CHAPTER 3: GLOBAL SENSITIVITY ANALYSIS OF RUSLE ILLUSTRATES IMPORTANCE OF COVER MANAGEMENT ACROSS ENVIRONMENTS IN PREDICTING SOIL EROSION RATES

Natalia Carmona-Estrada, Elizabeth Harper, Fabrice DeClerck, Alexander K. Fremier. In revision. *Geomorphology*

1. Abstract

Soil loss remains a critical issue for sustained agricultural production and reduction of downstream environmental impacts. Modeling soil loss at watershed scales helps researchers and decision makers quantify the impact of policy and land use decisions. The Revised Universal Soil Loss Equation (RUSLE) is a common empirical model used for quantifying soil loss. This model is widely applied across spatial extents and environmental conditions despite a lack of site-specific data for many regions. To better understand the consequences of the broad applications of RUSLE and to provide recommendations for prioritization of site specific data collection, we performed a global sensitivity analysis (GSA) on three dissimilar factor estimate datasets, covering varying scales (plot and watershed) and environmental conditions (temperate and tropical). The GSA technique allowed us to rank factor importance in estimating erosion rates and identify important factor interactions controlling soil loss across environmental conditions. We also compared the robustness of both global and local sensitivity analyses in assessing factor contributions to model uncertainty. Using a non-parametric approach (Random Forest and Classification and Regression Trees), we found that the greatest soil loss comes from small proportions of the watersheds and is largely determined by the interaction of cover management with slope steepness in steep areas, and with soil erodibility in level areas. Results highlight the importance of cover management in soil loss predictions regardless of environmental condition and model parameterization. Our findings reinforce that conservation practices should be targeted at specific locations of high erosion by adjusting cover management, specifically root density

and surface cover. In addition, we argue that a global sensitivity approach is more robust than the local sensitivity analysis because higher order interactions among factors are quantitatively considered.

2. Introduction

Soil loss poses threats to biodiversity with significant on- and off-site impacts, including impacts to water quality, reservoir capacity, and food production (Pimentel et al., 1995; Bilotta et al., 2012). Decision makers and land managers require efficient scientifically defensible findings to prioritize implementation of soil conservation programs. Empirical and physical-based models are commonly used to quantify the mechanisms and patterns of soil loss across scales, environmental context, and land use. Model parameterization is a key step in representing inherent environmental variability (Box-Fayos et al., 2006), in particular, it is necessary to identify the factors and parameter estimates that produce the most uncertainty in model predictions for different environmental conditions and scales of data resolution.

Empirically and physically based models are commonly used to predict watershed scale soil loss from a range of systems (WEPP -Flanagan and Nearing 1995; RUSLE - Renard et al., 1997; EUROSEM - Morgan et al., 1998). One of the most commonly applied models is the Universal Soil Loss Equation (USLE) and its revised version RUSLE (Wischmeier & Smith, 1978; Renard, et al., 1997,Table 2). These empirical models are used to predict soil loss over large scales, particularly in data poor locations (Mueller et al., 2005; Bewket & Tefari 2009). Although physical-based models more precisely represent the forces control soil loss, empirical models remain widely used due to the lack of available data to parameterize more physical-based models (Gaffer et al., 2008; Bewket & Teferi, 2009).

The Universal Soil Loss Equation (USLE) was formulated from more than 10,000 plot years of basic runoff and soil loss data measurements on agricultural lands during 50 years in the United States

(Wischmeier & Smith, 1978). In the 1990s, the USLE equation was revised and improved to be applicable across a wider range of environmental conditions and crops (Renard et al., 1997). Both equations estimate long-term average annual soil loss (A) per unit of area ($A = R \cdot S \cdot L \cdot C \cdot K \cdot P$). Factor estimation for both models is relatively straightforward at different scales, and includes topography (L and S factor), soil erodibility (K factor), cover management (C factor), support practices (P factor), and rainfall- runoff erosivity (R factor) (Renard et al., 1997; Bryan, 2000, Table 2). Two main limitations of empirical models are: 1) soil loss is a stochastic process with greater variability for soil losses of lower magnitudes (Nearing et al., 1999; Nearing, 2000), and 2) processes that drive soil loss vary with spatial scale (plot and watershed) and location (Lal, 2001).

