 1 billion hectares (Dixon 1995, Ramachandran Nair et al. 2009, Zomer et al. 2009). Specifically in the LAC region agroforestry covers around 200-357 million hectares of land, depending on the definition: a minimum of 10% or 30% tree cover (Somarriba et al. 2012). That breaks down into 14-26 million hectares in Central America and the Caribbean and 88-315 million hectares in South America. The most common type of agroforestry throughout LAC is intercropping with shade trees and commercial crops, particularly coffee and cocoa, though silvopastoral systems and biodiversity-based sustainable forestry projects have also been widely promoted in LAC, more than any other region in the world (Vandermeer and Perfecto 2005).

There are no clear numbers available on the adoption rates of conservation structures, partly because this is a rather hazy category that includes a number of different practices, including crop rotation and cover crops, which are also considered part of the conservation agriculture package. The best way to get a general idea of the extent of adoption of these techniques is to look at the summary statistics of several different studies of the adoption of soil and water conservation (SWC) practices. For example, a study of 180 households in two villages in the Peruvian Antiplano (Posthumus 2005) found that 59% of farmers had adopted some type of SWC, and that specifically 14% had slow-forming terraces, 55% had bench terraces, and 16% had infiltration ditches. In more general terms, several studies based on satellite imagery estimate that there are approximately 1 million ha of terraced land in Peru, but much of it (61% in one area) has been abandoned (Denevan and Hartwig 1986, Masson 1984). Similarly, Wright (1963) found that 80% of terraced land in northern Chile was abandoned; in both cases this was linked to lower availability of water, since terraces traditionally were combined with irrigation (Guillet et al. 1987).

Caviglia-Harris (2003) found that 7% of sampled farmers used sustainable agriculture in the western region of Rondonia, Brazil in 2000, compared to 13% in 1996, though this was much higher for farmers who took part in a conservation extension program (at 95% and 100%, respectively). A survey of farmers in 95 villages in Honduras (Jansen et al. 2006) showed that the average level of adoption of any type of conservation practices was 17%, though this varied by livelihood. Jansen et al. (2006) also reported adoption for several separate conservation practices, including live barriers (24% adoption on average), contour planting (17%), terraces (26%), and tree planting/intercropping (36%), though 42% of farmers still burned their land to prepare it, despite known negative environmental impacts.

In Ecuador the Sustainable Land Use Management Program (SULAMAN), run by the government, has reportedly had a great deal of success in promoting adoption of conservation practices by farmers, including contour cultivation, use of green manures, crop rotation, strip cropping and intercropping (Nimlos and Savage 1991). By 1990 they had trained 3,500 small farmers who were operating over 10,000 hectares under soil conservation and up to two-thirds of farmers living in the province where the program began were participating. Witter et al. (1996) studied another conservation promotion program, Plan Sierra, in the Dominican Republic. They found that 95% of Plan Sierra participants had adopted conservation practices compared to 25% of non-participants.

Section 2: Market and Governmental Institutions Affecting CSA Adoption

2.1: Carbon Contracts and other Payments for Environmental Services

In designing and studying projects that promote CSA practices, it is important to consider the surrounding institutional context, including economic incentive programs. For decades some country government and donor agencies have sponsored "payments for environmental services" (PES) programs which compensate farmers who adopt practices that offer ecosystem services like biodiversity conservation or watershed protection. With the advent of global carbon markets under the Kyoto Protocol and UNFCC, there are an increasing number of PES programs which pay farmers to adopt practices that sequester carbon, including agroforestry and zero tillage.

These programs can have a significant effect on farmer adoption of CSA practices.

PES programs take a number of different forms, but they tend to focus on channeling payments from various donors and the private sector, particularly hydroelectric companies, ecotourism operators, and businesses purchasing carbon offsets (Balvanera et al. 2012). In 2005 there were 287 on-going PES programs aimed specifically at forest environmental services, specifically watershed protection, landscape beauty, biodiversity and carbon sequestration (Grieg-Gran et al. 2005). Though many PES programs exist outside the purview of the UN and address many different types of environmental services, currently only afforestation and reforestation programs qualify for funding under the Clean Development Mechanism (CDM); nine such projects were registered in LAC in February 2011 (Locatelli et al. 2011). Other international programs focused on forestry PES programs include REDD+, which has over 40 active pilot projects in LAC alone, and the UNFCC Adaptation Fund, of which one of the first projects, initiated in September 2010, was a water management project in Honduras (Locatelli et al. 2011). This Adaptation Fund, financed by a 2% levy on CDM carbon offsets, is the only mechanism under the UNFCC which explicitly links climate change mitigation and adaptation.

PES programs are currently on the rise in LAC region, where they are actually more common than any other region in the world. Costa Rica was the first country in LAC to establish such a program, in 1997, and there are currently 29 total programs in that country which have promoted conservation practices on 251,124 total hectares (Balvanera et al. 2012). Other countries in the region with large PES programs include: Mexico which has 15 PES programs covering 2.44 million ha, in Colombia there are 19 covering 1.16 million ha, in Brazil there are 11 covering 2.07 million ha, and 9 in Bolivia covering 609,305 ha (Balvanera et al. 2012). The highest payment rate of all the programs was in Costa Rica, but as a share of income it was highest in Ecuador, where farmers earned up to 30% of income from PES payments (Grieg-Gran et al. 2005).

Carbon mitigation projects are the most common PES program directly relevant to climate change. Pago por Servicecios Ambientales (PSA) is the name of the Costa Rican program, under which land users receive payments for new plantations, sustainable logging, and conservation of natural forests. The costs of PSA are covered 80% by a national tax on fossil fuels and 20% by the government sale of carbon credits originating by public protected areas

(Montagnini and Nair 2004). The government of Mexico operates a very similar program which focuses on forest conservation in hydrologically critical watersheds (Pagiola et al. 2005). There are NGO-based PES programs as well, including Fondo Bioclimatico in Chiapas, Mexico. It was set up through a partnership of ECOSUR (El Colegio de la Frontera Sur) and a coffee producers union in 1995, and currently serves 450 farmers in 21 communities. ECOSUR scientists monitor and measure carbon sequestration and organize the contracts between the producers and various European countries seeking to purchase carbon off-sets (Nelson and de Jong 2003).

Very few studies have evaluated the effects of PES programs, but the qualitative studies which exist report that positive impacts include improved local natural assets (soil, windbreak protection, water quality, tourism), increased knowledge and access to training, and increased income diversification (Grieg-Gran et al. 2005). However, PES programs face a number of challenges, including limited funding, expensive monitoring and other implementation costs, low adoption because a flat payment rate if offered for services even for land with differing opportunity costs, lack of clear directives and achievement criteria for participants, insecure land tenure, and weak legal support (Nelson and Chamitz 2002, Hall 2008, Southgate and Wunder 2008, Murillo et al. 2011). Furthermore, though many see PES programs as a way to improve the environment while also fighting poverty, others say that the programs can exacerbate poverty, particularly in regions with insecure land tenure, because it excludes landless workers and women from the land and causes land values to increase beyond the purchasing power of many poor farmers (Landell-Mills and Porras 2002, Kerr 2002, Grieg-Gran et al. 2005, Kosoy et al. 2008). To reduce these various problems, recent literature has made a strong theoretical argument that PES programs should provide conditional payments directly from the service users to the provider under prices determined via negotiation (Ferraro and Kiss 2002, Hardner and Rice 2002), but none of the current programs in LAC operate under such a model.

A number of studies of CSA adoption have found a significant effect of subsidy and incentive programs on adoption. A positive effect of subsidies and incentive programs on soil conservation adoption was found by Ashby et al. (1996), Ellis-Jones and Mason (1999), Pagiola 1999, Posthumus (2005), and Frangi et al. (2003). On the other hand, a number of studies suggest that subsidies can have a negative effect on adoption in the long-run, because farmers abandon the practice as soon as the payment stops. Furthermore, some of the more successful soil conservation adoption programs, like Project Sierra in the Dominican Republic and SULAMAN in Ecuador have not involved support payments (Nimlos and Savage 1991, Lutz et al. 1994, Witter et al. 1996).

Several case study examples suggest that support programs, particularly subsidies for no-till equipment, have had a positive effect on the adoption of conservation tillage among smallholders (Erenstein et al. 2008, Kassam et al. 2009), though empirical evidence is less clear. De Herrera et al. (1999) found a significant, positive effect of government subsidies on conservation agriculture adoption in Panama. A review of conservation agriculture adoption by Knowler and Bradshaw (2007) found four cases in which government subsidies had a positive effect on adoption (Napier and Camboni 1993, Swinton 2000), but a number of other cases where subsidies had no significant effect (Traoré et al. 1998, Soule et al. 2000).

With regard to agroforestry, Antle et al. (2007) created an econometric-process simulation model to assess the economic feasibility of carbon sequestration contracts in the highlands of Peru. They found that paying farmers to adopt agroforestry and terraces via the C sequestration market would only be profitable, and thus likely to induce farmer participation, if farmers were paid over $50 per Mg C. They also found that if farmers were paid $100 per MgC this would increase incomes by 15% and reduce poverty by 9%, compared to a $13-47/ha income increase for adoption without a carbon contract, suggesting that PES systems could significantly increase the benefits and adoption of agroforestry.

On the subject of irrigation, Ringler et al. (2000) reported that traditionally there have been heavy irrigation subsidies, but the effects of these subsidies are mixed: on the one hand, they do increase adoption by lowering costs, but on the other hand they have tended to disproportionately favor better-off farmers at the expensive of small, marginalized farmers. Overall, there is a dearth of rigorous empirical study on the effect of PES programs and subsidies in general for the four different target technologies, specifically in Latin America. Future impact studies should test the effect of such support programs more rigorously.

2.2: Agricultural Insurance Programs for Climate Change Risk Mitigation

Another economic institution factor which could play a major role in farmer adaptation to climate change is insurance. Weather insurance, whether private or government-sponsored, helps to mitigate farmers' risk from climate change. This could either serve as a complement to promotion of CSA practices, since both help with adaptation, or it could slow such adoption, since those with insurance are more susceptible to moral hazard. It is important to understand the different existing and potential insurance instruments, some of which avoid the moral hazard problem, and to analyze their effects on adoption of CSA and adaptation to climate change as a whole.

Climate change presents both new threats and new opportunities to the global insurance industry. Threats include the compounding of climate change risk across the entire portfolio, particularly for agricultural insurance and emerging markets, which raises costs of operation. Opportunities include increase need and willingness to pay for insurance among developing-country farmers and the advent of a number of new products like weather derivatives, cat bonds, microinsurance, and hedge funds which invest in greenhouse gas emission credits (Mills 2007). Weather derivatives are put and call options based on weather indices, which can be purchased by farmers or other actors to hedge climate risk. Cat bonds, or catastrophe bonds, are sold either by the government or insurance companies and pay investors 3-20% interest in years without a natural disaster, but in years with a natural disaster the investors forfeit their principal, which is used to pay claims to policyholders. Microinsurance is insurance targeted at low-income people which involves small premiums and low coverage caps, to reduce the level of risk to insurance companies.

The UNFCC specifically calls on the parties of the agreement to consider insurance-related instruments to help low-income countries adapt to climate change. Disaster-related losses globally were $54 million annually in 2004 and as a share of national income, losses in developing nations are double losses in developed nations (Arnold and Kreimer 2004). As an example of the huge risks posed by weather, Hurricane Mitch increased the number of poor people in Honduras by 165,000 and four years after the storm GDP was 6% lower than that of pre-disaster projections (Linnerooth-Bayer and Mechler 2006). Insurance schemes could help to reduce the impact of storms and other disasters exacerbated by climate change.

More than 40% of farmers in developing countries face threats to their livelihoods from adverse weather, but only 1% of households in low-income and 3% of households in middle-income countries have catastrophe coverage, compared to 30% in high-income countries (Linnerooth-Bayer and Mechler 2006). Currently Latin America has a very low penetration of agricultural insurance, with only 1.5% of world market premiums (Candel 2007). The insurance coverage which does exist is not equitably distributed, among income classes or across countries. Within the LAC region, Brazil accounts for 27% of insurance coverage, Mexico for 25.7%, Puerto Rico for 13.4%; though the latter is a small state, residents there have access to the US' National Flood Insurance Program, so coverage is disproportionately high (Candel 2007). A review by Mills (2007) of agricultural insurance in the LAC region reveals additional differences across countries. For example, Argentina insures 30% of its total area, all through private insurance and the majority of plans pay 60-90% of the difference between actual and historical yields. By contrast, Chile only 2% of cropped area is insured, through a mix of public and private insurance with subsidized premiums.

