doi:10.2489/jswc.71.2.91

Conservation agriculture on steep slopes in the Andes: Promise and obstacles

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Abstract: Small-scale farming in Ecuador's highlands is associated with excessive soil erosion, degradation of soil health, and agricultural productivity loss. Conservation agriculture (CA) offers promise in these areas. Minimum disruption of soil and maintenance of permanent groundcover, two CA pillars, reduce erosion and can increase soil health and productivity. Despite its promise, CA has not been widely adopted by Andean region farmers, and factors such as uncertainty about CA benefits, risk aversion, and high discount rates have been offered as explanations for lagging adoption. This paper combines an analysis of CA trial data from farmer fields and an analysis of two farm-household surveys to measure potential benefits from adoption and identify correlates of adoption. The analysis reveals actions to promote more widespread adoption of CA. Data are from a unique five-year research project in Bolivar Province, Ecuador. Yield and cost of production data from on-farm trials are used to estimate costs and benefits of CA, household data are used to analyze the determinants of CA adoption, and data from a choice experiment help estimate willingness to pay for CA attributes, such as increased yield and reduced erosion. We find that CA practices yield more and cost slightly less (over five years) than conventional practices, but differences are not large. The adoption analysis shows that farm size and labor access are not associated with adoption, but farmers who perceive soil loss on their farm to be severe are much more likely to adopt. This aversion to soil loss is examined in the choice experiment, which finds that farmers are most interested in economic considerations, such as increasing yields and saving increasingly costly labor. CA holds promise in such systems, but diffusion efforts must be carefully tailored to address farmer needs.

Key words: conservation agriculture—discrete choice experiment—economic viability—Ecuador—probit

Farmers in Ecuador's highlands face a challenge of increasing agricultural productivity while conserving the natural environment. The region has diverse natural and social systems, and diversity affects farming practices and environmental outcomes. While household livelihoods are varied, most farm-household income comes from agriculture (Barrera et al. 2012). Large portions of higher elevation areas have been cultivated under indigenous systems since pre-Columbian times, but current farming is characterized by smallholder production, generally of less than 4 ha (10 ac).

Throughout the highlands, agricultural productivity is relatively low due to constraints, such as poor soil quality, erratic rainfall, and natural risks (Alwang and Sowell 2010). Farmers are experiencing stress from natural factors, such as climate change, which reduces water availability, increases rainfall and temperature variability, and concentrates rainfall events. An additional stress comes through economic integration of these areas with the broader national and global economies. Market forces reduce labor availability, increase access to alternative inputs and production technologies, and raise values of agricultural products (Amaya and Alwang 2012; Alwang and Sowell 2010; Zimmerer 2007). In many communities, outmigration of workers is driving up wages. As labor becomes increasingly scarce, farmers seek labor-saving alternatives, such as new, less labor-intensive crops, or new management practices. The tightening of labor markets affecting agriculture elsewhere in the developing world is impacting mountain farming systems in Ecuador.

Farmers have addressed these challenges by adopting low-input production practices, expanding the agricultural frontier into fragile areas, and diversifying their livelihoods (Larochelle and Alwang 2012; Barrera et al. 2012). Demand for agricultural technologies has shifted; labor scarcity increases demand for labor-saving technologies, while stagnating productivity induces demands for resource-conserving production practices. Market conditions, such as increased prices and variability, create incentives for new production practices and new crop alternatives (Carrion 2013).

Highland yields are low because crops are nutrient deficient, soil structure is poor, and erosion is widespread. Inadequate and unpredictable rainfall threatens crop production, and intense, short-duration precipitation contributes to runoff. Farming in the western highlands is associated with off-farm damages from erosion-caused siltation. Flooding in the Guayas River is a common occurrence, and the Ecuadorian government is investing in flood control measures, such as aggressive dredging to mitigate damages from siltation (Ecuador Times 2013; Las Olas 2014).

Conservation agriculture (CA) holds promise to increase productivity and sustainability in these areas. Conservation agriculture comprises a set of practices intended to conserve and improve efficiency through integrated management of soil, water, and biological resources. This article summarizes the experience of a research project designed to understand the technical feasibility and economic viability of CA for smallholders in Bolivar Province, Ecuador.

The next section of this article provides an overview of the literature on CA and discusses

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what is known about CA in the context of smallholder agriculture. Following this, the study area is described. The economic viability of selected CA practices is then analyzed. As CA is found to be economically viable, to reduce labor use at critical times, and to be associated with less erosion, the paper next investigates correlates of adoption. With information on these correlates, the analysis is then deepened to show that farmers value certain CA attributes more than others. This valuation helps explain the low rates of adoption and suggests that better-designed CA outreach will stimulate additional spread of the technology.

Conservation Agriculture: Potential and Promise. Conservation agriculture has been shown to improve soil productivity and soil health over time. Its three pillars are (1) minimal soil disturbance to reduce erosion and build soil health, (2) permanent soil cover to increase soil carbon (C) content and retain moisture, and (3) improved crop rotations to enhance productivity and manage agricultural pests (FAO 2012). Benefits of CA include decreased labor use during planting and weeding, increased and stabilized yields, decreased losses from pests and diseases, reduced erosion and improved soil health, and increased soil C. While the CA literature focuses on on-site benefits to adopting producers, by maintaining permanent cover and minimizing soil disturbance, CA can reduce erosion and mitigate external damages (Kassam and Friedich 2011).

Conservation agriculture, however, also has skeptics. In a widely cited paper, Giller et al. (2009) note that evidence about the positive impacts in smallholder systems in the developing world is sparse. As an example, Dalton et al. (2014) and Farris (2015) report on field trials conducted in Africa showing no significant impacts of CA on short-term yield. Further factors limiting adoption of CA include increases in input costs (mainly herbicides), equipment costs and access to appropriate machinery, and competing uses for ground cover crops (Alwang et al. 2013). Compared to conventional practices, short-run costs of CA are often higher and yields lower. Necessary investments in tools may increase the burden of CA, particularly for farmers lacking access to credit (Govaerts et al. 2009; Giller et al. 2009). These challenges are common to many regions of the developing world where CA adoption has lagged behind its potential (Knowler and Bradshaw 2007).