Table 2. RUSLE factor description, units and reference. Each factor parameters used to construct the theoretical dataset.

Factor (description)	**Independent parameters**	**Source**
Long term average soil loss - A ($t \cdot ha^{-1} \cdot yr^{-1}$) $A = C \cdot K \cdot L \cdot S \cdot R \cdot P$		Renard et al., 1997
***C*:** cover-management: Crop type and management practices such as the impacts of previous cropping and management, the protection offered to the soil surface by vegetative canopy, erosion reduction due to surface cover, and surface roughness (Dimensionless, but less erosive crops or land cover have smaller values)	*Sp*: Percentage of land area covered by surface cover; *Bur*: Mass density of live and dead roots found in the upper inch of soil ($lb \cdot acre^{-1} \cdot in^{-1}$); *b*: effectiveness of surface cover; *Bus*: mass density of incorporated surface residue in the upper inch of soil ($lb \cdot acre^{-1} \cdot in^{-1}$); *Cf*: surface soil consolidation factor; *Ru*: surface roughness; *H*: Canopy height (ft); *Ru*: Surface roughness; *Fc*: Fraction of land surface covered by canopy (%); *Cur*: Impacts of the subsurface residues ($acre \cdot in \cdot lb^{-1}$)	Yoder et al., 1997
***K*:** Soil erodibility: Soil profile reaction to hydrologic processes (e.g. raindrop impact, surface flow, roughness (topographic or induced), and rain water infiltration). K is affected by physical, chemical and mineralogical soil properties and their interactions and is calculated as an average annual value ($ton \cdot ha \cdot h \cdot ha^{-1} \cdot MJ^{-1} \cdot mm^{-1}$)	*s*: Soil Structure; *p*: Soil Permeability; *OM*: Organic matter (%); *M*: (%Silt +%Very fine sand)(100-%Clay)	Romkens et al., 1997
***LS*:** Topography: Slope length (L) which is the horizontal distance from the starting point of the overland flow until deposition or channel formation and slope steepness (S), the slope gradient effect on soil erosion	Θ: slope angle (degrees); λ: Slope length (ft)	McCool et al., 1997

Factor (description)	Independent parameters	Source
(Dimensionless)		
R**:** rainfall- runoff erosivity: The effect of raindrop impact and rate of runoff associated with rain of moderately sized storms with occasional large storms. ($MJ \cdot mm \cdot ha^{-1} \cdot h^{-1} \cdot y^{-1}$).	*j*: No events per year; *I*: Erosive rain Intensity ($in \cdot hr^{-1}$)	Renard et al., 1997
P**:** Support practice The runoff reduction rate by implementing practices such as contouring, strip-cropping, terracing and sub-surface drainage (Dimensionless)		Foster et al., 1997

RUSLE has been applied at different scales, both, in the US where the data were originally collected (Renard & Ferreira, 1993; Gardiner & Meyer, 2001; Gaffer et al., 2008) and elsewhere, including regions with differing environmental conditions (Biesemans et al., 2000; Lu et al., 2004; Bewket & Teferi, 2009; Falk et al., 2009). Likewise, the purposes of applying RUSLE have been diverse. For example, to assess past, present and projected soil loss at a global scale (Yang et al., 2003), soil loss risk (Lu et al., 2004; Schuler & Sattler, 2010), policy effect on soil loss (Schuler & Sattler, 2010), soil management (Wang et al., 2007), conservation priority or policy design (Burke & Sugg, 2006), and more recently, ecosystem service provisioning (Nelson et al., 2009).

Reviews of USLE and RUSLE have demonstrated its capacity to accurately predict on-site soil loss at the plot and the watershed scale. At the plot scale, both equations predicted measured soil loss accurately (coefficient of correlation R^2>0.75, Nash Sutcliffe model efficiencies > 0.72), but both models tend to over predict and have lower accuracy for lower measures of soil loss (<10 ton ha^{-1} y^{-1}) (Nearing et al, 1999; Tiwari et al., 2000). At watershed scales, assessments of transported eroded sediment and measured sediment loads at the basin outlets demonstrated that RUSLE can be used to estimate soil loss in South East Asia (R^2>0.72) (Ranzi et al., 2012) and in Kenya (R^2= 0.80) (Mutua et el., 2006).