LAC countries have, in fact, been the pioneers of multi-peril insurance, with programs established in Brazil in 1954, in Costa Rica in 1970, in Mexico in 1971, Chile in 1980, the Dominican Republic in 1984, and Venezuela in 1984 (Wenner 2005). Multi-peril insurance is the most attractive type of insurance to farmers, but it also entails much higher losses and requires much higher overhead costs, because of the need to monitor many claims, and it is often cost prohibitive without government subsidies (and leads to high deficits for the government). Those countries which have higher insurance penetration tend to be those which have supported the development of alternative instruments that reduce moral hazard and risk. This is the case in Mexico, which has one of the largest and most successful government crop insurance programs in LAC. Unlike many of the other government insurance programs in the region it has been operating profitably since 2000 (Mills 2007). Over 15% of cropped area is insured, and many different products are offered including yield loss, revenue loss, and cost coverage insurance; there is also a weather-based index insurance option. In the 1960s the Mexican government offered 45-61% premium subsidies for crop insurance, making the purchase of insurance a prerequisite for receipt of a bank loan. The system was liberalized in the 1990s and currently offers only a 30% subsidy, provides cat bonds and index insurance options, and reduces moral hazard by only insuring 70-90% of losses (Mills 2007, Linnerooth-Bayer and Mechler 2006).

A number of studies explore the role that insurance can play in helping low-income countries to adapt to climate change. Some scholars have found that insurance is a superior way to deal with climate risk when compared with ex-post disaster relief programs, since the latter are often ad-hoc, untimely, not properly organized and targeted, increase public deficits and/or dependence on foreign aid, and increases moral hazard (Mills 2007). On the other hand, crop insurance may potentially increase moral hazard and thus decrease adoption of CSA practices. That is, when farmers know that they will receive a pay-off if their production is low, they have an incentive not to invest in labor time, inputs, and adaptation technologies which can help keep yields high. This is particularly a problem of multi-hazard insurance with a general premiums based on individual crop losses; the problem can be mostly avoided if index insurance is used, in which all farmers in an area receive an automatic pay-out based on general weather patterns in their region (Besley 1995, Hess 2003, Carter et al. 2006, Barnett and Mahul 2007, Collier et al. 2009). When moral hazard is reduced insurance may actually help to stimulate adoption of CSA practices by serving as a price signal. That is, where farmers have no concept of the monetary value of adaptation, insurance premiums act a as a gauge of this value and farmers are in some cases more likely to adopt CSA if the cost is below that of the insurance premiums (Collier et al. 2009).

Insurance companies actually also help to support adaptation and mitigation efforts to climate change in order to help reduce the level of risk in their portfolios. For example, Storebrand, Norway’s largest insurance company, has invested in sustainable forestry practices and the insurance company Swiss Rw has contributed to reforestation efforts in Haiti (Mills 2007). The Caribbean Disaster Mitigation Project (CDMP) is an example of a successful public-private partnership to support climate change adaptation efforts: United Insurance partnered with USAID and several local NGOs to help homeowners to retrofit their homes against hurricanes, and they received reduced insurance premiums as a result (Mills 2007). Though this particular example is not in the agricultural sector, similar programs could be designed for agriculture in the future.

Unfortunately, there are currently no empirical analyses of the effects of insurance programs on farmer well-being and CSA adoption in LAC. This type of study should be conducted in the future. Organizations which seek to promote CSA should pay attention to the existence of insurance and take that into account as a possible factor in their impact studies; they could also consider introducing some type of microinsurance instrument as part of their program.

Section 3: Conservation Agriculture

Conservation agriculture (CA) is a system of farming in which 30% of more of a field remains covered with crop residues, mulches, or cover crops at all times; tillage of the land is reduced or eliminated; and crop rotations are used to reduced pest pressure, which would otherwise rise in the absence of tillage (Giller et al. 2009, Stagnari et al. 2010). This system has several goals, including prevention of soil erosion, maintaining soil structure and increasing organic matter content, and improving water infiltration and retention, all of which have the potential to increase long-term yields and reduce yield variability even in the face of climate change (Bot 2001). Some studies have shown that CA reduces soil CO_2 emissions, thus it has both climate change adaptation and mitigation potential (La Scala et al. 2006, Stagnari et al. 2010).

Additionally, CA reduces marginal costs because farmers no longer have to pay the fuel and labor costs of multiple tractor passes; however, it often involves higher up-front expenses in the form of specialized equipment, plus increased herbicide use or labor for hand-weeding, making it less accessible to small farmers (Wall 2007, Giller et al. 2009). Though the adoption levels of CA in the LAC region are fairly high, they tend to be concentrated among wealthier farmers and industrial operations, though in some regions efforts have been made to better target CA to smallholder farmers as well (Sorrenson 1998, Wall 2007, Kassam et al. 2009). This section will cover literature on the estimated benefits of CA in different regions of LAC, the main factors affecting adoption of CA, and recommendations for how to better target and assess CA promotion projects in LAC, particularly among smallholders, in the future.

3.1: Effects of Conservation Agriculture on Soils and Crop Yields

There are many empirical studies on the effects of CA, both on soil properties and yields, in different LAC countries, though the vast majority of peer-review literature focuses on tillage rather than the other two components of CA, with a few exceptions. Another point which should be made early on is that the effects of CA have generally been found to differ based on type of soil, with a positive effect only expected on fine-texture soils because of increased risk of compaction and nutrient-leaching on coarse-textures soils (Giller et al. 2009). A study of CA on several soil types throughout Brazil (Zinn et al. 2005) did in fact find that in coarse-textured soils no-till led to a reduction in SOC over time compared with conventional tillage, but in fine-textured soils, like oxisols, this was not the case. For the literature reviewed below we do not report the soil texture in each case (though the researchers invariable do report this), but where there is a positive effect of CA the soil is mostly of a finer texture.

Alegre (1991) reviewed the studies on CA in Latin America which had been conducted through 1990 and found that the majority of rigorous studies took place in Brazil. The estimated effects of CA varied by region and type of soil, but fairly consistent yield increases found for no-till systems compared with conventional tillage. For example, Derpsch et al. (1986) found 19% higher wheat yields and 34% higher soybean yields under no-till in a 7-year experiment in Parana, Brazil, largely because water retention was consistently higher under no-till. A number of other studies in Brazil found that no-till was the most effective system for promoting infiltration and reducing soil erosion (Mondardo et al. 1979, Sidiras et al. 1982, Roth et al. 1986). Eltz et al. (1989) found that no-till increase aggregate stability and nutrient availability in the upper layer of the soil, leading to a 22% increase in grain yields.

Alegre (1991) also reviewed three different studies which examined the effects of tillage on a sandy loam soil in Gualba Rio Grande do Sul, Brazil; two of these studies found that soil loss was significantly lower for no-till compared to conventional systems (Machado 1976, Levien et al. 1990), though Bertol et al. (1989) found no significant different in soil erosion between tillage methods, but instead found that the key component was maintaining ground cover. Machado (1976) also found that bulk density of soil under no-till was 11.5% lower and that soil organic matter was 127% higher. In a 12-year study in southern Brazil, DeMaria et al. (1999) found that no-till led to higher levels of P and K and soil organic matter (SOM) but lower levels of Mg than conventional tillage, and that crop rotation helped soils to retain SOM, but that none of these changes in soil properties resulted in a difference in yields.

In another study, Garcia-Prechac et al. (2004) looked at the effects of no-till and crop-pasture rotation (CPR) systems versus conventional tillage in Uruguay; results showed that soil erosion was six times lower under no-till and three times lower under CPR when compared to conventional tillage. SOM accumulation was also higher under no-till when crop residues were left on the soil, and even higher under the CPR systems. By contrast, a study in eastern Paraguay and the adjacent areas of Brazil found that in the first years after a transition from conventional tillage to no-till SOM levels declined (from 1.59% to 1.45%), though they increased again after 10 years under no-till (to 1.9%). Franchini et al. (2012) presented the results of a 23-year study of tillage and crop rotation in a wheat-soybean system in southern Brazil. That study found that with few exceptions, no-till showed higher soybean yields than conventional tillage from the 7th year of the experiment onwards (with the yield advantage of no-till increasing steadily over time), especially under crop rotation and in growing seasons with lower water availability. The yields of wheat and maize were not influenced by the tillage systems, but the wheat yields were increased by crop rotation.

A few studies have focused on the effects of crop rotation or cover without also looking at tillage. For example, Calonego and Roselom (2010) specifically examined the effect of crop rotation on soybean cropping in Brazil, compared to traditional crop succession with chiseling. Results showed that in the first year yields were higher with chiseling, but that rotation with pearl millet and triticale, because of their aggressive root systems, was able to increase root penetration and yields in subsequent years even without chiseling. Scopel et al. (2004) is a review of the potential and observed advantages of direct-seed mulched (DMC) systems throughout LAC, and it includes a chart of the different benefits provided by the most useful cover crop species. However, that study does not statistically estimate the effect of DMC on soil properties and crop yield.

After Brazil, perhaps the second largest body of research on CA in LAC has been conducted in Mexico. Long-term research conducted by CIMMYT in El Batan, Mexico showed that over a 10-year period (1996-2006) grain yields for both wheat and maize were consistently higher and more stable when grown under the full CA recommended practices when compared to conventional tillage systems (Govaerts et al. 2005, Erenstein et al. 2012). According to Govaerts et al. (2005), average maize yield over the period from 1991-2004 was 48% higher and that of wheat was 27% higher in the no-till, crop rotation system with (full or partial) residue retention compared to the plots with conventional till, continuous cropping and no residue retention. However, these yield benefits did not manifest themselves until 5 years after establishment of the plots.

Results in Mexico on no-till alone, as opposed to the full CA package, are more ambiguous. For example, Astier et al. (2006) conducted a 2-year study in central Mexico on maize with green manures left on the surface (no-till) or tilled into the soil, and found that soil N and C as well as yields were higher under the system with tillage and green manures, though conventional tillage with no green manure had by far the lowest yields and soil nutrient levels. Roldán et al. (2003) compared no-till and conventional tillage systems with varying levels of retained residues in the Patzcuaro Watershed in central Mexico and found that no-till had higher soil nutrient levels than conventional till, but that this increased further under higher levels of retained revenue. That study did not also look at yield effects.

There are also a number of studies of the effects of CA in Argentina, particularly the Argentine pampas (Diaz-Zorita et al. 2002, Fabrizzi et al. 2005, Alvarez and Steinbach 2009), because adoption in that area has been very high: over 70% of annual cropping area was under no-till in 2009. Alvarez and Steinbach (2009) reviewed 35 different field experiments conducted in the region and found that water infiltration and aggregate stability were significantly higher in soils under limited tillage, but they found few other positive effects. In most cases no-till increased soil compaction, soybean yields were not affected by the type of tillage, and wheat and corn yields were 10-14% lower under limited tillage without fertilizer (though not significantly different when fertilizer was added) (Alvarez and Steinbach 2009).

Another review of tillage in the Argentine pampas (Diaz-Zorita et al. 2002) utilized data from records of growers collected by the Regional Consortium for Agricultural Experimentation (CREA) and found that soil organic carbon (SOC) was lower under moldboard plow and chisel-tillage systems than conservation tillage and that SOC levels had a significant positive correlation with crop yields. They also found that in long-term, no-till systems periodic deep tillage increased maize yields, though adding more nitrogen fertilizer had an even greater marginal effect. Fabrizzi et al. (2005) looked at the effect of tillage on a corn-wheat rotation in different area of Argentina, near Buenos Aires, and found that no-till (compared with minimum till) led to higher water storage during the critical growth stage of corn and most of the wheat life cycle, that wheat yields were the same in both systems, but that corn yields were actually lower for no-till compared to minimum with no N fertilizer but the same when N fertilizer was applied.