Conservation agriculture practices have been applied in some developing country contexts. In India, minimum-tillage reduced labor use by nearly 30% (Lai et al. 2012). Maize (*Zea mays* L.) yields in Mexico doubled under CA (Govaerts et al. 2005). In Paraguay, no-tillage decreased erosion from 21.4 t ha^{-1} to 0.6 t ha^{-1} (9.5 tn ac^{-1} to 0.26 tn ac^{-1}; Saturnino and Landers 1997). In Zimbabwe, CA for maize improved water filtration up to 65% and increased soil retention by nearly 170% (Thierfelder and Wall 2012). In Brazil, no-till methods for a soybean (*Glycine max*)–maize rotation increased soil C by 6.2% (Bayer et al. 2006).

To date, most spread of CA has occurred in extensive systems (e.g., maize, wheat [*Triticum aestivum* L.], and soybeans) or in relatively small-scale systems under intensive farming in flat areas (Derpsch 2005; Hobbs et al. 2006). Conservation agriculture has not been widely adopted in highland systems in Latin America. Studies have demonstrated profitability of individual conservation practices in such systems (Swinton 2000; Swinton and Quiroz 2002; Knowler and Bradshaw 2007), but few have examined entire CA production systems in the South American highlands.

Study Site. Farmers in the Illangama and Alumbre subwatersheds of the Chimbo River in Bolivar Province (figure 1) farm small, steeply sloped landholdings. Smallholder farming systems began to evolve in Ecuador following the 1964 (failed) and 1973 (more successful) land reforms (Blankstein and Zuvekas 1973). Prior to these reforms, extensive livestock predominated under the hacienda system where laborers were connected to the hacienda through institutional mechanisms, such as indentured servitude (Alwang et al. 2013). The 1973 reforms divided large haciendas, and former tenants were provided land. The land divisions were not accompanied by provision of agricultural services, such as extension, and farmers in the area are relatively new to crop production. Thus, prevailing farming systems have not benefitted from multiple generations of experimentation and adaptation.

The Illangama microwatershed covers roughly 12,950 ha (32,000 ac) and extends between 2,804 and 4,511 m above sea level (masl; 9,200 and 14,800 ft above sea level [fasl]), with crop farming between 2,804 and 3,658 masl (9,200 and 12,000 fasl). The primary system is potato (*Solanum tuberosum*)-pasture production; other common crops include quinoa (*Chenopodium quinoa*), barley (*Hordeum vulgare* L.), wheat, melloco (*Ullucus tuberosus*), and faba beans (*Vicia faba*). Illangama producers are indigenous, and their families have been present in the area for generations but are relatively new to crop production.

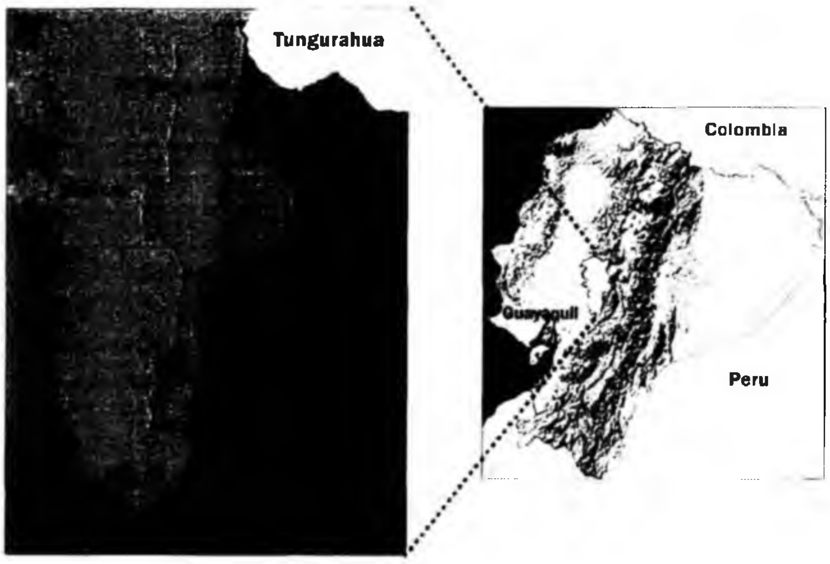
The Alumbre covers 6,475 ha (16,000 ac) and ranges from 2,012 to 2,804 masl (6,600 to 9,200 fasl) with agriculture found throughout (Barrera et al. 2012). Agriculture is mainly a mixed maize–beans (*Phaseolus vulgaris*) system, with nearly continual maize cropping. Other crops include peas (*P. sativum*), wheat, and Andean fruit. The population is primarily mestizo and relatively new to farming, arriving in the area following different natural disasters in their home villages in the 1980s and 1990s (table 1).

Livelihoods in the area are diverse. Households earn incomes from sources including crop production, livestock and dairy, off-farm and self-employment, and remittances from migrant family members. In Illangama, crop agriculture and livestock account for about 61% and 13%, respectively, of household incomes. Own business incomes make up about 8%, while off-farm wages account for 16%. In Alumbre, crops and livestock account for about 52% of household income, off-farm wages contribute around 30%, and own business incomes about 9%. Migration and receipt of remittances is much more common in Alumbre, where remittances from migrated family members account for almost 10% of household income. In Illangama, it accounts for approximately 1% of household income (Andrade 2008).

The subwatersheds are characterized by conditions that threaten environmental sustainability (Barrera et al. 2008). Landholdings are relatively small (about 4.8 ha [12 ac] per household, on average), household sizes are relatively large (more than five members per household), and dependency is high (35% of household members are dependent—under 18 or older than 65 years). Substantial subdivision of lands has occurred since 2000, productivity is low, and residents are increasingly encroaching on protected páramo lands, particularly for grazing livestock. These lands, which start at elevations above 3,962 ha (13,000 ft) are pristine and are used to protect drinking water sources.

As a result of these conditions, a program for research on CA in the area was established in 2009 (SANREM CRSP 2009).

Figure 1
Location of study subwatersheds.



The national partner for this research (the autonomous agricultural research institute [INIAP]) has worked for many years in the area and has built up an impressive network of collaborators. This network facilitated project implementation and created linkages to local governments and farmer groups. The project was designed to test the viability of CA, evaluate alternative CA production systems, understand social conditions, identify determinants of adoption, and provide information for further diffusion of CA. Following five years of project implementation, results are now available.

In addition to applied research and outreach activities, the Sustainable Agriculture and Natural Resource Management (SANREM) project built capacity through undergraduate and graduate training in agronomy, soil science, plant pathology, and social sciences. Seven masters and two doctorate students were trained and conducted research as a part of the project. Six Ecuadorean students conducted thesis research, many more assisted in data collection, and 16 US undergraduate interns participated in six-week research internships in Ecuador to collect and analyze data. These research projects were jointly supervised by US and Ecuadorean academic advisors. Published output includes analyses of social and economic conditions (Barrera and Alwang 2012; Alwang et al. 2013; Barrera et al. 2012), analyses of nitrogen (N) availability in highland systems (Escudero et al. 2014), and graduate theses and dissertations.