Assessments of the individual importance of each factor in model uncertainty at the plot scale found that the cover-management factor (*C* factor) was the most important in determining soil loss under different agriculture systems, with the second most important factor being topography (Risse et al., 1993; Benkobi et al., 1994; Ferreira et al., 1995). At the watershed scale, discrepancies exist regarding which factor produces the most model uncertainty, with some studies highlighting the topographic factor (Biesemans et al., 2000), the slope steepness (Falk et al., 2009), and rainfall-runoff erosivity (Zhang et al., 2013). In all cases, local sensitivity analyses (LSA) were applied to understand model uncertainty.

LSA is a common statistical method to assess uncertainty or importance of individual factor impact on model predictions (e.g. Renard and Ferreira 1993; Risse et al., 1993; Ferreira et al., 1995). However, LSA is limited in that it does not assess factor interactions as it estimates the contribution of each factor to model predictions by varying each one of the factors at a time while holding other factors constant (Saltelli et al., 1999). LSA is a constructive analysis, but it does not capture the potential interactions among factors (Wagner 1995; Harper et al., 2011). Global sensitivity analysis (GSA) is a more robust approach because it considers higher order interactions among factors or parameters to assess model uncertainty and to estimate factors of importance (Harper et al., 2011). GSA varies all factors simultaneously to sum all factor uncertainty and evaluate the combined impact of each factor on the model prediction (Wagner, 1995). For the RUSLE, despite the wide application and accuracy assessments, a GSA has not been completed. Results from a GSA (described in section 3.1) will further help focus model parameterization when the model is applied to new environmental contexts.

The overall goal of this study was to understand factor contributions to uncertainty in RUSLE predictions over a range of factor and parameter estimate conditions. To do this, we selected two datasets with factor estimations covering different scale of source data and environmental conditions. We also created a randomized synthetic dataset with the widest possible range of factor and parameter estimates from the original values used to created RUSLE to test overall model sensitivity. Since the goal of our analysis was not to predict soil loss nor compare soil loss predictions across datasets, we did not select comparable datasets (e.g. same location, different source data, or vice versa) nor validate model predictions against observed data. We reviewed model accuracy assessments and parameterization methods from the literature, but do not perform an accuracy assessment with our dataset as model accuracy does not directly impact our goal of confirming whether factor or parameter estimation influences model sensitivity. The results of this study provide a description of model sensitivity within and amongst factor estimates across different environmental conditions and can be used to focus parameterization efforts for future applications of RUSLE. The results are particularly important in data-poor areas where parameterization of physically-based models is limited.

3. Data preparation and description

In order to understand RUSLE sensitivity to parameterization, we conducted a GSA on two datasets parameterized at different scales (plot versus watershed), using different methods (ground collected data versus geographic systems proxies -GIS) and covering different environmental conditions (agriculture in level versus mountainous regions). We also created a synthetic dataset with the widest range of factor and parameter estimates. We performed a GSA of RUSLE on three datasets with different factor estimates to: 1) rank factor importance in predicting soil loss, 2) identify specific factor interactions predicting greater and lower soil losses, and 3) compare differences between LSA and GSA in assessing factor importance. These datasets represent the original data used to calibrate the model and environmental conditions where RUSLE is actively being applied.