Though many of the studies reviewed here found positive yield effects of CA, particularly in the long-term, there are other studies in the LAC region which found the opposite. Barber et al. (1996) studied the effects of four different tillage treatments (no-till, flexible till, chisel plowing only, and conventional disc tillage) on soil properties and crop yields in Santa Cruz, Bolivia. Results showed that after four years (eight seasons) the chisel plowing only system had the lowest level of soil compaction, followed by conventional tillage, then flexible tillage, then no-till. Yields significantly differed between treatments in only three out of eight seasons, and they were highly correlated with soil compaction, so no-till had the lowest yields. However, no-till resulted in the least chemical degradation, with higher SOM and N content than other treatments (Barber et al. 1996). Basamba et al. (2006) compared no-till to minimum tillage under different crop rotation systems in Colombia, and found moderately higher yields under minimum tillage and much more significant increases in yield due to crop rotation, particularly a maize-soybean-green manure rotation.

A great deal of evidence, worldwide and in LAC, suggests that CA offers the greatest benefits in drier areas than in areas with higher rainfall. For example, trials in Jaliso, Mexico found that the CA system led to 2.5% higher maize yields in zones with favorable rainfall (600-800 mm/year) compared to 74.4% higher yields in zones with marginal rainfall (400-600 mm/year) (Scopel 1996). Similarly, in another comparison of types of tillage in a semiarid zone of Mexico, Scopel et al. (2013) found that disk plowing resulted in the highest maize yields at the wetter sites but that conservation tillage produced the highest yields at the drier sites, under two different soil types. Analysis of soil properties under the different systems suggested that this difference is related to the fact that water uptake is the most limiting factor for production in the driest areas, and no-till significantly increased soil water retention.

A study in central Mexico over three years (Monneveux et al. 2006) found that no-till caused lower biomass and grain yields and increased ear rot during the wet season, but that it led to superior root development and water uptake during the dry season; however, that study did not find a significant difference between no-till and conventional tillage yields during the dry season. A long-term study of a rainfed maize system in the highlands of Mexico (Verhulst et al. 2011) found that yields under no-till exceeded those under conventional tillage by 1.5 Mg/ha (31%) on average from 1997-2009, but that the benefit of no-till was especially pronounced in very dry years, particularly in 2009 when there was a prolonged drought and the no-till system had a yield benefit over other practices of 4.7 Mg/ha (126%).

A few studies have attempted to estimate the economic returns to farmers of adopting CA practices, based on estimated yield benefits or penalties and changes in costs. In Nicaragua, Aleman (2001) reported a net return to no-till of $762.5/ha and to conventional till of $648/ha, while in the Dominican Republic Thomas (1985) found a net return to no-till of $109/ha compared to $261/ha for conventional till. Knowler and Bradshaw (2007) analyzed 29 different studies in developing countries worldwide and found a positive net present value (NPV) to CA adoption for 89.7% of those studies. That analysis included 18 studies in the LAC region, 88.9% of which had a positive NPV.

CA is also of interest because of its potential for climate change mitigation, in the form of increased carbon sequestration. Evidence on the effect of CA on carbon storage is mixed, however. Sisti et al. (2004) analyzed the differences in C levels in soils under no-till verses conventional tillage under several different crop rotation systems after a 13-year experiment in southern Brazil. Results showed that SOC was not significantly different between the two tillage treatments, though systems grown with vetch as a winter cover crop had significantly higher SOC levels. Manley et al. (2005) conducted a meta-regression analysis looking at the carbon accumulation under no-till and conventional till systems (using data from 51 different studies, or 374 total observations) and compared it to results of regression analysis on the cost of switching to no-till (using data from 52 studies, for 536 total observations). Results showed that no-till was a low-cost way to sequester carbon in some regions ($10/tC), especially the southern US, but very costly in other regions ($100-400/tC), particularly the US Great Plains, because carbon storage was very low for no-till in the prairie soils.

Manley et al. (2005) included only eight total studies from LAC, however, so no rigorous conclusions can be made about the cost of carbon sequestration in that region. With regard to carbon storage, Manley et al. (2005) included six different studies from the LAC region, including four from Brazil. In all six cases carbon sequestration was higher under no-till than under conventional tillage, with the proportional increase ranging from 3.8-22%. In another study, La Scala et al. (2006) compared sugarcane in Brazil under no-till and conventional tillage and found that no-till resulted in significantly lower greenhouse gas emissions.

Very few papers in any region of the world specifically look at the effect of tillage or other CA practices on yield variability, as opposed to level of yield. Rusinamhodzi et al. (2011) is one such paper; it looks at the effect of CA on maize yield variability in rainfed systems in Southern Africa, using stability analysis. Results showed that reduced tillage with crop rotation had a positive effect on maize yields, particularly after the 20th year, but that yield stability was not significantly affected by tillage treatment, contrary to expectations. Verhulst et al.’s (2011) long-term study in Mexico did not explicitly analyze yield variance, but it did report the standard error for the yield data, which was much lower under the no-till system (0.02) compared to the conventional system (0.23) for the full period from 1997-2009. Franchini et al.’s (2012) study in southern Brazil also found that over the long-term no-till and crop rotation promoted more stable yields, particularly in years with little rainfall.

3.2: Adoption of Conservation Agriculture

There is a fairly extensive literature which seeks to determine the factors affecting adoption of CA practices by farming households, though relatively few of these have been conducted in the LAC region. Knowler and Bradshaw (2007) conducted the largest review of CA adoption studies to date, covering 31 different analyses, of which five originated from studies in Latin America. The factors which appeared most often in the studies analyzed by Knowler and Bradshaw (2007) included awareness of soil erosion problems, education, age, experience with CA in the past, farm size, rainfall, presence of steep slopes on the farm, land tenure, off-farm income, labor arrangement, extent of social networking with other farmers, extensions services, and subsidies for CA adoption. However, while many of these variables had a positive correlation with adoption more often than not, the results were mixed and inconclusive for age, farm size, rainfall, land tenure, off-farm income, and labor arrangement.

Several studies found a positive correlation between farmer age and adoption (Warriner and Moul 1992, Okoye 1998), while others found a negative (Gould et al. 1989, Clay et al. 1998) or insignificant (Neill and Lee 2001) correlation. Theory suggests that younger farmers might be more open to innovation, but that older farmers might have more experience and capacity for expensive investment, so these inconclusive results are not all that surprising.

Likewise, an increase in off-farm income might be expected to increase the likelihood of adoption because it means the farmer has more money to spend on investments, but it also might mean the farmer spends less time and energy on farm operations, so he would be less likely to adopt a new technique. Thus, it is not so surprising that off-farm income yields inconclusive results: it was found to be positively (Fuglie 1999), negatively (Okoye 1998), and insignificantly (Smit and Smithers 1992) correlated with adoption in equal measure.

Theory more clearly suggests that farm size should be positively correlated with adoption, since larger farmers have a greater capacity for expensive investments. However, the empirical results on farm size were quite inconclusive, since an equal number of studies found a positive (Smit and Smithers 1992, Fuglie 1999) or negative (Shortle and Miranowski 1986, Clay et al. 1998) correlation with adoption.

Similarly, theory suggests that farmers who own their own land, as opposed to temporary tenants, should have a higher incentive to invest in new technologies like CA, so there should be a positive correlation between land ownership and adoption. However, in Knowler and Bradshaw (2007) only two studies out of 13 which included a tenancy variable found a positive correlation (Clay et al. 1998, Neill and Lee 2001) while two others found a negative correlation (Smit and Smithers 1992, Fuglie 1999) and the remaining 9 found no significant relationship. On a related note, security of land tenure was found to be positively correlated with adoption of conservation practices in two other studies in the literature (Fujisaka 1994, Bewket 2007).

Rainfall level also showed mixed results. Theory both suggests that in higher rainfall year or environments production will be higher, so farmers will have more money to invest in new technologies, but that no-till has an advantage over conventional tillage in drier areas. Thus, it is not surprising that several studies found a positive correlation between rainfall and adoption (Gould et al. 1989, Kaliba et al. 2000), while some (Fuglie 1999) found a negative correlation and several others found the variable to be insignificant (Rahm and Huffman 1984, Clay et al. 1998). The variation across studies for rainfall, land tenure, and other factors indicate that the effect of these factors on propensity to adopt may be context-specific.

Most studies analyzed by Knowler and Bradshaw (2007) did indicate a positive correlation between overall income and adoption (Gould et al. 1989, Saltiel et al. 1994, Somda et al. 2002). Experience was found to be positively correlated with adoption (Rahm and Huffman 1984, Clay et al. 1998) or insignificant (Traoré et al. 1998) but was never found to be negatively correlated with adoption. Likewise, education was found to be positively correlated with adoption in most cases (Rahm and Huffman 1984, Shortle and Miranowski 1986, Wariner and Moul 1992, Traoré et al. 1998). In several studies of soil conservation adoption, farmers' opinion on the severity of soil erosion in their area was a significant factor (Allmaras and Dowdy 1985, Shiferaw and Holden 1998, Traoré et al. 1998). Related to this, farms with medium (10-40%) or very steep (>40%) slopes were found to have a significantly higher likelihood of CA adoption in many studies (Shiferaw and Holden 1998, Soule et al. 2000, Neill and Lee 2001).

Access to information on the relevant technology via extension services, connections to other farmers, and other sources, is expected to have a significant positive correlation with adoption. Empirical evidence tends to support this hypothesis. Several studies directly included availability of information as a variable and found a positive correlation with adoption (Traoré et al. 1998, Prokopy et al. 2008). Other studies found a correlation between adoption and a specific source of information, such as visits from extension agents (Feder and Umali 1993, Fujisaka et al. 1994, Kaliba et al. 2000), experience working with an NGO (Bandiera and Rasul 2006), or participation in field trials and workshops (Traoré et al. 1998, Kaliba et al. 2000).

Several studies have shown that social network effects play a major role in the adoption of new technologies (Conley and Udry 2003, Bandiera and Rasul 2006, Knowler and Bradshaw 2007, Prokopy et al. 2008). For example, Conley and Udry (2003) found that pineapple farmers in Ghana changed their levels of fertilizer use based on the experiences of neighboring farmers. Bandiera and Rasul (2006) analyzed adoption of sunflower cultivation in Mozambique and found that the relationship between adoption and the number of adopters was an inverse-U. That is, farmers were generally more likely to adopt a new technology if others in their social network were also adopting the technology, but farmers who knew many other adopters often chose to free-ride on the information gathered by others, perhaps waiting for a subsequent season to adopt the technology, depending on the results. Several studies of CA adoption found that membership in a producer organization positively correlated with adoption (Smit and Smithers 1992, Traoré et al. 1998, Swinton 2000).

Other variables found to be significant by a small number of technology adoption studies include gender (Bandiera and Rasul 2006, Ragasa 2012), risk perception (Guerin and Guerin 1994), suitability of the technology to meet the farmer's needs (Fujisaka 1994, Bewket 2007), complexity of the technology (Guerin and Guerin 1994), and cost of the technology (Fujisaka

1994). Specifically for CA adoption, some studies include cost of fuel, cost of pesticides, and crop loss due to weeds (Allmaras and Dowdy 1985, Traoré et al. 1998). Although these variables are likely correlated with the decision to adopt, they are problematic because it is difficult to accurately measure risk perception and the suitability or complexity of a technology, and because cost variables are more likely to change over time than from one farmer to another in the same time period, so their effect cannot be captured in the cross-section models which are most commonly used.

There are somewhat mixed results on the effect of gender on CA adoption. Ragasa (2012) conducted a review of 35 studies of technology adoption which include gender as a variable and found that female-headed households consistently have a lower adoption rate than male-headed households, primarily due to differentiated access to complementary inputs and services. However, determining the true effect of gender on adoption is problematic, because the definition of female-headed household is inconsistent across studies and because most female-headed households are more resource-poor than male-headed households, so most studies do not adequately disentangle the effects of gender and income (Ragasa 2012).