Materials and Methods

The project began with a participatory assessment of stakeholders in the study area conducted in March of 2009. This assessment included interviews with local officials, farm organizations, and farmers. Local students served as translators, who were needed for the Illangama watershed where residents mostly speak Quichua; in Alumbre, Spanish is spoken. Village transects were conducted. Workshops were held where participants mapped household assets, identified challenges to farming, and discussed alternatives for managing soil fertility and reducing erosion. Limited agricultural productivity and lack of access to new technologies featured prominently in these discussions, and alternatives for incorporating CA components into production systems were explored.

An early 2000s effort, supported by INIAP, had introduced no-till maize production into the Alumbre subwatershed. This low-technology option uses a stick to perforate the ground, after which maize seed and fertilizer are added. While the technology did not spread, participants in the 2009 Alumbre meetings were familiar with the technique. In the Illangama subwatershed, farmers were somewhat familiar with an

Table 1
Conditions in Chimbo subwatershed (Alwang et al. 2009).

Location and agroecological conditions	Productive activities
Illangama	
• Region: Páramo and Andean mesa	• Agriculture: potato, pasture, quinoa, faba, chocho, and barley
• Life zones: subalpine or boreal, mountain, low mountain and cool temperate	• Animal production: cattle and others
	• Tourism, handicraft production, dairy, and off-farm labor supply
• Temperature (°C): 7.2 to 12.8	
• Altitude (m): 2,800 to 5,000	
• Annual rainfall (cm): 50.8 to 12.5	
Alumbre	
• Region: Andean mesa and subtropical	• Agriculture: maize, beans, peas, blackberry, tree tomatoes, and vine tomatoes
• Life zone: low mountain and premountain	• Animal production: poultry and swine
• Temperature (°C): 15 to 18.9	• Agroindustry: medicinal plants, cacao, and organic coffee
• Altitude (m): 2,012 to 2,800	• Off-farm labor supply
• Annual rainfall (cm): 76.2 to 139.7	

Table 2
Conservation agriculture (CA) practices included in field trials in Bolivar Province, Ecuador.

Watershed	Rotation	CA factors (experimental treatments)	Notes
Illangama (old trial)	Potato-oats-vetch-barley-faba bean	Tillage (conventional, reduced); groundcover (removed, retained); fertilization; deviation ditches	Four-year cycle; deviation ditches are used to slow erosion
Illangama (new trial)	Potato-oats-vetch-barley-faba bean	Tillage (conventional, reduced); groundcover (removed, retained); fertilization	Four-year cycle; fertilization treatment: added/no added nitrogen (N) to potatoes
Alumbre (old trial)	Maize/oats-vetch-bush beans/oats-vetch	Tillage (reduced, no-till); groundcover (removed, retained); fertilization	Two-year cycle
Alumbre (new trial)	Maize/groundcover-bush beans/groundcover	Tillage (reduced, no-till); groundcover (removed, retained; natural grass, oats-vetch); fertilization	Two-year cycle

ancient technique for low-till potato planting. This system, known as *wacha rosada*, involved cutting at an angle into the pasture, folding the turf flap up, and planting the tuber under the flap. Tillage alternatives were familiar to farmers in both watersheds, but current tillage involved complete plowing using mechanical or animal traction.

Conservation Agriculture Experiments. Discussions at community meetings turned to potential CA rotations and CA practices for each subwatershed. Rotations were chosen to include crops normally produced in the area, and cropping sequences in each rotation followed agronomic guidelines. These rotations were combined with tillage options, groundcover options, fertilization, and physical structures to reduce soil erosion (table 2). Experimental plots were established on fields of three farmers in each watershed; a complete randomized block design was employed. The trials followed the prescribed rotation for the five-year duration. Outcome variables included physical and chemical soil properties (measured at baseline and project end), yields, input costs, and net value of production. These were measured for each crop in each treatment during the experiment.

The economic analysis of CA compared to the conventional practices was based on the aggregated (over the entire production cycle) value of total production minus total cost. Physical and chemical soil properties were also measured at baseline and project end. Measures were taken of (1) total C, N, and phosphorus (P); (2) plant available N and P; (3) available cations; and (4) potentially mineralizable N and particulate organic matter. No statistically significant differences were obtained, so the project focused on economic measures (SANREM CRSP n.d.). Costs were measured for all variable inputs, including labor (valued at the prevailing wage rate) and a depreciation calculation for fixed inputs. Crop outputs were weighed and valued at prevailing market prices (costs of shipping to market were included on the cost side). Crop residues can be left in the field (in the groundcover treatments) or removed and fed to animals. When they are removed, their value was included in the computation of total value of production; the weight removed was multiplied by local prices. When the residues are left on the field, their value is implicit—changes are expected in terms of subsequent yields due to fertility enhancement and soil moisture improvement, but the residue itself has no explicit economic value.

Economic analysis of the trials gives information on net benefits of specific combinations of CA practices. However, many farmers are not aware of these benefits and a diffusion strategy requires further information about the correlates of adoption and how farmers themselves value different CA attributes. This information is provided through analyses of two household surveys.

Household Surveys. Two household surveys were undertaken. One measured farmer knowledge and determinants/correlates of adoption of CA practices. The second was a part of a choice experiment designed to measure farmer valuation (willingness to pay) for different attributes of CA. These analyses complement each other by providing information about household-level factors associated with prior adoption of CA and about which attributes (labor savings, increased yield, or erosion reduction) farmers value most. The adoption analysis is intended to facilitate better targeting of outreach measures toward those farmers whose attributes indicate they have a higher likelihood of adoption. The willingness to pay analysis reveals the appropriate content of the outreach message.