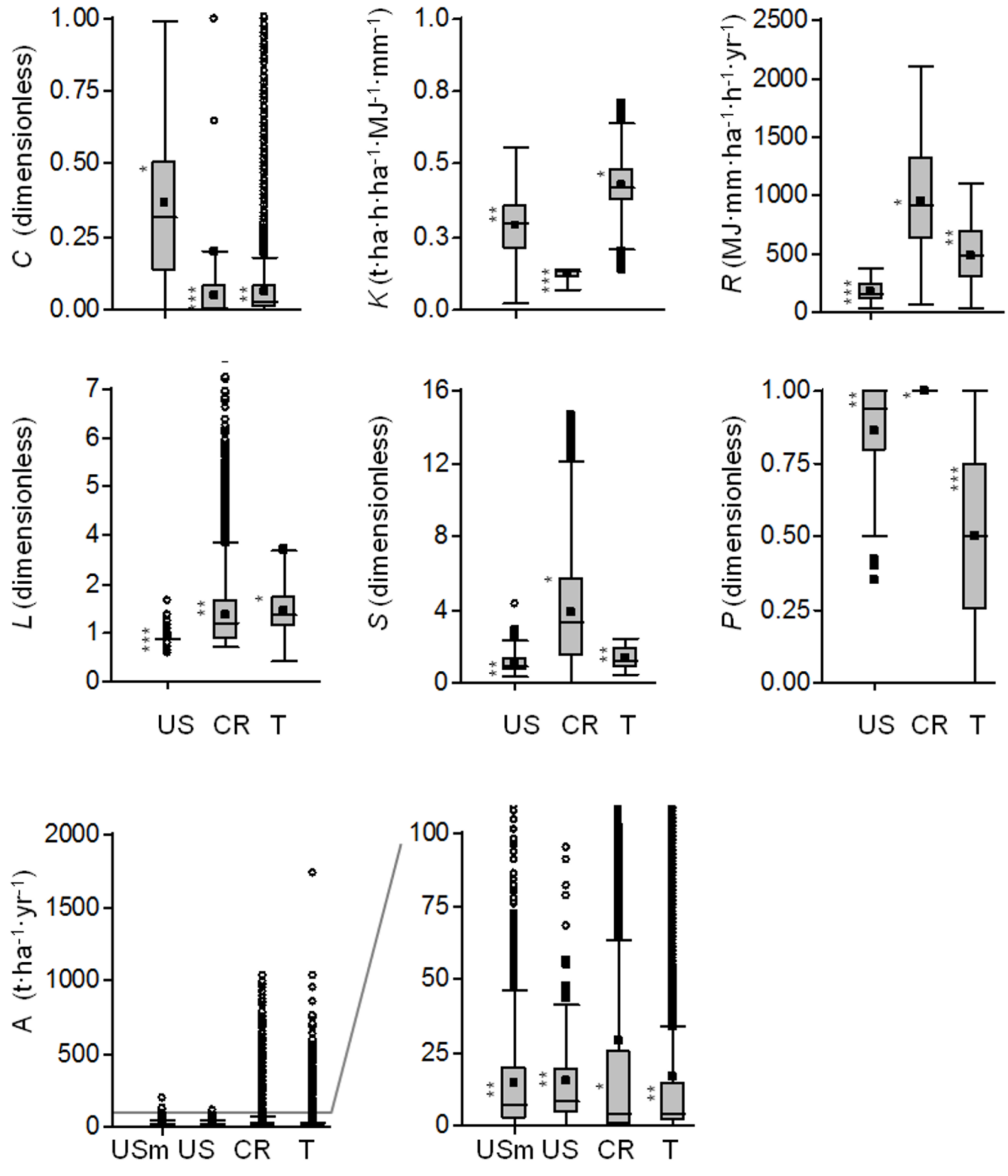
3.1. US dataset.

The purpose of the US dataset is to understand how RUSLE behaves when applied at the plot level where the model was originally calibrated. The US dataset comprises 1,704 plot years of data from natural runoff in 198 plots at 21 sites, with annual measurements of soil loss and estimates of each

RUSLE factor (*C*, *R*, *LS*, *P*, *K*) also used and analyzed by Rapp (1994) and Tiwari et al., (2000). Because this dataset provides estimates for the *L* and *S* factors combined (*LS*), we used equations from McCool et al. (1997) to estimate the *L* and *S* factors separately. The US dataset was primarily collected and measured prior to 1960 and therefore it does not represent modern agricultural practices or instrumentation to measure each factor (Risse et al., 1993). Tiwari et al. (2000) estimated a Nash and Sutcliffe model efficiency of R^2=0.72 (i.e. accuracy in predicting measured soil loss).

The range of the estimates for the *L* and *S* factors in the US dataset was relatively narrow because data were obtained from agricultural erosion plots where 80% of the data had a slope length (*L* factor) lower than 25 m and 70% of the plots had a slope steepness (*S* factor) lower than 10° (Figure 10). The cover management factor (*C* factor) included values for 21 crops, mostly annual crops with large average *C* values (erosive crops). This dataset covers a wide range for the rainfall, runoff erosivity factor (*R* factor) and soil erodibility (*K* factor) (Figure 10).