Ding et al. (2009) specifically considered the possibility that increasing climate change, and the ensuing increase in droughts, might increase farmer interest in and adoption of CA techniques. They use Zellner's SUR technique and panel data from states in the mid-western US to estimate the rate of adoption of no-till and conservation tillage compared to conventional tillage. Results showed that, controlling for other factors, extremely dry conditions in recent years increase the adoption of conservation tillage, while spring floods in the year of production reduce the use of no-till.

There are a number of issues which are unique to adoption of CA by smallholder farmers in developing countries. Wall (2007) discusses some of the major constraints to CA adoption by smallholders, including weak links to extension services to acquire information on CA (which is a relatively knowledge-intensive technology), tight networks among farmers which may work to reinforce traditional tillage practices, the need in many areas to use crop residues for animal feed, particularly when there is prolonged drought (doubly unfortunate because this is the time when CA has the greatest positive effects), limited access to input and output markets as well as capital and credit to make investments in direct seeding machinery, and the fact that where manual weeding is done instead of chemical weed control CA might actually increase the amount of required labor. Thus, smallholder farmers in areas with more integrated markets, with higher labor availability, access to machinery and herbicides and other inputs, and who are in contact with extension services would be more likely to adopt CA practices.

A few studies look specifically at the factors affecting CA adoption in the LAC region. De Herrera et al. (1999) examined adoption of no-till for maize in Azuero, Panama and found that motivated by potential cost savings rather than longer term considerations such as reduced soil erosion. Results of the empirical analysis showed that factors affecting adoption included:

land tenure (renters were less likely to adopt than land owners), lack of access to direct seeding equipment, and lack of information on CA technologies. A case study of conservation tillage adoption in Guaymango, El Salvador by Sain and Barreto (1996) suggested that adoption was high, with 94% of cropped area under CA by 1983, because of two major factors: the combination of components to increase productivity with elements to improve environmental sustainability into a clear "package" of recommended practices, plus the use of incentives to encourage adoption of CA (improved credit and input access). They also found that areas with more cattle, a longer grazing period, and a high market value for crop residue had lower rates of CA adoption.

In a study of the adoption of mulching with crop residues and cover crops, Erenstein (2003) found that adoption was much higher among large scale farmers, particularly in no-till systems in the southern cone of South America, and that successful adaptation of mulch drills was crucial in promoting adoption. Erenstein et al. (2012) also found that CA adoption in Mexico is low among smallholders because of lack of access to seed drills and other necessary inputs, the need for techniques less reliant on herbicides, and competition for crop residues to feed livestock. However, Ersenstein et al. (2012) also found that in recent adoption studies in India 60-74% of no-till adopters didn't own a drill and instead gained access to one via a producer cooperative or a service provider who rented out a machine to them.

Neill and Lee (2001) did not study CA adoption directly, but rather dis-adoption of maize-velvet bean crop rotation systems in Honduras, which is highly related. This crop rotation system was widespread in the 1970s-1980s, but by 1997 only 38% of surveyed farmers still practiced the system, 45% had previously practiced but abandoned the system, and 16% had never adopted. The key motivations for dis-adoption were: rising weed pressure, which was more difficult to deal with under the rotation system; decreased tenure security, including reclamation of parcels by the land owner; rising land values in some areas which induced farmers to sell or move; preference for switching to pasture or another crop as market values for products change; drought or excess rain which made the system more difficult to manage; lack of sufficient land (with land sizes shrinking and minimum parcel sizes necessary to practice the rotation profitably); and the high cost/difficulty of herbicides or other maintenance.

3.3: Lessons for Future CA Projects and Impact Analyses

This review of the CA literature suggests a number of recommendations for how to improve future projects aimed at promoting CA in the LAC region. First, it is apparent from the literature that the vast majority of current empirical studies of the effects of CA are restricted to just a few countries, primarily Brazil, Mexico and Argentina. These effects cannot be generalized to other countries and regions, because CA has dramatically different effects depending on the climate and soil type in a given area (Zinn et al. 2005, Giller et al. 2009). In each region where CA is promoted it is important to gather accurate, local information on the expected effects as soon as possible, ideally prior to promotion of the technology to farmers.

Furthermore, because CA is composed of three separate components—reduced or no tillage, crop rotation, and retention of ground cover through crop residues or cover crops—it is difficult to parse out the effects of each of these components. Where studies have tried to do this, they have found that benefits are much higher with the entire CA "package" and that adopting no-till alone, for example, may result in negligible or even negative yield effects (Sisti et al. 2004, Basamba et al. 2006, Rusinamhodzi et al. 2011, Evenstein et al. 2012, Franchini et al. 2012). This has several implications. First, many studies of "CA" do not make clear the exact mix of practices which they used, and it is difficult to do meta-analyses of CA projects when each one might be a different combination of practices. Those studies which do purport to estimate the yield effects of "no-till" may in fact report estimates with an upward bias due to the effect of crop rotation or cover crops, and farmers who adopt no-till without one of the other components (perhaps because of the pressure to use all crop residues as livestock feed) will not experience the expected yield benefits. Thus, it is crucial to conduct more research in the future which carefully parses out the effects of the different CA components to enable cost-benefit analysis of the separate components and provision of more accurate advice to farmers.

Studies of CA should also make sure to compare not only no-till to conventional tillage, but to also to include treatments of flexible or reduced tillage. In several studies where an intermediate tillage treatment was included it led to the highest yields, superior to both the no-till and conventional till extremes (Barber et al. 1996, Basamba et al. 2006). More studies should attempt to evaluate the effect of CA under different input regimes, since in some cases no-till was found to have a negative yield impact unless chemicals and N fertilizer was applied (Fabrizzi et al. 2005, Alvarez and Steinbach 2009). Furthermore, studies of the effects of CA currently concentrate primarily on soil characteristics and yield levels, but very few studies have looked at the effect on yield variability (Rusinamhodzi et al. 2011, Verhulst et al. 2011, Franchini et al. 2012) despite the fact that the projected future increase in climate, and therefore yield, variability is considered a greater challenge than mean temperature and precipitation changes (IPCC 2001, Zegarra 2005, Rozensweig and Tubiello 2007).

Another lesson from existing studies is that it is crucial to conduct long-term studies of the effects of CA; many of the studies which found no significant impacts of CA on soil or yields took place over 5 years or less (Astier et al. 2006, Roldán et al. 2003), but the longer-term studies, of 10 to 23 years, all found more positive results of CA adoption (Erenstein et al. 2012, Franchini et al. 2012). Of course, proving the long-term benefits of CA still does not guarantee adoption since many farmers make decisions based on immediate profitability, but it may facilitate calculations of the optimal incentives needed to encourage adoption. Qualitative evidence suggests that grants and other assistance for obtaining no-till planting equipment is especially important in promoting CA adoption by smallholders (Sorrenson 1998, Wall 2007, Kassam et al. 2009), and it would be easier to justify such an expense if the long-run benefits to individuals and society were accurately estimated ahead of time.

Another lesson still which can be derived from this review is that CA should be promoted first in the regions where it is likely to have the largest positive effects. This would include dry areas at risk of increased drought under climate change projections, since so many studies have shown that CA has a higher marginal effect on yields under water-limited conditions (Scopel 1996, Scopel et al. 2013, De Vita et al. 2006, Monneveux et al. 2006, Verhulst et al. 2011). However, since most of these studies took place in Mexico, this hypothesis ought to be explicitly tested in more areas. CA has also been shown to have a greater affect, and to be adopted more readily, in areas with steeper slopes and more severe erosion problems (Shiferaw and Holden 1998, Traoré et al. 1998, Soule et al. 2000, Neill and Lee 2001, Pautsch et al. 2001), so this could also be used to target the promotion of CA.

Greater emphasis ought to be placed on the factors that encourage smallholders to adopt, since their adoption rates currently lag behind wealthier, industrial farmers (Gould et al. 1989, Sailte et al. 1994, Somda et al. 2002, Kassam et al. 2009). Other factors which were the most conclusively correlated with adoption included experience, education, extension, social networks, farmer perceptions of a soil erosion problem, the demand for crop residues as livestock feed, and costs of CA inputs (Knowler and Bradshaw 2007, Wall 2007). Awareness of these factors could be used to better target extension efforts and incentive programs. For example, in very dry areas where CA has the biggest effect but poor farmers feel greater pressure to remove crop residues to feed livestock, incentives may be necessary. In contrast, in other areas where, based on physical and market conditions, CA both leads to cost reductions short-term yield increases subsidies may not be necessary, and emphasis should instead be placed on spreading awareness of CA. Avoiding subsidies where they are not necessary is crucial, to avoid dependence of farmers on the subsidies and promote long-term adoption (Nimlos and Savage 1991, Lutz et al. 1994, Witter et al. 1996).

This review also suggests that the information on C sequestration under CA is still very limited (Sisti et al. 2004, Manley et al. 2005). Research should be done under a wider variety of conditions (more soil types, climates, in different countries) and combinations of the three different CA components. Such data would help with development of an efficient mechanism for measuring the C sequestered by individual smallholders farmers would make it easier to connect them to global carbon trading markets, as is done by the Fondo Bioclimatico program in Chiapas (Nelson and de Jong 2003). Such programs could be expanded in the future to incentivize farmers to adopt CA, directly increasing their incomes as well as increasing their level of adaptation to the risks of climate change.

Finally, methodology of studies of both the effects and adoption of CA could be improved by doing more rigorous paired comparison trials between treatment and control groups. The best way to do this would be to roll out future CA extension, promotion and PES programs using a randomized control design, selecting treatment farmers randomly and collecting the same data over time on adoption, agronomic factors, and yields from this treatment group and a randomly-selected control group with similar baseline characteristics.

Section 4: Irrigation

Irrigation is any way of artificially delivering water to an agricultural field, thereby reducing one's reliance on natural rainfall patterns and decreasing one's vulnerability to climatic variation. It can take a number of forms, including surface (flood or furrow), sprinkler, and drip irrigation (surface or sub-surface). The source of irrigation water also comes from many different sources, including hand-drawn or pumped well water, water diverted from natural rivers, or water delivered via diversion canals from man-made reservoirs or run-off catchment structures. Larger irrigation projects require significant infrastructure investment and often involve the local or national government, which must get involved to help with water allocation and distribution. There are also micro-irrigation technologies, however, which require lower levels of investment and can be accomplished by individuals or small local communities. Finally, there are technologies and methods which aim to increase water use efficiency (WUE) of cropping systems, including "deficit irrigation" in which water is only delivered during the crucial growth stages of a crop. This section explores the literature on the estimated effects of these different forms of irrigation and methods to increase WUE, as well as the determinants of adoption of these technologies, with a focus on smallholder production systems.

4.1 Effects of Different Irrigation Types on Crop Yields and WUE

Worldwide, irrigated land comprises 15% of total cropped areas but supplied 36% if production (Howell 2001). The disproportionate share of production on irrigated land is even greater for some middle-income countries: 70% of grain in China and 50% of grain in India is produced on irrigated land, while in Brazil only 5% of cropped land is irrigated but this accounts for 35% of production (Howell 2001, Laclau and Laclau 2009). Across Latin America, those countries with the highest cereal production are also those with the highest proportion of irrigated land (Ringler et al. 2000, San Martin 2002). This indicates that irrigation significantly increases yields, though the amount of this increase varies widely by crop, irrigation system, and geographic location. Irrigation not only helps to increase yields on existing land, but it enables cultivation of land which would not be arable without irrigation technology. For example, Mitchell (1976) reported that small-scale, community-managed irrigation in the Peruvian highlands made possible a doubling of the cropped area under corn, beans, quinoa and squash. Across Latin America there is a great deal of potential for increased irrigation development, particularly in countries which currently exploit less than 2.5% of available water resources, including Brazil, Bolivia, Colombia, Ecuador, and Venezuela (San Martin 2002).