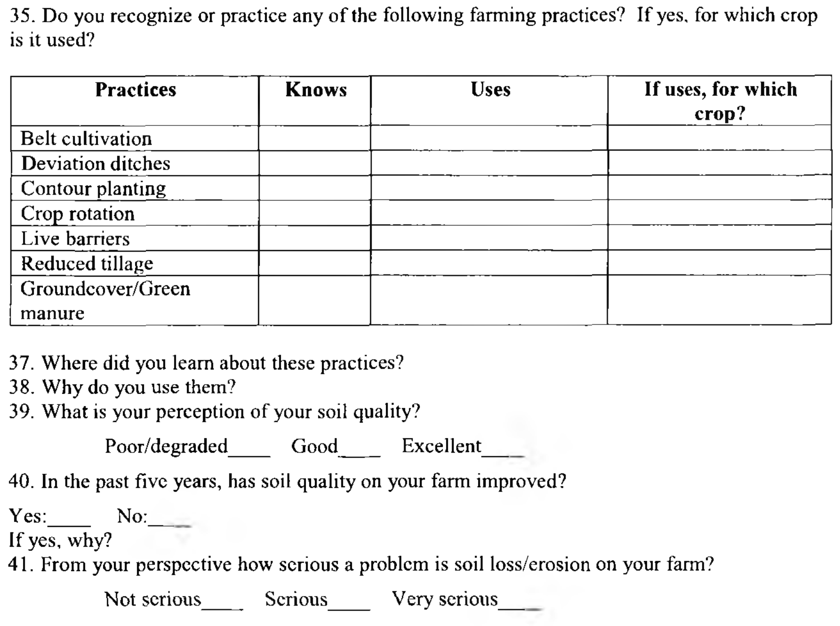
The first survey was a random sample of 319 households conducted in the two watersheds during 2011, the project's midpoint. The survey gathered information on demographics, farm conditions, and on knowledge and adoption of CA practices. The survey involved a two-stage sample design; the community was selected in the first stage and in the second, households within selected communities were identified. Since there was no prior information on community-level characteristics, the first stage was an unweighted random sample. At the second stage, lists of villagers were obtained and 12 households were selected at random from each village. At the time of the survey, Alumbre had 1,717 households in 60 communities and Illangama had 244 households in 16 communities. The size of the communities varies, but the sample was not intended to be representative at the community level; it was powered to be representative at the subwatershed level. Precision in measurement of landholding size was used as the criterion for determining sample size since a prior measurement of variability in this variable was available from Andrade (2008). The survey was powered to be representative of each subwatershed. In general, survey representativeness is determined by sample size relative to variation in the variable of interest and degree of precision required (Snedecor and Cochran 1989). We used a significance level of 0.05, an effect size of 14%, and information about variability in landholdings (Andrade 2008) to calculate the sample size. Only three households in the two watersheds refused to participate; these were replaced with the next household on the list and nonparticipation was not a significant concern. The questionnaire contained eight modules covering household demographics, production practices, assets and income, and knowledge and uptake of CA (figure 2). Enumerators consisted of teams of local university students supervised by INIAP project staff; all interviews were done face to face. Respondents were either the head of the household, the spouse of the head of the household, or both. Part of the purpose of the survey was to understand gender biases in perceptions, and an analysis showed no bias for objective measures (Chao 2014).

The determinants of adoption of CA practices and the determinants of knowledge about CA practices were analyzed using this data set. A discrete probability model was used, where the dependent variable takes a value of zero or one, depending on whether the household implements at least one of the practices under consideration. Independent variables were identified by reviewing the extensive literature on agricultural technology adoption with a special focus on the correlates of adoption of CA in the developing world. Feder et al. (1985) review factors associated with agricultural technology adoption in developing countries and conclude that household-level factors include education and experience of the farmer (ability to obtain information and manage innovations), access to labor, and access to information, whether through extension contacts or other sources. Farm size is usually found to be positively related to adoption, particularly when the technology exhibits scale effects (as is the case of CA, where machinery is often needed). Perceived risk has also been shown to be an important factor, and risks associated with not adopting CA include potential loss of productivity due to erosion.

Knowler and Bradshaw (2007) summarize literature on CA adoption and note that many factors associated with adoption of other agricultural technologies also affect adoption of CA. The most common significant variables in their meta-analysis of the literature are education, age, farm size, access to off-farm income, experience, exposure to erosion damages, access to information, and access to labor. The problem Knowler and Bradshaw note is that many of these variables have wildly different signs and significance across the surveyed literature. They conclude that it is difficult to make conclusions about a specific case, but that subsequent analyses should include these variables.

Figure 2

Questions about uptake and perceptions of conservation agriculture in household survey.



35. Do you recognize or practice any of the following farming practices? If yes, for which crop is it used?

Practices	Knows	Uses	If uses, for which crop?
Belt cultivation			
Deviation ditches			
Contour planting			
Crop rotation			
Live barriers			
Reduced tillage			
Groundcover/Green manure			

37. Where did you learn about these practices?
38. Why do you use them?
39. What is your perception of your soil quality?

Poor/degraded____ Good____ Excellent____

40. In the past five years, has soil quality on your farm improved?

Yes:____ No:____
If yes, why?
41. From your perspective how serious a problem is soil loss/erosion on your farm?

Not serious____ Serious____ Very serious____

Discrete Choice Experiment. The second survey, conducted as a part of the choice experiment, collected information from 233 producers from the two subwatersheds. A listing exercise identified 709 producers from 19 communities in Alumbre and 244 producers from 9 communities in Illangama. An initial target of 225 grower interviews with proportional coverage across both watersheds and individual communities was set. Participating farmers were randomly selected, first weighting for differences across watershed populations followed by individual community populations. In circumstances where growers were not home and unable to be interviewed, a nearest neighbor approach was used. Enumerators included undergraduate students with sufficient language knowledge to clearly present the discrete choice experiment (DCE).

Minimal amounts of demographic information were collected in this survey, as its main purpose was to administer a DCE. DCEs are a stated preference technique, similar to contingent valuation, used to determine the value of product attributes. DCEs are applied in many fields and have increasingly been implemented in developing countries to analyze topics such as health policy, the value of biodiversity, and environmental conservation and economic development tradeoffs (Hanson et al. 2005; Bennet and Birol 2010; Cerda et al. 2014).

The DCE complements the analysis of correlates of adoption by evaluating how farmers value the following five attributes: (1) Four Year Yield, (2) One Year Yield, (3) Planting Labor Days, (4) Weeding Labor Days, and (5) Soil Erosion (Barrowclough and Alwang 2014). Attributes "Four Year Yield" and "One Year Yield" were chosen to measure valuation of potential changes in productivity associated with CA. In the short run, adopters face potential yield losses (Giller et al. 2009). In the long term, productivity is expected to increase. "Planting Labor Days" and "Weeding Labor Days" were included to see how farmers value labor, an especially critical input given tightening labor markets. The supply of labor has decreased recently and its price has increased. Conservation agriculture is expected to lower planting labor, as fields do not have to be hand-hoed under CA tillage regimes. In the short term, labor for weeding will increase because tillage reduces weed populations.