Figure 10. Factor distribution and estimates for the US, CR and T (theoretical) datasets (Box-plot). Mean values are represented by the black squares. Different numbers of asterisk (*) mean significant differences between mean values (Fisher LSD test, p-value<0.05). The estimated (US, CR, and T) and Measured (USm) soil loss (A) across datasets at the bottom.



The annual measurements of both soil loss and RUSLE factor estimates were averaged per plot to perform the GSA. We used averaged values since the RUSLE is better at predicting long-term average values than annual values or isolated events (Wischmeier & Smith, 1978; Renard et al., 1997). We tested differences in the annual and averaged values to assess the effect that sampling variability (among plots, sites and within plots) of both soil loss and RUSLE factors have on the sensitivity analysis results from the GSA and LSA.

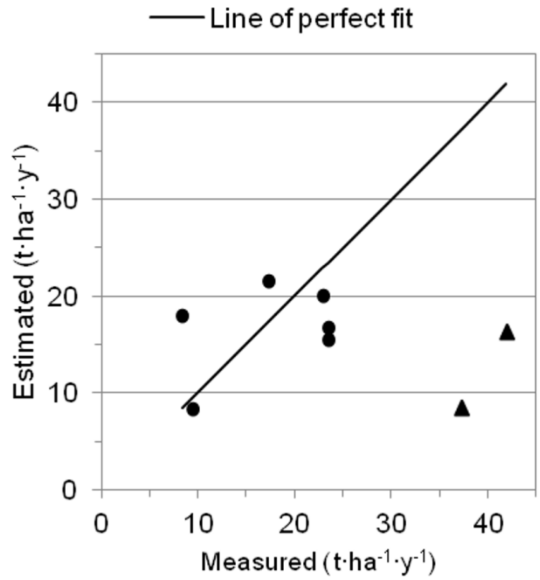
3.2. Costa Rica dataset.

The purpose of this dataset is to understand how RUSLE behaves when applied to conditions outside the data range of the original dataset. We estimated RUSLE factors for a set of watersheds in Costa Rica (CR) using a widely applied methodology for estimating potential soil loss at a watershed scale (Yang, et al., 2003; Hoyos, 2005). We performed our analysis in the uppermost portions of the Pacuare (area 64,919 ha) and the Reventazon (area 175,915 ha) watersheds located on the Caribbean side of CR's central mountain range. The *L* and *S* factors were estimated from a digital elevation model with 10 meter resolution and with the ArcInfo™ Arc Macro Language program developed by Van Remortel et al. (2004). The *C* values for local crops were collected from previous studies in the region (Gómez-Delgado, 2002; Marchamalo-Sacristian, 2004), whereas the land uses were defined by a 1996 LandSat image classification (Pedroni, 2003). The *K* values were obtained from FAO surveys at a national level and soil type classification at a scale of 1:200,000 (FAO, 1989). The *R* factor was estimated using the total storm energy (E) and a maximum 30 minute intensity (I30) for each erosive storm (i.e. storms with total accumulated rainfall greater than 13 mm and separated by at least 6 hours) for 148 station years of measurements in 54 meteorological stations of the Costa Rican Institute of Electricity– (ICE; Gómez-Delgado, 2002). The *P* factor was assumed to be 1.0 because no detailed information about the support practices in the watersheds exists.

The CR dataset comprised an area of 240,834 ha with 2,675,934 pixels so it was necessary to sub-sample to generate factor estimates. We randomly sampled the CR dataset with 30,000 pixels to overcome computer and program limitations. The sampled dataset was not statistically different from the complete CR dataset (we tested each factors using T test, p-value>0.05). In contrast to the US study site, the CR site includes a topographically complex terrain with long, steep slopes and elevation ranges from 70 to 3,470 meters above sea level. This region is characterized by intense rainfall events and high mean annual precipitation (3,251 mm yr^{-1}) (Waylen et al., 1995). The *C* factor range and estimates in the CR dataset are smaller than the US dataset (Figure 10). The *C* factor range in the CR dataset is low because 52% of the area is covered by forest (low erosive land cover), while the other 34% is covered by perennial crops such as coffee (18%), pastures with trees (13%) and bi-annual sugarcane (3%) (low/medium erosive land cover), and annual or ornamental crops (high erosive land cover).