The majority of empirical studies of the effects of irrigation on agriculture have been conducted in industrialized countries. Only a few studies of irrigation exist in the LAC region, and almost all of those are limited to Brazil. A field experiment of two varieties of wheat in Londrina, PR, Brazil found that irrigation increased the yields of both varieties, by an average of 51.5% (Destro et al. 2001), though one variety was less sensitive to water stress than the other. Cesano et al. 2013 collected data on irrigation in seven different districts in Brazil and found that in all districts the average benefits of irrigation (in terms of production and revenue increases) outweighed the costs, with annual net profits from irrigation ranging from 17% to 126% across the different districts

There is also a fairly extensive literature in Brazil which seeks to determine the optimal type and level of irrigation for certain commercially important crops like processing tomato (Silva and Marouelli 1999, Marouelli 2003, Marouelli and Silva 2007). Marouelli and Silva (2007) explained how drip irrigation is superior to surface or deficit irrigation systems for this croppin system because it was found to reduce water use by 30% while not adversely affecting yields. They then tested a number of different levels of drip irrigation at various life stages of processing tomato growth in order to develop the optimal irrigation strategy for the crop under local conditions.

It is also crucial to consider the water use efficiency (WUE) of irrigation systems, since that has a major impact on the quantity of water that is actually available for crop production and this is especially critical in arid areas with increased risk of drought. Across LAC irrigation efficiency currently ranges from 30-40% (San Martin 2002), so there is a lot of room for improvement. According to Ringler et al. (2000) increase efficiency of irrigation systems, and agricultural water use in general, should be a key priority for the LAC region in its attempt to deal with climate change. A number of studies have investigated various measures to increase WUE, including use of drip irrigation and sensor technology which automatically irrigates when soil moisture drops below a certain level (Dukes et al. 2003, Erdem et al. 2006). Unfortunately, little work exists currently on the effect of such technologies in LAC.

Another way to increase WUE, which has received more attention in LAC, is a system called Deficit Irrigation (DI), which involves irrigating only at critical growth stages of a plant. According to Geerts and Raes (2009) this type of irrigation will not maximize yields, but can help to stabilize yields and optimize water productivity. The difficulty arises in that DI requires an extensive knowledge of the physiology of a crop (Kirda et al. 2005), and thus to apply it successfully in LAC would require a great deal more of studies looking at specific crop response to water stress over their lifecycle in a variety of regions and environments. The review of DI worldwide by Geerts and Raes (2009) included only two studies which had been conducted in LAC countries, specifically Brazil and Bolivia (Marouelli and Silva 2007, Geerts et al. 2008). The study by Geerts et al. (2008) tested the effects of DI on quinoa production in the Bolivian Antiplano. Results showed that at one site, with adequate rainfall during the crucial growth stage, DI had no effect on yields but that yields were 147% higher under DI at the site with low rainfall. They also found that DI enabled stabilization of quinoa yields at 1.2-2 Mg/ha while requiring half the water of full irrigation.

4.2 Adoption of Irrigation

Despite its potential to stabilize and increase yields in areas with limited rainfall, the adoption of irrigation, particularly by smallholders, remains low in the LAC region. There is quite an extensive literature on irrigation adoption in developed countries which looks either at the choice to adopt irrigation at all or the type of irrigation system chosen (Caswell and Zilberman 1986, Dinar and Yaron 1992, Negri and Brooks 1990, Dinar and Zilberman 1991, Green et al. 1996, Mendelsohn and Dinar 2003, Koundouri et al. 2006). Results of these studies generally suggest that the significant factors affecting irrigation adoption include: farmer income/wealth level, the price of water, the cost and availability of irrigation inputs, crop prices, farm size, farmer organization characteristics, soil type, and climate conditions (ambient temperatures and average precipitation). The study by Koundouri et al. (2006) specifically looks the decision of farmers in Greece to adopt a more efficient irrigation technology under a situation of increasing uncertainty due to climate change. They found that farmers did, in fact, choose to adopt the technology in order to hedge against production risk, and that farmers in areas with a higher aridity index were more likely to adopt. They also found that a number of human capital variables like education, receipt of extension services, and awareness of climate change increased adoption.

Mendelsohn and Seo (2007) developed a theoretical model of farmers' choices of farm type (crops, livestock or both) and whether to irrigate or not, and they tested the model using data from 2000 farmers across Latin America. Results showed that the decision to adopt irrigation was significantly affected by average temperatures and precipitation in an area, the type of farming adopted, and soil type. Seo (2011) analyzed public and private irrigation schemes in South American countries; in the sample 65% of farmers received no irrigation, 21% relied on public water schemes for irrigation, and the remaining 15% used private irrigation schemes. Results showed that public irrigation has not increased in response to increasing temperatures, though private irrigation has increased. Furthermore, private irrigation investment is done gradually, while public irrigation investments are made in large lumps distributed with large time gaps in between, which often results in either local over-provision or under-provision of services. Dinar and Keck (1997) also looked at private irrigation investment in LAC, specifically in Colombia, and found that it was significantly influenced by violence, climate, and governmental price and credit policies.

Cunha et al. (2013) conducted an empirical study of the determinants of irrigation adoption among smallholder farmers in Brazil; they expressly wanted to investigate the role of irrigation on climate change adaptation, so they included a number of climate variables. Results showed that increased winter temperatures, increased temperature variability, decreased mean and winter precipitation, higher water resources in a region, increased soil erosion, internet access, and higher education level all increased the likelihood of a farmer adopting irrigation.

Cesano et al. (2013) discussed efforts by a local organization, Adapta Sertão, to help smallholder farmers in a semiarid region of Bahia, Brazil to adapt to climate change, and their current main effort in this regard is facilitating adoption of drip irrigation. They have implemented a pilot project in Bahia since 2006 in four municipalities which includes several components which they have pinpointed as key for success. First, identified private vendors of the irrigation technologies who were interested in expanding their markets and created partnerships between these vendors and local farmer associations for distribution and promotion. Adapta Sertão also successfully piloted microfinance programs to help farmers pay for the irrigation technologies. Finally, they conducted weekly monitoring of the systems, including crop yields, costs, and revenues, which enabled them to show that drip irrigation was highly profitable, thus attracting more farmer interest and investment by various organizations.

4.3 Lessons for Future Irrigation Projects and Impact Analyses

This review suggests that irrigation can have a dramatic effect on stabilizing and increasing yields of many crops, and that farmers are increasingly interested in adoption of irrigation because of increased climate variability (Mendelsohn and Dinar 2003, Koundouri et al. 2006, Cunha et al. 2013). Though a few studies have already addressed this topic, more research is clearly needed on the effect of different irrigation types and amounts on the yield of different important crops in LAC, in order to determine the technologies which will help farmer to achieve optimal yields with the lowest amount of water (Ringler et al. 2000, San Martin 2002).

To that end, more studies should be conducted in the future on the effects of irrigation on yield level and variability across a wider geographic area in LAC, because most of the existing studies are limited to Brazil. Within each region, and for the most important region-crop pairings, different types of irrigation ought to be tested, because each technology entails a different cost and WUE, and thus optimal the technology may vary depending on local conditions (Erdem et al. 2006, Marouelli and Silva 2007, Cesano et al. 2013). Deficit irrigation should be further investigated as an option for particularly drought-prone areas (Geerts and Raes 2009). However, this will require even more detailed study by crop and region to determine the critical growth stages for different plant species (Kirda et al. 2005, Geerts et al. 2008). Where detailed research on the effects of different types and amount of irrigation exists it has enabled the development of better irrigation management guidelines; this is the case for tomatoes in Brazil, but for few other crops in LAC (Marouelli and Silva 2007).

Furthermore, this review reveals that the majority of irrigation research has been conducted on research stations under controlled conditions. Of all the papers covered in this study, only Cesano et al. (2013) gathered data directly from farmers using irrigation and used it to assess the economic benefits of adoption. However, even that study did not have a control group, and thus it did not adequately isolate the treatment effect. In the future, more studies should be conducted of the effect of irrigation in fields managed by smallholder farmers. The treatment effect can be isolated by using a randomized control design in rolling out irrigation promotion and incentive projects, or by using non-controlled data and propensity-score matching to generate statistically comparable treatment and control groups.

With regard to adoption, this review shows that farmers are increasingly interested in adopting irrigation technologies, and particularly technologies with a higher WUE, because of the increased risk of climate variability (Koundouri et al. 2006, Cunha et al. 2013). But farmer wealth level, crop prices, and input costs are major determinants of irrigation adoption; installing irrigation is an expensive investment which many smallholder farmers do not find affordable (Green et al. 1996, Mendelsohn and Dinar 2003, Koundouri et al. 2006, Cunha et al. 2013, Cesano et al. 2013). Because these are also the farmers most vulnerable to the effects of climate change, efforts specifically targeting them should be a priority in the future.

Current studies indicate that smallholder farmers who face a higher risk from climate change (i.e., those who live in areas with higher temperature variability, lower precipitation, and high soil erosion) are the most likely to irrigate (Cunha et al. 2013). Future projects aimed at promoting irrigation could consider targeting these most at-risk areas first, since this would likely both generate the highest impact per farmer and maximize the rate of adoption. Smallholders who farm only crops, as opposed to those who also raise livestock, are also more likely to irrigate (Mendelsohn and Seo 2007). Differentiating into livestock production could actually also be viewed as an adaptation to climate change. Organizations interested in helping facilitate adaptation could thus both encourage more diversification into livestock and target the promotion of irrigation to crop-only farmers.

Finally, this review indicates that public irrigation projects are not responsive to increasing risks due to climate change, and that because investment is done in large chunks it often causes local under or over-investment (Seo 2011). In contrast, private irrigation investment was much more responsive to changing climate conditions and allowed farmers to make smaller, gradual investments which better addressed their needs. This suggests that smaller-scale projects operated by local microfinance organizations or producer cooperatives might be more successful in both promoting and distributing irrigation technologies to smallholder farmers (Seo 2011, Cesano et al. 2013). However, the government can still play a critical role by promoting stable crop prices and credit availability through policy decisions, since this has been found to have a significant impact on private irrigation investment (Dinar and Keck (1997).

Section 5: Agroforestry

Agroforestry is a broad term which encompasses a number of different practices, but essentially amounts to incorporating trees into agricultural systems to increase sustainability (Steppler and Nair 1987). It can include direct intercropping of timber or native shade trees with other agricultural crops, either annuals or perennial tree crops. Agroforestry also encompasses silvopastural systems, wherein livestock are grazed on forages grown under tree canopy, and improved fallow systems in which fast-growing leguminous trees are used to more rapidly restore fertility to degraded soil. In all these different systems trees are incorporated into the landscape in several different ways, including block planting, alley cropping, contour planting, border planting or live fences, and as windbreaks (Current et al. 1995). This section will review studies on the effects of these various types of agroforestry (AF) systems on environmental sustainability, yields of agricultural products, and farmer incomes in LAC, as well as studies of the factors affecting AF adoption. We will then discuss implications of the literature on future AF promotion projects and impact assessments.

5.1 Effects of Agroforestry Practices on Environmental Conditions and Yields

Agroforestry (AF) is generally recognized as the CSA practice with the greatest potential for climate change mitigation, via high C sequestration in tree species and in the soil (IPCC 2000, Wright et al. 2000, Kandji et al. 2006, Verchot et al. 2007). In South America specifically it is estimated that AF systems can sequester 39-102 Mg C/ha in humid tropical areas and 39-195 Mg C/ha in dry lowlands over a 50 year period (Kandji et al. 2006). Of course, the level of C storage varies by tree, so the level of sequestration, and therefore the potential revenues that can be earned in the carbon market, vary dramatically by region and system. For example, Oelbermann et al. (2004) looked at the C storage levels in alley cropping systems with one tree species, *Erythrina poeppigiana*, in Costa Rica. In 4-year plantation the C storage was 120 Mg C/ha while in 19-year plantations it was 180 Mg C/ha. In both cases the majority of C was in the form of SOC (Oelbermann et al. 2004).

In addition to these mitigation effects, AF also can play a significant role in adaptation to climate change: deep roots mean that trees can access more water, they increase soil porosity, reduce run-off and increase soil cover which increases infiltration and thus water use efficiency, they have higher evapotranspiration rates and thus help to aerate the soil, contribute organic matter to the soil via leaf litter, lower the temperature under the canopy and thus create a buffer against temperature increases, and they produce higher value products which can strengthen farmers' income levels (Rojas-Blanco 2006, Verchot et al. 2007).