The attribute "Soil Erosion" was included to obtain values of potential changes in erosion due to CA. Soil erosion is a serious problem in both watersheds, and CA can reduce erosion. Since yield changes over time are already included in the study, this attribute measures how farmers value external (off-farm) consequences of erosion. The cost of production ("Cost") was also included as an attribute; the responses to changes in cost are used to compute willingness to pay for the other attributes (Barrowclough and Alwang 2014).

Results and Discussion

Results are presented as follows: (1) experimental trial results, (2) model of the correlates of CA adoption, and (3) valuation of CA attributes from the DCE. The experimental trial analysis comprised a statistical comparison (using ANOVA) of the net returns of experimental treatments. The analysis is for the entire rotation; year-to-year variability is not considered, and we focus on medium-term profitability (this helps maintain consistency with the DCE).

Field Trial Results. The general finding from the analysis of CA field trials is that CA is slightly more profitable over five years than current farming practices. Each watershed had two sets of experiments—called "old" and "new" trials—and results are presented for each. The old trial in Alumbre included the maize, oats (*Avena sativa*)-vetch (*Vicia sativa*) cover, beans rotation and covers two cycles (in the second cycle, the plots were split and maize fertilization was added as a factor). Results for this trial show that zero tillage is the preferred option; it leads to higher yields of all crops, and the highest net profit. Retained residues left as groundcover are associated with lower profits (US$4,419 ha^{-1} [US$1,782 ac^{-1}] when residues are retained compared to US$6,622 ha^{-1} [US$2,670 ac^{-1}] when they are sold; table 4). Retention as groundcover is associated with higher yields (T7 [zero tillage, residue retention, and fertilization of maize] had the highest energy-equivalent yield of 155,905 Mcal ha^{-1} [62,865 Mcal ac^{-1}] for the rotation, compared to 136,943 Mcal ha^{-1} [55,219 Mcal ac^{-1}] for T5 [zero tillage, residue removal, and fertilization of maize]), but the feed value of the biomass cannot be ignored. Residue retention on fields is likely to raise yields of all crops over time, and this increase may offset the feed value lost. In the five years of trials, changes in soil quality were not statistically significant and the yield benefit does not offset the feed value lost.

The new Alumbre trial examined the same rotations as the old, tested natural grass compared to oats-vetch, and examined maize fertilization impacts (table 5). Treatments T2 (reduced tillage, residue removal, and no fertilization of maize) and T3 (reduced tillage, residue retention, and fertilization of maize) have highest net benefits, but T2, because it is associated with lower cost of production, is likely to be preferred because it requires fewer outlays. Again, residue retention does not pay for itself, even though the lower costs associated with leaving the residue in the field make residue retention more attractive compared to the old trials. Fertilization is only of questionable value in the CA production system. Interestingly, the treatment with the highest physical value of production (T4 [reduced tillage, residue retention, and no fertilization of maize] produced 139,019 Mcal ha^{-1} [56,056 Mcal ac^{-1}], compared to 114,445 Mcal ha^{-1} [46,147 Mcal ac^{-1}] for T3, 98,416 Mcal ha^{-1} [39,684 Mcal ac^{-1}] for T2, and 98,416 Mcal ha^{-1} [32,992 Mcal ac^{-1}] for the control) was the least attractive of the CA options in economic sense. The low economic value of T4 (compared to its energy value) is due to its high production of biomass, particularly oats-vetch. This production has its cost and contributes very little to the bottom line.

The Illangama trials examined CA in the context of a potato pasture system, focusing on field-level productivity and returns without examining crop-livestock interactions. The "old" trial results show positive economic benefits associated with using deviation ditches to reduce runoff and enhance soil fertility. These investments pay for themselves (on-farm) in the short five-year span of this experimental trial and should be incorporated into CA diffusion packages. The "old" trials also show that reduced tillage options produce higher economic benefits than conventional tillage and, like the maize–bean rotation in the Alumbre watershed, maintenance of groundcover has virtually no effect on medium-term profitability. The "new" trials confirm the findings (table 6) from the "old" trials, but provide evidence that in the medium term removal of residues is economically optimal. Potatoes need supplementary N applications to produce high yields, and N pays for itself.

Three main messages emerge from the experimental trials: (1) CA is technically and economically feasible in small-scale steep-sloped production systems; (2) in the relatively short time of the trials, soil health had not improved enough to be evident in increased yields; and (3) farmers may be reluctant to maintain groundcover due to its low benefits and competing use as a livestock feed.

Knowledge and Adoption of Conservation Agriculture. The 2011 household survey showed a fairly extensive spread of knowledge about CA practices, and relatively high levels of adoption of some practices (67% adopted improved rotations and 39% adopted reduced tillage), but less widespread adoption of practices such as use of groundcover (13% were familiar with the use of groundcover, while only 7% had adopted it). The analysis of trial data discussed above shows that the economic returns to CA adoption are relatively small and, if steps are to be taken to promote further adoption, more information is needed about which factors make households more likely to adopt. Information messages can then be tailored to this group.

Farms in the area are relatively small, and those in Illangama tend to be smaller than in Alumbre (table 3). As noted above, farms are diversified with the mean farm household producing 3.5 crops in a given season. Importantly, extension visits tend to be infrequent, as only 25% of the households report having had a visit from an extension officer in the prior year. In the context of relatively new production practices, such as CA, access to information can be an important constraint to widespread diffusion. While 72% of respondents claim to be using at least one of a broadly defined set of conservation practices (the mean uptake is 1.7 practices per household), knowledge about specific practices is a clear constraint to their adoption. The gap between the percentage of households who claim to be aware of each practice and those adopting is relatively small; access to more information about CA may stimulate its spread. These descriptive statistics suggest that a rigorous analysis of the determinants of adoption and farmer knowledge will provide insights to help design a technology transfer program.

The analysis of the correlates of adoption and of knowledge about CA practices treats the outcome variable as binary—either the household adopts or not, or knows about CA practices or does not. The probit model is the appropriate analytical tool in such cases. In the probit model, households are assumed to make decisions about adoption of or learning about CA based on expected benefits. Benefits from CA adoption depend on household-specific attributes X (e.g., age of household head, sex of the household head,

Table 3

Summary statistics from household 2011 survey conducted by the Sustainable Agriculture and Natural Resource Management Collaborative Research Support Program.