To estimate errors in model prediction we performed a correlation analysis between measured and estimated sediment loads in eight stations in the Pacuare and Reventazon watersheds. We used the tool N-SPECT to estimate sediment loads at each stations (Eslinger et al., 2005). We used the average sediment loads measured by ICE during 1996 for the eight available stations in the studied watersheds. Before the correlation analysis, we excluded two basins with high gravel mining and frequent landslides, erosion factors not accounted in RUSLE which leaded to underestimation of sediment loads (Figure 11). The correlation coefficient between measured and estimated sediment loads for the remaining six basins was R^2=0.4. Importantly, however, given that our analysis focused on model sensitivity and not accuracy, we consider this level of correlation between predicted and observed sufficient to continue the analysis.

Figure 11. Comparison of the average sediment load estimated and measured at the outlet in eight basins of the Pacuare and Reventazón watersheds in Costa Rica. Underestimated sediment loads in basins represented with a triangle are due to other erosive processes not captured by RUSLE (i.e. gravel mining landslides).



3.3. Theoretical dataset.

The purpose of the theoretical dataset is to evaluate model uncertainty given the large possible range of factor and parameter estimates. We used the reported maximum and minimum values for each parameter and estimated each RUSLE factor according to the equations from the Agriculture Handbooks 537 and 703 (Wischmeier & Smith 1978; Renard et al., 1997 respectively; APPENDIX D). The ranges of the parameters in this dataset are based on maximum and minimum values corresponding to a physical process or plot measurements (Supplementary material I). This is the only dataset that provided us with information at the parameter level (Table 2, APPENDIX D). Here, parameters were used to estimate each one of the six factors of the RUSLE and can be a fixed number or a range of values that are independent of one another (APPENDIX D).

We created a script in Matlab to create 30,000 Monte Carlo simulations of randomly chosen parameter estimates (Sobol' 2001). Each parameter set was created by randomly drawing from a uniform distribution within the documented parameter ranges, and each factor value was estimated using the reported equations (Renard et al. 1997, Supplementary material I). Random interactions between parameters were constrained (when required) to represent real interactions; for example, to estimate the *K* factor the percentage of clay, silt and sand must sum to one hundred. We used the 30,000 Monte Carlo simulations at factor (six factors) and at parameter level (18 independent parameters, Table 2 and APPENDIX B) in the GSA. This randomization process breaks potential correlations between parameters and factors, but does not impact the GSA results (Harper et al. 2011).

3.4. Unstructured datasets.

The aim of the unstructured datasets was to validate the theoretical dataset and assess how correlations among factors affect GSA outcomes. In both the US and CR datasets, factors were cross-correlated (e.g. greater rainfall- runoff erosivity at greater altitude and slope steepness in CR), but factors in the theoretical dataset were uncorrelated since we know the maximum and the minimum values but not how the factors cross-correlate. To assess the effect of factor correlations on GSA results, and assess the validity of the results from the theoretical dataset, we disaggregated cross-correlations in the US and CR datasets by randomly selecting (with replacement) new estimates from the original datasets. Unstructured datasets had the same sample size as their corresponding structured datasets but the factor estimate combinations were different. We compared GSA outcomes from the structured and unstructured datasets.

4. Methods

We conducted three statistical analyses. First, we tested if there were significant differences in factor distribution and factor mean values across datasets. Second, we performed a GSA on the US, CR and theoretical dataset to assess factor importance and factor interactions determining soil loss. We also performed the GSA on the unstructured US and CR datasets to assess the effect of potential cross-correlation among factors and validate the results from the Theoretical dataset. And finally, we performed a LSA on the US dataset to compare the LSA and GSA statistical methods.

4.1. Statistical Analyses

Analysis of variance and mean value comparisons among datasets: We tested differences between factor estimates and estimated soil loss across the three datasets. We tested factor estimate distributions using an ANOVA using a significance value of $p < 0.001$.We tested factor mean value differences using Fisher's Least Significant Difference – LSD. All analyses were performed in the R statistics software (R core team, 2012).