There is actually a long history of AF research and promotion in the LAC region, much of it conducted by the Centro Agronomico Tropical de Investigacion y Ensenanza" (CATIE) in Costa Rica. Muschler and Bonneman (1997) reviewed 31 studies of AF conducted in affiliation with CATIE between 1979 and 1994 only. That report summarizes the key benefits of AF systems in LAC: amelioration of the microclimate, increased soil fertility, reduced soil erosion, increased crop growth, and increase economic viability of the integrated system. However, they pointed out that outcomes are highly site-specific and tree-specific. Muschler and Bonneman (1997) also summarized the key limitations of AF systems: depending on political and demographic pressures, more intensive systems which maximize food production may be necessary, and this may not be compatible with AF, and there is a time lag before full benefits are realized which may make the systems infeasible for smallholders. In some cases AF systems have lower yields than conventional systems, though the outcome can vary dramatically, even in nearby areas with similar climates (Kater et al. 1992, Jonsson et al. 1999).

In 2011 there were nine reforestation and afforestation projects being implemented in the LAC region under the UNFCC's CDM program and 11 more projects in the region operating under the Climate, Community and Biodiversity standards established in February 2011 (Locatelli et al. 2011). Most of these projects focus on carbon sequestration, though they also include measures to address adaptation. For example, in northern Peru a GTZ project called AdapCC has facilitated carbon contracts between a local coffee producers association and Café Direct, a UK-based trading company; 10% of the carbon payments are used to fund adaptation measures (Locatelli et al. 2011).

One very important type of AF in the LAC region is shade-grown coffee and cocoa (Current et al. 1995, Vandermeer and Perfecto 2005). Both crops are understory trees, and research has shown that shade can increase the sustainability of these crops and in the case of coffee it may actually help to increase yields, particularly in a situation of increasing climatic extremes (Muschler 1997, DaMatta 2004, Lin et al. 2008). Coffee phenology is highly vulnerable to the quantity and timing of precipitation (Nunes et al. 1968, Magalhaes and Angelocci 1976, Cannell 1985, Carr 2001), and the optimal temperature for Arabic coffee is between 18°C and 21°C (Alegre 1959). Climate fluctuations can have a devastating effect on coffee yields, as evidences by the 40-80% observed production decreases in southern Mexico in ENSO years (Castro Soto 1998).

Shade helps keep the coffee cooler during the day and warmer at night (Lin 2007), so moderately shaded coffee plants have been found to experience photosynthetic rates three times higher than plant under full sun (Kirkpatrick 1936, Nutman 1937). Shade also prevents overbearing of fruit on a branch, therefore preventing biennial fluctuations in yield (Cannell 1983). However, the effect of shade on coffee yields is still inconclusive because of the many confounding factors which also affect production (Beer et al. 1998): some studies show a decrease in yield with more shade (Lagemann and Heuveldop 1983, Nolasco 1985), others show an increase (ICAFE 1989, Ramirez 1993, Muschler 1997). In a study conducted in Chiapas, Mexico, Soto-Pinto et al. (2000) found that coffee yields were actually highest under 23-38% shade cover, though production decreased with shade cover over 50%. But tthere is generally a consensus in the literature that shade has more positive than negative effects in situations of high climatic variability and temperature extremes (Lin et al. 2008, Schroth et al. 2009).

Some limited research exists on AF systems with other commercial crops in LAC. For example, Ilany et al. (2010) compared soil nutrient characteristics of 30- and 50- year-old yerba mate plantations in Argentina grown under monoculture or intercropped with a native tree species. Results showed lower soil nutrient levels for intercropping in younger plantations, but the opposite in older plantations, indicating that AF has a long-term positive effect on soil fertility. However, the study did not look at the effects of intercropping on yields.

There is a great deal of research on the positive effects of improved fallows on soil conditions and subsequent crop yields, though much of it has been conducted in African countries (Sanchez 1999, Kandji et al. 2006). In the LAC region, Kettler et al. (1996) found higher biomass yields on improved fallows in Costa Rica, but no significant difference in subsequent bean yields. Kass and Somarriba (1999) reviewed traditional fallow systems in Latin America, some of which used leguminous trees as part of the rotation. One example of this a traditional cropping system in southern Brazil in *Bracatinga* trees (a local leguminous species) are grown on fallow land for a period, then thinned for under-planting of a maize and bean intercrop. Studies of the system have shown that it is more profitable than fertilized maize and beans grown with chemical inputs, and that crop and firewood production in the system do not decline over the first three years as they do in the same system without *Bracatinga* intercropping (Baggio et al. 1986, Graça et al. 1986).

Nichols et al. (2001) experimented with the use of AF systems to restore degraded pastureland in Costa Rica, comparing mono-cropped plantation of a commercial timber species (fertilized and unfertilized) to intercropping of the timber species with leguminous trees, cover-crops, or beans. Results showed that timber growth was highest in the plots intercropped with leguminous trees and tree height was comparable to the fertilized plots, meaning that the AF system can be used as a low-cost substitute for chemical inputs (Nichols et al. 2001). A similar experiment was conducted by Plath et al. (2011) in degraded lands in Panama, looking at growth of native timber trees in mono-culture or planted with leguminous companion trees. Results showed no significant difference in tree growth between the treatments but better water uptake and higher total biomass production in the intercropped treatments.

A number of studies have attempted to calculate the economic benefits of AF systems to farmers. Current et al. (1995) reviewed 21 AF projects in eight countries of Central America and found that alley cropping was the most cost-effective system, requiring only 56 man-days per year of labor, with a payback period of 1.9 years and a cost-benefit ratio of 2.1. Contour planting was another very profitable system, requiring 116 man-days of labor per year, with a payback period of 2 years and a cost/benefit ratio of 1.6. Interplanting trees with annual crops required 165 man-days/year, had a payback period of 3.4 years and a cost/benefit ratio of 1.8. Interplanting perennial crops with other tree species required 139 man/days per year, had a payback period of 4 years and a cost/benefit ratio of 1.8. Finally, block planting required only 53 man-days/year but had a payback period of 4.9 and the highest cost-benefit ratio, at 2.5.

Grieg-Gran et al. (2005) conducted case studies of four AF PES projects, two in Costa Rica and two in Ecuador. Results showed that the monetary value of payments varied greatly across projects: one project paid $6-12/ha (30% of average household expenses on basic necessities), another paid $68-119/ha (covering all establishment costs and generating an estimated annual return on 12-27% over 30 years), another paid $225/ha (16% of average participant income, though only 4% for smallholder participants), and the last paid $515 (which only covered 60% of establishment costs). Non-monetary benefits of the PES schemes included increased diversification and thus risk, increased tenure security, strengthened community organization, decreased erosion, increased biodiversity, and increased ecotourism. Reported problems and limitations included a drop in water quality in one case, deterioration of road quality in another (due to increased traffic by forestry equipment), and the fact that in several cases participants lost eligibility for other government benefit programs (Grief-Gran et al. 2005).

5.2 Adoption of Agroforestry

There are two main types of empirical AF adoption studies: ex-post studies, which look at the adoption outcomes in given regions and use regression analysis to determine the impact of various factors; and ex-ante studies, which rely primarily on social and financial analyses of on-farm trials of AF innovations to assess adoption potential (Mercer 2004). The most important ex-ante studies in the literature are Franzel and Scherr (2002), which reviews AF studies in Kenya and Zambia, and Current et al. (1995) which reviews 21 AF projects in Central America.

Current et al. (1995) suggested that a number of key factors affect AF adoption in Central America. First, farmers are attracted to adopt AF by financial results, based on the profitability of a given system compared to alternative land uses, the resource requirements of the given system, local costs of labor and materials, and local prices for tree products. Adoption is also affected by risk management issues, including the extent to which a given AF system stabilized yields and provided multiple sources of income. Current et al. (1995) observed that farmers first adopt for family subsistence needs, and then pay attention to marketing opportunities, which are often increased by local producer organizations or NGO projects. The study also found that adoption is greater on large farms, though smallholders were not always excluded: in El Salvador, for example, 40% of participants in a community nursery program had less than 1 ha of land (Current et al. 1995). Lack of formal land tenure decreased adoption but was not a binding constraint; in fact, lack of tree ownership and disposal rights was much more problematic.

Current et al. (1995) also found that external factors like demonstrations, technical assistance, trainings, provision of planting materials, programs to increase credit access, and other financial and material incentives increased adoption. With regard to extension, the report suggested that in most successful instances of adoption the farmers adopt AF gradually, over a period of 5-10 years. The report also discussed a successful program in Guatemala which saw 550 farmers adopt AF over a 5 year period. The program succeeded because the dissemination model was demand-driven, with choice of the supplied seedlings based on farmer input from community meetings. Farmers tend to prefer specific tree species for AF based on: their familiarity with the species, growth performance, ease of propagation and management, market values of products, multiple uses, and interactions with other crops (Current et al. 1995).

In addition to the extensive work by Current et al. (1995), there are several ex-ante adoption studies which focus on the LAC region. For example, Vosti et al. (1998), which discussed the adoption potential of cocoa and coffee intercropped with bandarra, rubber and black pepper in the western Brazilian Amazon. That study found that major constraints to AF adoption by smallholders included investment requirements, negative cash flows in early years, and uncertain demand for AF products. Additionally, a study of silvopastoral systems in Costa Rica found that the primary barriers to adoption were high financial risk, incomplete knowledge, limited access to capital and markets, and the poor genetic quality of livestock (Jansen et al. 1997). In some cases cumbersome regulations and procedures, including restrictions on the harvest and transport of timber in AF systems, have reduced adoption. Panama, Honduras and Nicaragua still have very cumbersome regulations, but Guatemala and Belize have adopted simplified protocols which have improved farmer attitudes toward AF (Somarriba et al. 2012).

The most comprehensive work on ex-post AF adoption studies is Pattanayak et al. (2003) which summarized the findings of 32 different studies, a few of which were conducted in LAC. According to that review, the most conclusively significant factors in AF adoption include: security of land tenure (included in 72% of studies, and positive in 100% of those cases), membership in a producer group (included in 44% of studies, positive in 100% of those cases), and access to extension (included in 32% of studies, positive in 100% of those cases). However, most studies of adoption look at land tenure as a simple binary variable—formal private tenure or lack thereof. The reality in many cases in LAC is much more complicated, because of the prevalence of community tenure over forests and agricultural land more generally. Examples of community land management include the ejidos of Mexico, Community Forestry Concessions in Guatemala, Indigenous Territories in Panama and Costa Rica and the Mayangna Territories in Nicaragua (Klooster and Masera 2000, Locatelli et al. 2011).

Other variables like education, market access, land size and wealth have been included in many AF adoption studies, but overall results have not been conclusive (Pattanayak et al. 2003). For example, some studies have found that wealthier farmers are less risk averse and therefore more likely to adopt AF, but others have found that poor farmers in isolated areas are more likely to adopt AF out of necessity, in order to grow more fruits and other products for household subsistence (Peterson et al. 1998, Adesina et al. 2000, Casey and Caviglia 2000, Neupane et al. 2002, Mercer 2004, Degrande et al. 2010, Sood and Mitchell 2011, Gyau et al. 2012). In addition, authors such as Besley and Case (1993), Conley and Udry (2003), Acemoglu et al. (2008) emphasize the influence of social learning on technology adoption in general, and Gamboa (2010) found social networking to have a significant effect on AF adoption in Ecuador.

Caviglia-Harris (2003) looked at the choice between using slash and burn agriculture and adopting more sustainable agricultural practices in Rondonia, Brazil. The practices examined included AF, pisciculture and apiculture, all of which were promoted by a local producers group called the Association of Alternative Producers (APA). Results showed that the most important determinants of adoption were membership in a cooperative union, number of years that the family resided on the same lot, and knowledge of sustainable agricultural practices. Other significant factors which increased the probability of the adoption were: locality (for example, adoption was highest in Ouro Preto, where APA was based), number of female members of the household over age nine, distance to the closest market center, and a dummy for 1996 as opposed to 2000, suggesting that the adoption did not in fact intensify over time.