	All sample		Illangama		Alumbre	
Variable	**Mean**	**sd**	**Mean**	**sd**	**Mean**	**sd**
Age in years	47.40	16.25	39.04	12.00	50.21	16.54
Male	0.59	0.49	0.54	0.50	0.61	0.49
Years education	6.12	4.36	5.58	4.67	6.30	4.24
Number workers in family	3.36	2.11	4.20	2.36	3.07	1.94
Farm size (ha)	3.70	5.84	1.58	1.13	4.47	6.56
Crops produced	3.51	1.50	4.53	1.73	3.17	1.24
Has irrigation (%)	25	0.43	36	0.48	21	0.41
Extension visit in prior year	0.25	0.43	0.34	0.48	0.22	0.41
Knows about (% households saying they know about)						
Rotations	70	0.46	92	0.27	63	0.48
Reduced tillage	42	0.49	75	0.44	31	0.46
Deviation ditches	17	0.38	36	0.48	10	0.31
Contour planting	13	0.34	28	0.45	8	0.28
Belt planting	13	0.34	28	0.45	9	0.28
Live barriers	41	0.49	66	0.48	33	0.47
Cover crops	13	0.33	12	0.33	13	0.33
Uses (% households using each practice)						
Rotations	68	0.47	92	0.27	59	0.49
Reduced tillage	39	0.49	76	0.43	26	0.44
Deviation ditches	12	0.32	31	0.47	5	0.22
Contour planting	10	0.31	22	0.42	6	0.24
Belt planting	8	0.27	21	0.41	4	0.19
Live barriers	34	0.48	64	0.48	25	0.43
Cover crops	7	0.25	6	0.24	7	0.26
Any practice	72	0.45	95	0.22	64	0.48
Number of CA practices used	2	1.63	3	1.56	1	1.38
N	319		80		239	

Notes: CA = conservation agriculture. N = nitrogen.

Table 4

Results of Tukey test (ANOVA) for net benefits of old trials, 2010 to 2014, in Alumbre, Ecuador.

Treatments	Gross benefits (US\$ ha^{-1})	Total costs (US\$ ha^{-1})	Net benefits (US\$ ha^{-1})
T1 = Reduced tillage, residue removal, and fertilization of maize	11,432ab	6,202a	5,229bc
T2 = Reduced tillage, residue removal, and no fertilization of maize	10,671bc	5,965b	4,706bcd
T3 = Reduced tillage, residue retention, and fertilization of maize	9,473cd	5,365c	4,110cd
T4 = Reduced tillage, residue retention, and no fertilization of maize	8,868d	5,134d	3,844d
T5 = Zero tillage, residue removal, and fertilization of maize	12,088a	5,465c	6,623a
T6 = Zero tillage, residue removal, and no fertilization of maize	11,282ab	5,221d	6,060ab
T7 = Zero tillage, residue retention, and fertilization of maize	9,213d	4,793e	4,420cd
T8 = Zero tillage, residue retention, and no fertilization of maize	8,535d	4,545f	3,989cd

Notes: With removal = cut plant and remove residue from field. With retention = cut plant or chemically kill and leave residue in fields as cover. Different letters represent statistically significant differences ($p \leq 0.05$).

Table 5
Results of Tukey test (ANOVA) for net benefits of new trials, 2010 to 2014, in Alumbre, Ecuador.

Treatments	Gross benefits (US$ ha^{-1})	Total costs (US$ ha^{-1})	Net benefits (US$ ha^{-1})
T1 = Minimum till, maize with fertilization, natural grass, and residue removal	6,430c	2,890c	3,540b
T2 = Zero till, maize with fertilization, natural grass, and residue retention	7,102b	2,525d	4,578a
T3 = Zero till, maize without fertilization, oats-vetch, and residue removal	8,121a	3,535a	4,585a
T4 = Zero till, maize without fertilization, oats-vetch, and residue retention	5,751d	3,249b	2,501c

Notes: With removal = cut plant and remove residue from field. With retention = cut plant or chemically kill and leave residue in fields as cover. Different letters represent statistically significant differences ($p < 0.05$).

Table 6
Results of Tukey test (ANOVA) for net benefits of new trials, 2010 to 2014, in Illangama, Ecuador.

Treatments	Gross benefits (US$ ha^{-1})	Total costs (US$ ha^{-1})	Net benefits (US$ ha^{-1})
T1 = Conventional tillage, natural grass with removal, potato, oats-vetch with removal, and barley and faba bean	7,732b	3,896a	3,836b
T2 = Reduced tillage, natural grass with removal, potato, oats-vetch with removal, and barley and faba bean	9,055a	3,883a	5,172a
T3 = Reduced tillage, natural grass without removal, potato, oats-vetch without removal, and barley and faba bean	8,665ab	3,821a	4,844a
T4 = Reduced tillage, natural grass without removal, potato (reduced N), oats-vetch without removal, and barley and faba bean	7,914b	3,266b	4,648ab

Notes: With removal = cut plant and remove residue from field. With retention = cut plant or chemically kill and leave residue in fields as cover. Different letters represent statistically significant differences ($p < 0.05$). N = nitrogen.

education, membership in an agricultural association, and access to credit), and location-specific attributes, such as watershed (Z), and a disturbance term. Nonadopters (Y = 0) receive benefits:

$$U_{i0}(X, Z) = \beta_0 X_i + \Upsilon_0 Z_i + \epsilon_{0i} . \quad (1)$$

Adopters (Y = 1) receive benefits:

$$U_{i1}(X, Z) = \beta_1 X_i + \Upsilon_1 Z_i + \epsilon_{1i} . \quad (2)$$

Household *i* adopts only if $U_{i1} > U_{i0}$ and, since utility is random,

$$P(Y = 1) = P(U_{i1} > U_{i0}), \text{ and} \quad (3)$$

$$P(Y = 1) = \Phi(\beta X_i + \Upsilon Z_i), \quad (4)$$

where Φ is the cumulative distribution function for the standard normal distribution and $\beta = \beta_1 - \beta_0$ and $\Upsilon = \Upsilon_1 - \Upsilon_0$. Since the coefficients of a probit are not directly interpretable, we present marginal effects, interpreted as the marginal change in probability of adoption (or knowledge) associated with a one-unit change in the independent variable.

Based on the literature review, the adoption model includes in X the following factors: age, sex, education of respondent, number of male workers, farm size, number of crops produced, access to irrigation, whether a family member is a member of a farmer group, whether household was visited in past year by an extension agent, and whether soil loss is considered to be extreme by the respondent. All of these factors are mentioned by Feder et al. (1985) and are among the more important variables noted by Knowler and Bradshaw (2007).