Global sensitivity analyses: We used the GSA approach designed by Harper et al. (2011). This GSA approach uses Random Forest (RF) to rank factor and parameter importance and Classification and Regression Tree (CART) to analyze and visualize the complex relationships among model factors. Random Forest is an improved version of CART, since it is a forest (a collection of trees) where each tree is created by bootstrap sampling and where the factor and parameter at each node of the tree is randomly selected (Cutler et al., 2007). For each tree, 30% of the data (called the out of bag - OOB data) are randomly sampled and used to estimate model efficiency by cross validating results with the other 70% of the data (Cutler et al., 2007). Model efficiency is estimated as one minus the ratio between the mean squared error (MSE) and the variance of the response variable (Pang et al., 2006) (Table 3). We used the *R* package randomForest 4.6-2 to estimate model efficiency (Breiman & Cutler, 2011).

The contribution of each factor to model predictability can be assessed by two metrics from RF. The first metric, the lost efficiency metric, estimates factor importance by calculating the changes of the mean squared error when each factor is randomly permutated. The second metric, the node impurity metric, measures changes in the residual sum of squared errors by splitting the factor at each node of the tree (Breiman & Cutler 2012). Node impurity values for each factor were normalized by the sum of the total node impurity and estimated the relative importance of each factor (Table 3). *R* package randomForest 4.6-2 was used to estimate both factor importance metrics (Breiman & Cutler, 2012). To visualize the higher order interactions between factors, we applied a CART analysis on each dataset. With CART we were able to identify the specific factor combinations that generated lower and greater estimates of soil loss (*R* package rpart 3.1-50; Therneau & Atkinson, 2010).

Table 3. Description of model efficiency measures and factor/parameter importance metrics for both global and local sensitivities analysis.

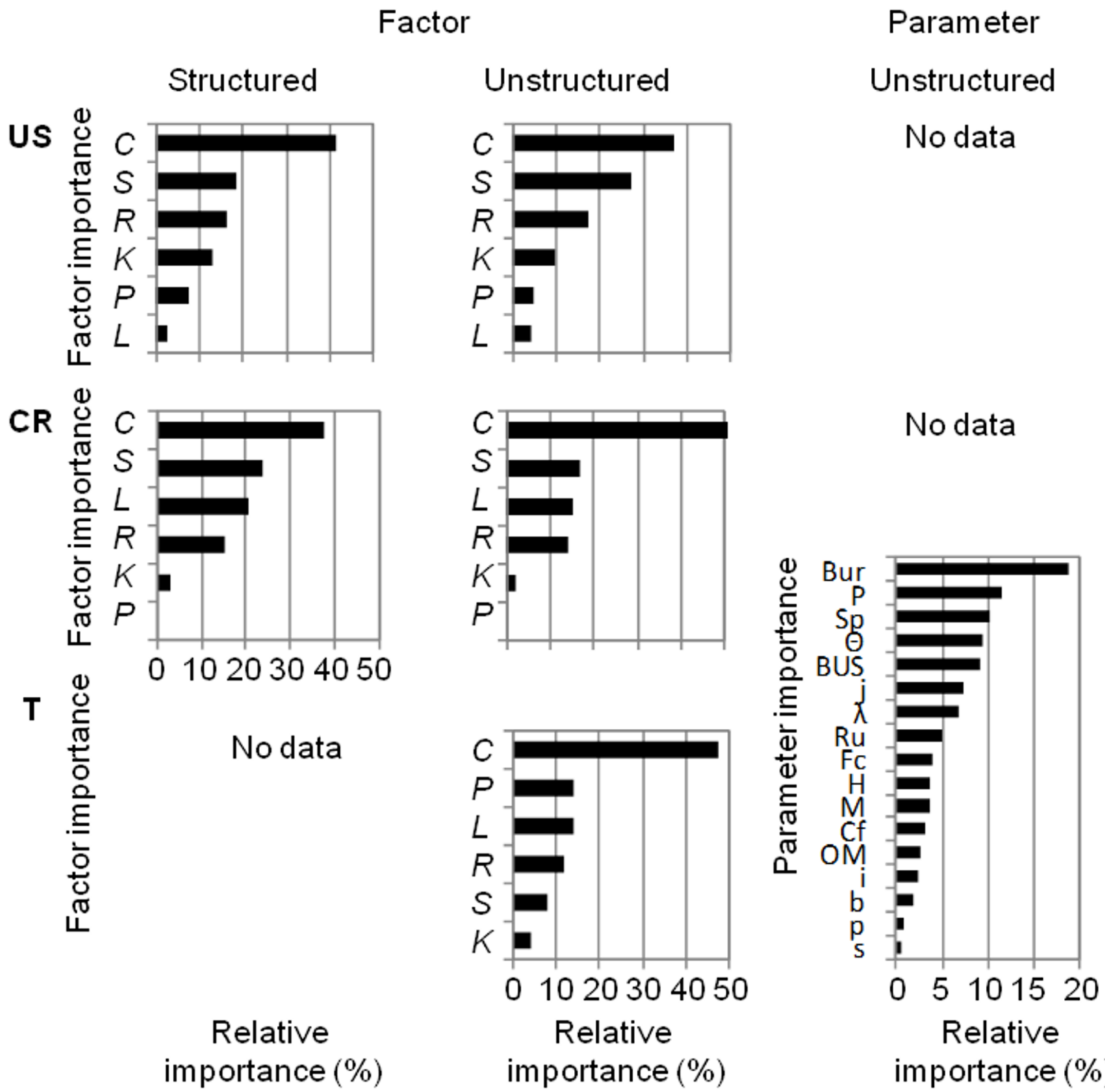
Metric	LSA	GSA
Model efficiency (i: 1...*n* factors/parameters; M_i: measured value of the i^{th} observation; E_i: estimated value for the i^{th} observation, M_{avg}: measured average value)	$R^2 = 1 - \frac{\sum_{i=1}^{n}(M_i - E_i)^2}{\sum_{i=1}^{n}\left(M_i - M_{avg}\right)^2} \times 100$ R^2= 1: perfect model; R^2= 0: model results are not better than the mean; R^2= -1: model predictions worse than using the mean (Risse et al., 1993)	$R^2 = 1 - \frac{MSE}{Var(M)} = 1 - \frac{\frac{1}{n}\sum_{i=1}^{n}(E_i - M_i)^2}{\frac{1}{n}\sum_{i=1}^{n}\left(M_i - M_{avg}\right)^2} \times 10$ Pang et al. (2006)
Lost efficiency metric	Estimates the difference between the original model efficiency (R^2) and a new model efficiency estimated after replacing a factor values by its mean value	Estimates each tree mean squared error (MSE) between the OOB data and 70% of data the left after randomly permutating each factor value at a time. MSEs are averaged over all trees and normalized by the standard deviation of the differences (Breiman & Cuttler., 2012)
Node impurity metric	NA	Is the decrease on the residual sum of squared errors (RSS) after splitting on a factor. RSS values are averaged over all tress. Each factor's relative importance was standardized by dividing it by the total RSS.