Jansen et al. (2006) looked at the effects of a number of factors on the adoption of several conservation methods, including tree planting, in hillside communities in Honduras. The report focused on the effect of "livelihood strategy" of the producers (how do they earn income? for example: coffee + grains, or grains+horticulture+livestock). Results showed that tree planting was highest for coffee + grain producers, but was also high for those with the livelihood strategies of "coffee + grain + off-farm work," "coffee + off-farm work + livestock," "grains + off-farm work + horticulture," and "basic grains + horticulture." Tree adoption was also found to have a U-shaped relationship to local population density, and it was positively correlated with both the number of external organizations active in the area which focused on integrated development and those focused on production.

5.3 Lessons for Future Agroforestry Projects and Impact Analyses

This review suggests that some of the most promising AF systems in LAC include shade-grown coffee, improved fallows, and efforts to connect small farmers engaging in AF to carbon markets. On balance the literature finds positive effects of shade on coffee yield stability and sometimes even the level of yield, but work on other commercial crops is limited (Lin et al. 2008, Schroth et al. 2009). Leguminous trees can rehabilitate degraded land in as little as 8 months and a number of traditional systems in LAC already use fallows, so programs could build on and improve these systems in concert with small farmers (Kass and Somarriba 1999, Sanchez 1999, Kandji et al. 2006). AF has the highest estimated carbon sequestration potential of all CSA practices (Montagnini and Nair 2004, Oelbermann et al. 2004, Kandji et al. 2006), so it offers the greatest potential for smallholders to gain increased income from selling credits in the global carbon market. In order to realize the potential income gains for smallholders, efforts need to be made to expand existing programs which work with producer groups and to reduce the transactions costs and negative side-effects of these programs, including loss of eligibility for other government services (Grieg-Gran et al. 2005).

As with the earlier CSA technologies examined in this report, AF research in LAC needs to be expanded in geographic scope, because currently it is limited primarily to Costa Rica, Brazil, and Mexico (Somarriba et al. 2012). The effects of AF vary widely by location (Muschler and Bonneman 1997), perhaps more than any of the other technologies discussed here, because the tree species most appropriate for AF will vary geographically, in addition to variation in the cropping system and the most appropriate type of AF arrangement. Some types of AF may be inappropriate for certain regions and cropping systems, because in some cases shade cover does lower crop yields significantly, and this may do more harm than good in places with major food security problems (Muschler and Bonneman 1997). Detailed assessments of AF systems, with a high degree of precision based on location, are needed because in some cases the same system has dramatically different effects even in neighboring countries with the same basic climate (Karter et al. 1992, Jonsson et al. 1999).

The review revealed that a number of potentially important AF cropping systems are currently poorly studied (Ilany et al. 2010). More studies are needed which cover other important crops but collect the same level of detail as that collected for shade-grown coffee (Nolasco 1985, Muschler 1997, Beer et al. 1998, Castro Soto 1998, Lin 2007, Lin et al. 2008), including data on underlying soil conditions, vegetative growth measures, and economic yields and yield variance. Also, in all future studies of AF systems the duration of the experiment should be long enough to make it through economic production, ideally over several seasons to enable observation of the effects of climate variation. Additionally, more research is needed which evaluates the potential cost-benefit ratios of various types of AF systems, in a site-specific context, since expected net economic benefits of AF were found to be a major factor in adoption (Current et al. 1995, Jansen et al. 1997, Vosti et al. 1998). More work should be done similar to that conducted by Current et al. (1995), calculating the labor and other input costs, the expected benefits, the payback period and overall cost/benefit ratio of various AF systems.

This review showed that farm size, wealth, livelihood strategy, and especially secure tenure can have a significant positive effect on AF adoption (Current et al. 1995, Pattanayak 2003, Mercer 2004, Jansen et al. 2006). There are several possible lessons to draw from this. First, projects promoting AF adoption purely for environmental reasons could target larger farmers, cash-crop producers, or those with secure tenure, to increase the rate of adoption. However, it also suggests that AF projects, particularly those targeted in this way, are likely to exacerbate inequality, further marginalizing poor farmers and those without secure tenure, particularly women and landless workers. The best AF projects will take this into account and provide some type of mitigating benefits to these marginalized groups. One option would be to offer larger adoption incentives to poorer farmers. Additionally, no empirical studies have looked at the effect of community land tenure on AF adoption and the distribution of benefits; because community tenure exists in several LAC countries future research should make an effort to study this relationship (Klooster and Masera 2010, Locatelli et al. 2011).

Finally, AF research in LAC could also be improved by the use of more participatory methods which directly involve farmer groups. This is particularly important in the selection of tree species for a given system, because both the rate of adoption and the ultimate impact of AF on climate change adaptation and incomes will be related to characteristics of the trees used, including ease of growth, familiarity to farmers, and market potential of the tree products (Current et al. 1995, Muschler and Bonneman 1997). While numerous empirical studies show that extension has a positive effect on AF adoption (Adesina et al. 2000, Casey and Caviglia 2000, Neupane et al. 2002, Pattanayak et al. 2003), the success of extension is higher where it works through social networks and established farmer groups since these institutions help to create buy-in and increase trust (Current et al. 1995, Caviglia-Harris 2003, Gamboa 2010).

Section 6: Soil Conservation Structures

This final section reviews structures for soil and water conservation (SWC) which include terraces, bunds, live barriers, contour cultivation, grass strips, diversion ditches, check dams, and irrigation pits. The goal of all these structures is a reduction of run-off and soil erosion, which can help to increase yields on steeply sloped land. Terraces are earth embankments constructed at a right angle to order to create a flat surface for cultivation even on a hillside (Obalum at al. 2011). Bunds, also called contour banks, are small banks built along the contour of a slope which help to hold in ponded water (Obalum et al. 2011). Both terraces and bunds are often combined with contour cultivation, which consists in cultivating the land on or close to the contour, and at right angles to surface water flow. Each furrow acts as a small dam, slowing down the movement of runoff over the soil and giving the water time to infiltrate into the soil (Obalum et al. 2011). Diversion ditches are channels dug into a hillside which channel water during a high rainfall event, either directing the water into a natural waterway or a hillside irrigation pit, a small reservoir which can be used to later deliver water to terraced land. Check dams are small dams built across the drainage ditch which help to reduce gullying and allows sediments to settle.

There is significant overlap in the SWC literature the literature on the other CSA practices covered thus far. For example, contour planting of trees and hedgerows is also covered in the AF literature, while cover crops figure prominently both in CA and SWC studies. Irrigation is also often intricately tied to SWC structures, because in many highland areas they are introduced together to make it possible to farm otherwise-non-arable land. This section of the report will cover the effects of SWC structures on soil erosion and crop yields, as well as the factors affecting SWC adoption. Some of the papers reviewed discuss adoption of “conservation practices” in general, including but not limited to specific conservation structures. Thus, in some ways this section is a catch-all group for all remaining studies of sustainable practices which did not fit well into one of the previously discussed CSA categories.

6.1 Effects of Conservation Structures

Pretty et al. (2006) reviewed 286 projects of various types in 57 developing countries, all aimed at promoting conservation and sustainable agricultural practices. Results showed that these practices increased production on 12.5 million ha out of the 37 million ha reviewed, that the average yield increase was 79%, and that the average increase in WUE was 257%. However, the Pretty et al. (2006) study was not limited to SWC structures only, but also included practices like Integrated Pest Management, AF, no-till, and aquaculture. Only a small number of papers on the effects of specific conservation structures could be found, and even fewer were specific to the LAC region. However, results of studies in other regions can also help to give an idea of the expected benefits of these technologies in LAC.

A large number of studies of SWC structures have taken place in the highlands of Ethiopia (Shiferaw and Holden 2001, Kato et al. 2011, Wolka et al. 2011). Shiferaw and Holden (2001) found that the estimated returns of a given SWC structure varied greatly depending on the crop, the farmer's discount rate (the level to which they value present income over the promise of future income), and steepness of the slope. In general, most of the different SWC structures did not generate positive net returns, except for grass strips, which were the lowest cost structure. Wolka et al. (2011) studied the effects of soil and stone bunds on soil properties over 10 years and found few significant differences, with one exception: in some years the pH level in the soil on non-bunded land was significantly lower, indicating a potential for bunds to reduce acidification of sloped land. Another study, of 1000 households in the Nile Basin of Ethiopia, analyzed the effects of eight different types of SWC structures on mean crop yields in both high- and low-rainfall areas (Kato et al. 2011). Results showed that stone bunds, soil bunds, grass strips, diversion ditches, planting trees, and contour cultivation all had a significant, positive impact on crop output in low-rainfall areas. In high rainfall areas only diversion ditches and trees had a significant positive impact on yields. On the other hand, only soil bunds had a significant effect in terms of reducing yield variance in low-rainfall areas, while all of the reviewed technologies helped to reduce variance in the high-rainfall areas.

Lutz et al. (1994) conducted a fairly comprehensive literature review of studies on soil erosion and the cost-benefit calculations of various SWC practices in Central America. The report estimated the amount by which production should crop over time, in the absence of soil conservation methods, for several different crops in different countries. Results showed, for example, that coffee yields in Costa Rica would drop by 33% and corn yields in Honduras would drop by 61% in 30 years (Lutz et al. 1994). This report also estimated the internal rate of return, initial investment, and number of years needed to break even for several difference SWC practices. For example, the report estimated that terraces for corn cultivation in Guatemala would generate a 15.6% rate of return but would still take over 100 years to pay off because of high initial costs. In contrast, diversion ditches for corn cultivation in Honduras had lower initial costs and an estimated internal rate of 21.9 or 56.5% (depending on the region of study) and a thus a payoff period of only 18 or 4 years, respectively.

Swinton (2000) performed regression analyses on data from 197 farms in the Peruvian Antiplanto to estimate the effect of SWC practices on the level of erosion and crop yield loss. Results showed that soil losses over 20 years were significantly decreased by longer fallow periods and the use of vertical furrows. This latter result contradicted expectations and past studies, which suggest that furrows should be oriented perpendicular to a slope, as in contour cultivation (Swinton 2000). With regard to crop yields, vertical furrows had no significant effect, but yields were significantly higher on land with longer fallows, in foot slope areas, and on non-sandy soils, a result confirmed by studies of the effect of fallow period length in Brazil (Silva-Forsberg and Fearnside 1997). Similarly, Hellin and Haigh (2002) looked at the effect of live barriers of vetiver grass on maize yields on steeply sloped land in Honduras. Results showed no significant difference in yields between the treatment and control plots, with one exception: in 1997, an unusually dry year caused by a severe ENSO episode, maize yields just above the live barriers in the treatment plots were 23% higher than those in the control plots, indicating that live barriers could play an important role in areas made drier by climate change, but may not be profitable under other circumstances.

Posthumus (2005) calculated the economic effects of adopting terraces in the Peruvian Andes. She stated that the primary benefit of terracing is increased water availability in the terraced land, which can increase productivity, though terracing also reduces the total surface area of agriculture and thus net profitability is not guaranteed and often requires a shift to a more intensified system or higher value crop. Empirical results showed that grain yields were 79% higher when terraces were used on hills with a 25%+ slope in one study region (Pacucha). However, though there no significant difference for the full sample in Pacucha or for any subset in the other study region, Piuray-Ccorimarca.

In the Posthumus (2005) study estimated profitability of terracing was high, with an internal rate of return (IRR) between 16-37% in 2002. However, estimated profitability was much lower (1% IRR) in 2003; this is explained by the fact that a dry spell in 2002 negatively affected non-terraced land more severely than terraced land, but such a dry spell did not occur in 2003. Furthermore, the marginal product of land was actually lower for terraced fields than non-terraced in the Pacucha region, because isolation and imperfect factor markets made intensification difficult; the opposite was the case in Piuray-Ccorimarca, which had better functioning markets and higher access to capital.

The literature also includes several case studies of SWC promotion projects in LAC. For example, Nimlos and Savage (1991) discuss the Sustainable Land Used Management Project (SULAMAN) in Ecuador which promotes soil conservation via a variety of practices, including bunds, contour planting and bench terraces, in addition to some CA and AF practices. Crop yields under the project’s various management technologies had increased significantly by 1990: 92% for garlic, 421% for peas, 216% for barley, 47% for beans, and 260% for potatoes. Furthermore, under terracing the value of the land increased dramatically, from about $65 per acre to $900 per acre per hectare (Nimlos and Savage 1991). Another case study was conducted in Piaui, Brazil (Oliveira et al. 2013), analyzing a community-led initiative to introduce a new mulch for watermelon cultivation. Results showed that watermelon yields doubled with use of the mulch.