The location-specific variable is a dummy variable reflecting whether the household is in the Alumbre watershed. The number of male workers is included to reflect labor, and its association with adoption while farm size accounts for scale effects. Both are expected to have a positive association with the outcomes. Access to extension and membership in farm groups are expected to increase access to information and have a positive relationship with knowledge and adoption. Soil loss is expected to have a positive sign because farms where soil loss is judged to be severe are more likely to take steps to mitigate the damage and to obtain information about conservation practices. This corresponds to the risk factor identified as important by Feder et al. (1985) and the slope, rainfall, and soil erosion rate effects noted in Knowler and Bradshaw (2007).

The dependent variable takes a value of one if the household adopts at least two (of three—improved rotations, reduced tillage, and/or groundcover) CA practices. In the knowledge regression, it takes the value of one if the household knows about at least two of the practices.

Correlates of adoption of CA are largely consistent with expectations, and the overall model fit is good (table 7; no model selection activities were undertaken—the "best" model was specified according to the literature, theory, and available survey variables). Households where soil loss is perceived as severe ("badloss") are 10% more likely to adopt CA compared to those who say soil loss is a minor or moderate problem. Extension visits ("extvisit") are positively (although only weakly significant) associated with adoption, while farmers with access to irrigation (10%) and with more diversified operations ("crops") are more likely to adopt CA than those with specialized farms (fewer distinct crops being produced). A one-unit increase in the number of crops is associated with a 4% increase in the probability of adoption. Importantly for CA outreach, farm size is not significantly correlated with adoption and access to family labor ("menwork") are not significant, although having more men working on the farm, as expected, reduces the probability of adoption. The surprising finding was the negative association between education of the respondent and CA adoption; those with highest levels of education (12 or more years ["ed2"]) and those with medium levels (6 to 11 years ["ed1"]) are 26% and 4% less likely to adopt CA compared to those with lower levels of education. The former effect is strongly statistically significant. These results may reflect that well-educated people are less dependent on farm income and, hence, relatively less likely to adopt a complex set of practices, such as CA.

The gender of the household head was not significantly associated with the probability of adoption, nor knowledge about CA. This is consistent with what is known about farming in these areas—women are heavily engaged in farming and farm decision-making (Hamilton 1998). It is also relatively good news from the perspective of CA outreach; as males increasingly migrate, adoption is not likely to diminish.

As expected, farmers in Alumbre are much less likely to adopt (33% less likely) compared to their counterparts in Illangama. In Illangama, soil loss is a severe problem. INIAP partners have been working for a longer time with Illangama farmers, so confidence in their recommendations is higher. Illangama also experiences more extreme rainfall events than Alumbre, and farmers complained about sudden washouts due to deluges during the participatory assessment and subsequent interactions with the research team.

The correlates of knowledge about CA are similar in magnitude and significance to those of adoption (table 6). This finding was expected since the two outcomes are highly correlated (r = 0.85) and more than 96% of the adopters report having knowledge of CA. The one variable with a strongly different effect is farm size, which has twice the impact on knowledge (an 8% higher likelihood of knowing about CA per additional hectare of land) compared to adoption. Families with larger farms are more likely to have CA knowledge than those with smaller farms, but are no more likely to adopt. This finding further reinforces the notion that in the context of smallholding farms in the Ecuadorean Andes, CA is a scale-neutral technology.

Findings provide optimism for design of a CA outreach program. All farm sizes can be targeted to receive CA messages, and neither education nor access to labor should lower knowledge acquisition or adoption. Diversified farmers in erosion-prone areas should be targeted first, as they are most likely to adopt. Extension contacts are not significantly related to CA uptake, providing some justification for transferring information through less costly means, such as farmer field days and farmer exchanges.

Valuation of Conservation Agriculture Attributes. The survey provides evidence that some adoption of CA has occurred, but the project needed to design an outreach program to promote more widespread adoption. This is particularly important because the trial results show profitability to be relatively low; long-term benefits of CA may exceed its short- and medium-term benefits. The adoption results presented above are backward looking in that they refer to associations between variables prior to the experimental results being realized. Dynamic conditions in the two watersheds also may affect viability of CA; wages are rising rapidly in the area due to outmigration of youth and young adults.

A DCE is used to identify attributes of CA that farmers themselves find valuable and provides important information about which attributes to highlight in outreach/promotional efforts. A random-parameter logit (RPL) is used to recover farmer willingness to pay (WTP) for each of the attributes included as variables in the model (Barrowclough and Alwang 2014). The model was estimated using the survey of 233 farmers described above. While the DCE was used to investigate several issues, including household attributes associated with higher probability of adoption of CA, here we report briefly on estimated WTP for the attributes discussed above: "Four Year Yield," "One Year Yield," "Planting Labor," "Weeding Labor," and "Soil Erosion."

Significant WTP values were found for all attributes with the exception of "One Year Yield" (table 8). Insignificant WTP for "One Year Yield" likely reflect a willingness to tolerate a slight decrease in short-term production to have higher future returns. Producers have a mean WTP value of 1.77% for a 1% increase in "Four Year Yields," meaning that they would be willing to pay 1.77% in additional current production costs to obtain a 1% increase in yield in year four. Farmers are willing to undertake investments if they think they will lead to long-term gains.

"Planting Labor" was found to have a mean WTP value of 1.03%. Labor effort is most concentrated during planting when labor markets are tightest, so the WTP values are plausible. With weeding operations accounting for a smaller share of total production cost along with the ability to be spread out when labor is not in high demand, "Weeding Labor" was found to have a lower mean WTP value of 0.40%. The higher value for "Planting Labor" is also consistent with the notion that producers understand and value the skills associated with particular planting practices compared to the more generic skillset required for weeding. The probit analysis showed that access to household labor is not associated with adoption of CA; the WTP analysis shows that farmers are concerned about saving labor during peak periods of demand.

This finding illustrates the complementarity of these two analyses. If one relied on the probit analysis alone, the conclusion might be that since household labor is not correlated with current/past adoption, farmers might not appreciate or value labor-saving dimensions of CA. Outreach materials might be designed without including information that CA is especially useful in reducing planting labor. In contrast, the DCE shows clearly that as farmers look forward, they want to save this increasingly scarce resource. Labor-saving technologies are valued by farmers.

While producers stated that they considered erosion to be highly important, they were unwilling to pay much to decrease it. Mean WTP values for "Low Erosion" and "Medium Erosion," respectively, were 0.27% and 0.11%. These low values suggest that farmers are unwilling to pay to mitigate off-farm and noneconomic effects associated with erosion. The probit analysis showed that farmers with more degraded lands were more likely to have adopted CA in the past. However, the mechanism by which CA provides them value is through reduction of yield losses associated with soil conservation practices and yield gains associated with more on-farm retention of soil. Outreach should highlight these potential gains. Suggesting that CA reduces off-farm damages is unlikely to influence producers to adopt such practices. If decision makers wish to reduce downstream damages, such as from siltation, by promoting CA practices in the highland areas, producers may need to be compensated to undertake such activities.

Table 7
Correlates of conservation agriculture (CA) adoption and knowledge about CA. Dependent variable = 1 if household adopts/knows about CA. Data collected from a 2011 survey conducted by the Sustainable Agriculture and Natural Resource Management Collaborative Research Support Program.

		Outcome					
		CA adoption			Knowledge about CA		
Variable	Description	Marginal effect	se	p	Marginal effect	se	p
Age	Age of farmer	-0.0025	0.0017	0.150	-0.0008	0.0018	0.669
Male	1 if male	0.0752	0.0530	0.156	0.0535	0.0541	0.321
Ed1	Education of farmer (6 to 11 years)	-0.0364	0.0560	0.516	-0.0615	0.0575	0.284
Ed2	Education of farmer (12+ years)	-0.2643	0.0829	0.001	-0.2522	0.0841	0.003
Menwork	Number of working age adults	-0.0259	0.0174	0.137	-0.0303	0.0179	0.089
Farmsize	Farm size (ha)	0.0006	0.0018	0.2869	0.0032	0.0023	0.639
Crops	Number of crops	0.0430	0.0188	0.022	0.0523	0.0195	0.007
Irrigation	1 if farm has irrigation	0.1048	0.0589	0.075	0.0782	0.0606	0.207
Extvisit	1 if extension visit in past year	0.0755	0.0564	0.181	0.0818	0.0580	0.151
Badloss	Farm experienced extreme erosion in past 5 years	0.1022	0.0542	0.059	0.1402	0.0559	0.012
Alumbre	1 if household is from Alumbre watershed	-0.3290	0.0580	0.000	-0.3247	0.0621	0.000
N		316			316		
r^2		0.202			0.189		

Notes: N = nitrogen. All dummy variables take value of zero if condition in column two is not met.

Table 8
Willingness-to-Pay (WTP) estimates† of conservation agriculture (CA) attributes.

Attribute	Improvement	Mean WTP	Confidence interval‡
One Year Yield	A 1% increase in one year yields	-0.55	-2.51 to 1.40
Four Year Yield	A 1% increase in four year yields	1.77**	0.28 to 3.26
Planting Labor	A 1% reduction in planting labor	1.03*	0.00 to 2.07
Weeding Labor	A 1% reduction in weeding labor	0.40**	0.09 to 0.70
Low Erosion	From high erosion to low erosion	0.27*	0.00 to 0.55
Medium Erosion	From high erosion to medium erosion	0.11*	0.00 to 0.22

***1% significance ** 5% significance * 10% significance.
†Random parameter logit with respondent characteristic held fixed.
‡Confidence intervals using the Delta method are taken at 90%.

Summary and Conclusions

Small-scale farming in the highlands of Ecuador is associated with extensive soil erosion and degradation of soil health and productivity. Erosion is not only causing damage in situ, but downstream damages in the Guayas River lead to very high fiscal costs. Conservation agriculture offers promise in these areas, but little evidence exists in the literature about the viability of CA under such conditions. This paper presents evidence from a multidisciplinary research effort to measure the economic returns to and prospects for adoption of CA in two watersheds in Bolivar, Ecuador. Experimental trials running for five years compared value of production net of input costs for promising CA rotations compared to current farmer practices. The paper further investigates obstacles to adoption and provides evidence about which attributes related to CA farmers in the area value most.

The trial data show that CA practices yield more and cost slightly less (over a five-year cycle) than conventional practices, but measured differences are not large. Measures of soil health between the plots at baseline and at project end did not reveal statistically significant changes in these parameters. Over time, soil health may increase, but the technologies need to show viability over a shorter time frame—so it is important to focus on yields and costs. Risk-averse farmers may be unwilling to adopt new practices unless the returns grow over time.

The analysis then turned to the correlates of adoption and efforts to understand which CA attributes were most highly valued by farmers. Small farm size and limited available household labor were not associated with lower CA adoption, but farmers who perceive soil loss on their farm to be severe are much more likely to adopt than those who do not. Outreach should be targeted to more degraded areas or areas that have been identified as being vulnerable to soil loss. Farmers in the upper Illangama watershed appear to be especially receptive to CA, possibly due to the more frequent occurrence of extreme weather events there.

The choice experiment shows that farmers are most interested in saving labor at key points during the cropping cycle. Farmers are receptive to technologies to save this scarce factor. Since 2011, labor markets in the area have tightened substantially and looking forward, farmers are interested in saving labor. Since CA replaces many labor intensive operations (land preparation, planting, and weeding) with less intensive practices, as labor markets continue to tighten and wages grow, CA is likely to become more attractive to area farmers.

The multidisciplinary nature of the SANREM project allows examination of physical relationships (inputs and outputs), their values and costs, and social processes affecting uptake. The combined effort is illuminating; while CA is technically feasible, in an economic sense it is only marginally better than the alternative, given current conditions. Over time, assuming that soil health improvements increase the relative differences in productivity and input prices, particularly labor, CA adoption should spread. In the meantime, outreach should stress those factors that farmers find most important: labor savings, especially during peak times; long-term productivity; and reductions in soil erosion.

The changing economic and social conditions mentioned in the article's introduction hint that strong measures are needed to make agriculture more environmentally sustainable. These results contain good news and bad news. The good news is that tighter labor markets, increased integration in global markets, and rising product prices will likely create incentives for increased adoption of CA. The environmental stresses caused by climate change are also likely to create conditions more favorable for widespread adoption. Since CA is scale neutral, as farms subdivide, the viability of the technology will not suffer. Out-migration will also place increasing responsibility on women, and the study found no substantial gender association with adoption.

The bad news is that CA is not a panacea. The differential returns to CA are relatively small and the small margins may make farmers skeptical of its promise. If widespread adoption is desired, incentives will be needed to compensate potential adopters for the uncertainty associated with a relatively unproven technology. Widespread adoption is needed, however, to reduce downstream damages from erosion originating in the subwatersheds. One alternative would be for the national government to institute a program of payments for environmental services whereby savings from reduced flood damages could be channeled into a payment scheme for upstream producers.

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