Ellis-Jones and Mason (1999) estimated the economic costs and benefits of planting live barriers for soil conservation in field of *Phalaris*, a popular fodder crop, in Bolivia. Using local data and simulation models, the report found that the economic viability of live barriers varied dramatically for irrigated versus non-irrigated plots, and based on the farmer’s discount rate. For example, live barriers would not be viable even with a discount rate as low as 5% if the yield increase was 5% or less. If the productivity increase was 10% then returns to live barriers would be positive, but only for irrigated fields and with a discount rate 10% or lower. Assuming a 20%-

30% productivity increase and a discount rate up to 20%, live barriers would be profitable on irrigated plots in all regions and non-irrigated plots in one of the study regions.

6.2 Adoption of Conservation Structures

Worldwide literature on SWC structure adoption suggests that some of the most important factors affecting adoption include: the extent to which a given practice is expected to increase on-site productivity, estimated net economic returns to farmers, transactions costs, property rights issues, and use of participatory extension methods (Pagiola 1999, Cramb 2000, Smith et al. 2007). There are a few studies which have estimated the factors affecting adoption specifically in countries in the LAC region, though many are not large-sample empirical studies. For example, in a case study of a new mulch-based conservation system in watermelon cropping in Brazil, Oliveira et al. (2013) found that adoption was increased by participatory methods involving farmers in the design process, and that it was increasing over time since collective benefits of the technology increased with greater adoption. Ashby et al. (1996) conducted a case study of factors affecting the adoption of live barriers for soil conservation in coffee farms in Colombia. They concluded that adoption was significantly increased by greater farmer participation in all levels of the process, including design, evaluation, and promotion of the selected SWC practice. For example, in later years of the project famers were invited to help select the species to be used in the live barriers, and this coincided with a big jump in adoption.

Case studies of the Plan Sierra conservation program in the Dominican Republic (Witter et al. 1996) and the SULAMAN project in Ecuador (Nimlos and Savage 1991) both concluded that adoption was high in project areas, even in the absence of government subsidies, because private economic returns to participating farmers were high and because of the strength of extension efforts. Witter et al. (1996) directly asked farmers their reasons for adopting SWC, and the key responses were: personal benefits of the conservation structures (43%), encouragement by family or friends who had adopted previously (28.7%), and encouragement by Plan Sierra extension agents (24.6%). In their study of live barrier adoption in the Inter-Andean Valleys of Bolivia, Ellis-Jones and Mason (1999) concluded that profitability and thus adoption was higher for irrigated than non-irrigated agriculture. The discount rate of a given farmer, local input and output prices, and the expected yield effects of the conservation structure were also expected to have an impact on adoption.

In Posthumus' (2005) study of the adoption of terracing in two different villages in the Peruvian Andes, she compared the adoption rates in the different villages and attempted to explain them according to village characteristics. She concluded that adoption was much lower in Pacucha than Piuray-Ccorimarca because it was much more isolated from markets, crop prices were lower, farmers were less educated and had fewer assets, and the main organization promoting conservation there did not employ the same types of participatory methods used in Piuray-Ccorimarca. Additionally, Posthumus (2005) found that the most active members of society, members in multiple associations and especially leaders, tended to be the first to adopt. Furthermore, she concluded that because of higher market access in Piuray-Ccorimarca the opportunity cost of labor constituted a higher barrier to adoption in that village.

There are also a few empirical studies of conservation structure adoption in LAC. For example, Hansen et al. (1987) applied a model used to test adoption of (unspecified) soil conservation practices in the US to a sample of 281 farmers in the Ocoa watershed in the Dominican Republic. Results showed that extension, credit access, and attitudinal measures of the farmer's orientation to change (an index of positive responses to questions about taking risks and considering migration) and propensity to adopt (and index of positive responses to questions about willingness to attend trainings on conservation and to invest in conservation) were all significant and positively correlated with adoption.

The most comprehensive study on SWC adoption in LAC is Jansen et al. (2006), which tested factors affecting adoption of four different conservation practices (live barriers, contour planting, terraces, and tree planting) in hillside communities in Honduras. Although several factors were included in the regression analysis, the most effort was taken to estimate the effect of "livelihood strategy" on adoption; that is, the income sources of the farmer (coffee + basic grains, basic grains + off-farm work + livestock, etc.). Results showed that the adoption of live barriers was increased by the number of community-based organizations in an area and the number of external organizations focus on integrated development but decreased by market access, and it had a U-shaped relationship to higher population density. The same results were observed for contour planting, except that external organizations did not have a significant effect. Terrace construction was significantly higher among those with the livelihood strategy coffee + basic grains, it had a U-shaped relationship to population density, increased with local community organizations, and decreased with higher market access. The results on tree planting were reviewed in Section 4 of this report.

Swinton's (2000) analysis of conservation practices in Peru's Antiplano included a regression analysis of the two practices found to decrease soil erosion in that region: fallows and vertical furrows. Results revealed that length of the fallow period was increased by: the value of well equipment available to a farmer, the number of adults in the household, membership in farmer associations, existence of a past natural resource project in the village, and the amount of land in a traditional collective crop rotation scheme. An increase in non-farm income decreased fallow period length. The proportion of land planted to vertical furrows was found the increase with association membership and for land in the footslope but to decrease for farmers with higher access to farming equipment and higher poverty levels. Surprisingly, crop prices were insignificant in both regressions and the effect of access to equipment was not consistent across regression variables. It is notable that the social capital variable, association membership, was the sole variable positively correlated with adoption of both conservation measures (Swinton 2000).

Posthumus (2005) also conducted regression analysis of the factors affecting adoption of bench terraces, slow-forming terraces, infiltration ditches, and conservation practices as a whole, in the two villages in the Peruvian Andes covered by her study. She found that in the village of Pacuca steeper slopes increased adoption of bench terraces and SWC practices as a whole; that larger farm area increased adoption of both types of terraces; that both family size and percent of farmland without stones decreased adoption of bench terraces and SWC practices in general; that education and age increased adoption for a sub-sample of farmers enrolled in one program (MARENASS); that farmers enrolled in MARENASS were much more likely to adopt SWC technologies than those enrolled in the other program (PRONAMACHCS), though participants in both programs had higher adoption rates than non-enrolled farmers; and that market access increased adoption of slow-forming terraces. In Piuray-Ccormarca the determinants of adoption were somewhat different; the most important factors included percent of agriculture without irrigation access, positive for adoption of both general SWC and irrigation ditches; long-term perspective of the head of household (positively correlated) and age (negatively correlated) for bench terraces; farm area for slow-forming terraces, risk taking preference of the head of household, and distance average distance from the house to the field for infiltration ditches.

6.3 Lessons for Future Conservation Structure Projects and Impact Analyses

A number of lessons can be drawn from this review. First, there are many different types of conservation structures, some of which have completely different effects and which are appropriate in some conditions but not others. For example, terraces and grass strips were generally found to have a higher positive effect in dry areas but structures like diversion ditches are more useful in high rainfall areas (Shiferaw and Holden 2001, Hellin and Haigh 2002, Posthumus 2005, Kato et al. 2011). More research ought to focus on testing the effects of different types of structures in the same area in order to determine which technology is optimal. Several studies in the current literature did compare multiple technologies (Lutz et al. 2004, Shiferaw and Holden 2001, Posthumus 2005, Jansen et al. 2006, Kato et al. 2011) but only three of these focused on LAC, and so this type of research ought to be expanded in the future.

The current research on SWC structures within LAC tends to be limited mostly to Peru and some of the Central American and Caribbean countries, like Honduras and the Dominican Republic (Hansen et al. 1987, Lutz et al. 1994, Witter et al. 1996, Swinton 2000, Posthumus 2005). To some extent this research is necessarily geographically limited, since conservation structures are most appropriate for highland areas with steep slopes. In fact, evidence suggests that economic returns and thus adoption levels are higher on more steeply sloped land (Posthumus 2005). However, empirical studies of both the effects and factors affecting adoption on conservation structures ought to be expanded within LAC to more thoroughly cover the highland and hilly areas in the region.

Furthermore, only one study reviewed here looked at the effect of SWC structures on soil characteristics other than erosion level (Wolka et al. 2011). Though emphasis on yield level and variance is more directly useful in understanding the impact of these technologies on farmers, it would also be useful to have more data on the effects of these structures on the underlying soil structure and characteristics. For example, Wolka et al. (2011) suggested that bunds help to reduce acidification of sloped land, and this phenomenon should be investigate in further studies.

This review also suggests that adoption of terraces in particular can lead to a significant trade-off between potential yield increases and surface area lost when terraces are built, if the previously un-terraced slope was cultivable (Shiferaw and Holden 2001, Posthumus 2005). Organizations seeking to promote adoption of terraces and other conservation structures need to be cognizant of this potential trade-off, since it means that in some cases terracing is only profitable if farmers simultaneously intensify their production or plant higher-value crops. On the other hand, where irrigation and terracing are introduced together this can actually increase the amount of arable land in an area (Guillet et al. 1987) by expanding production to land previously too steep and dry to cultivate.

Several studies have attempted to estimate the economic profitability of the SWC structures, revealing that it varies dramatically based on type of structure, level of rainfall, degree of slope, type of soil, type of crop, local market conditions, and many other factors (Nimlos and Savage 1991, Lutz et a. 1994, Witter et al. 1996, Ellis-Jones 1999, Pagiola 1999, Posthumus 2005, Jansen et al. 2006). Not only does the rate of return to farmers define the ability of SWC to increase incomes, and thus facilitate climate change adaptation, but it also is a crucial factor affecting adoption rates (Witter et al. 1996, Shiferaw and Holden 2001, Ellis-Jones and Mason 1999). It is crucial that future projects continue to estimate the rates of return to specific technologies under specific conditions, both prior to introduction of SWC practices (to the extent possible) and ex-post. The literature also provides fairly clear evidence that SWC structures have the potential stabilize crop yields in particularly dry years (Hellin and Haigh 2002, Posthumus 2005). This suggests that programs promoting SWC should target areas more vulnerable to climate change, both to maximize its positive effects for farmers and to increase adoption rates.

In general, risk-orientation and the long-term versus short-term view of farmers were found to play a significant role in perceived profitability of conservation structures and thus the level of adoption (Hansen et al. 1987, Ellis-Jones and Mason 1999, Shiferaw and Holden 2001, Posthumus 2005). The farmer discount rate is such an important factor in adoption of SWC (and probably other CSA technologies, though it was mentioned less often in other literatures) that future studies should make sure to take discount rates into account and should attempt to find a more reliable way of estimating them. In the current literature studies either assumed various discount values for the purpose of theoretical simulations (Ellis-Jones and Mason 1999, Shiferaw and Holden 2001) or they used a qualitative index of attitudinal questions to estimate it empirically (Hansen et al. 1987, Posthumus 2005). If it were possible to create a more accurate and quicker way to estimate the discount rate for farmers in a given area then this could be used to guide promotion efforts and determine optimal subsidy levels for SWC programs.

A number of studies also suggested that use of participatory methods in the development of SWC structures and their extension significantly increases the level of adoption, as do social network connections and group membership (Hansen et al. 1987, Ashby et al. 1996, Witter et al. 1996, Cramb 2000, Posthumus 2005, Oliveira et al. 2013). This should be taken account by future organizations seeking to promote SWC. Farmers within a given area should be engaged in participatory research methods to help determine what SWC practice is the most profitable and appropriate for a given location. This is particularly important given the evidence that expected returns and the rate of adoption vary dramatically by location, for example in the case of the dramatically different results between the two villages analyzed by Posthumus (2005) in Peru.

In conclusion, more information is needed on the effect of different types of SWC structures under a variety of circumstances—soil types, slopes, crops, irrigation level and type, rainfall level, and proximity to markets—in order to best target specific technologies for a given area. Additionally, this data should be collected via participatory research in local communities and with scientifically rigorous methods of measuring the treatment effects, including randomized control designs or propensity–score matching. This is true not just of the SWC practices review in this section, but of all the CSA practices reviewed in this report.

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