Comparison of LSA and GSA: For the LSA, we used the methodology proposed by Risse et al. (1993). LSA consists of estimating the Nash and Sutcliffe (1970) statistic. We compared both model efficiencies (pseudo R^2) estimated from the RF and LSA (Table 3). The LSA assesses the approximate contribution of each factor to the model predictability by estimating the loss of model efficiency. The loss of model efficiency value is estimated as the difference between the Nash - Sutcliffe statistic using all original factor values and the estimated Nash - Sutcliffe statistic after one factor's values are replaced by the factor's mean value; this process is repeated for each factor (Risse et al., 1993). We compared the loss of model efficiency values from LSA and RF. The US dataset is the only dataset with predicted and measured soil loss; and therefore, is the only dataset that provided information about model efficiency and the loss of efficiency metric.

5. Results

Global sensitivity analyses across all the datasets showed that the RUSLE predictions are most sensitive to the cover management factor (*C* factor) regardless of factor and parameter estimation (Figure 10and Figure 12). In most datasets, the relative importance of the *C* factor was twice as high as the second most important factor in each dataset (Figure 12). This result was consistent despite significant differences among factor estimates across datasets (Fisher LSD test, p-value <0.05) for all factors with the exception of slope length (*S* factor) in the US and theoretical datasets (Figure 10). We also found that estimated soil loss with the CR dataset was significantly greater than with other datasets (Fisher LSD test, p-value <0.05); yet, the US and theoretical estimated soil losses were not significantly different from each other (Figure 10). These consistent results across datasets indicate that the sensitivity of RUSLE model predictions is produced from the formulation (equations) of soil loss processes, with less uncertainty coming from variability in the parameter estimates. At the parameter level, root mass density (Bur) and percent surface cover (Sp) were found to be the most important parameters from the *C* factor driving uncertainty in model predictions (Table 2, Figure 12).

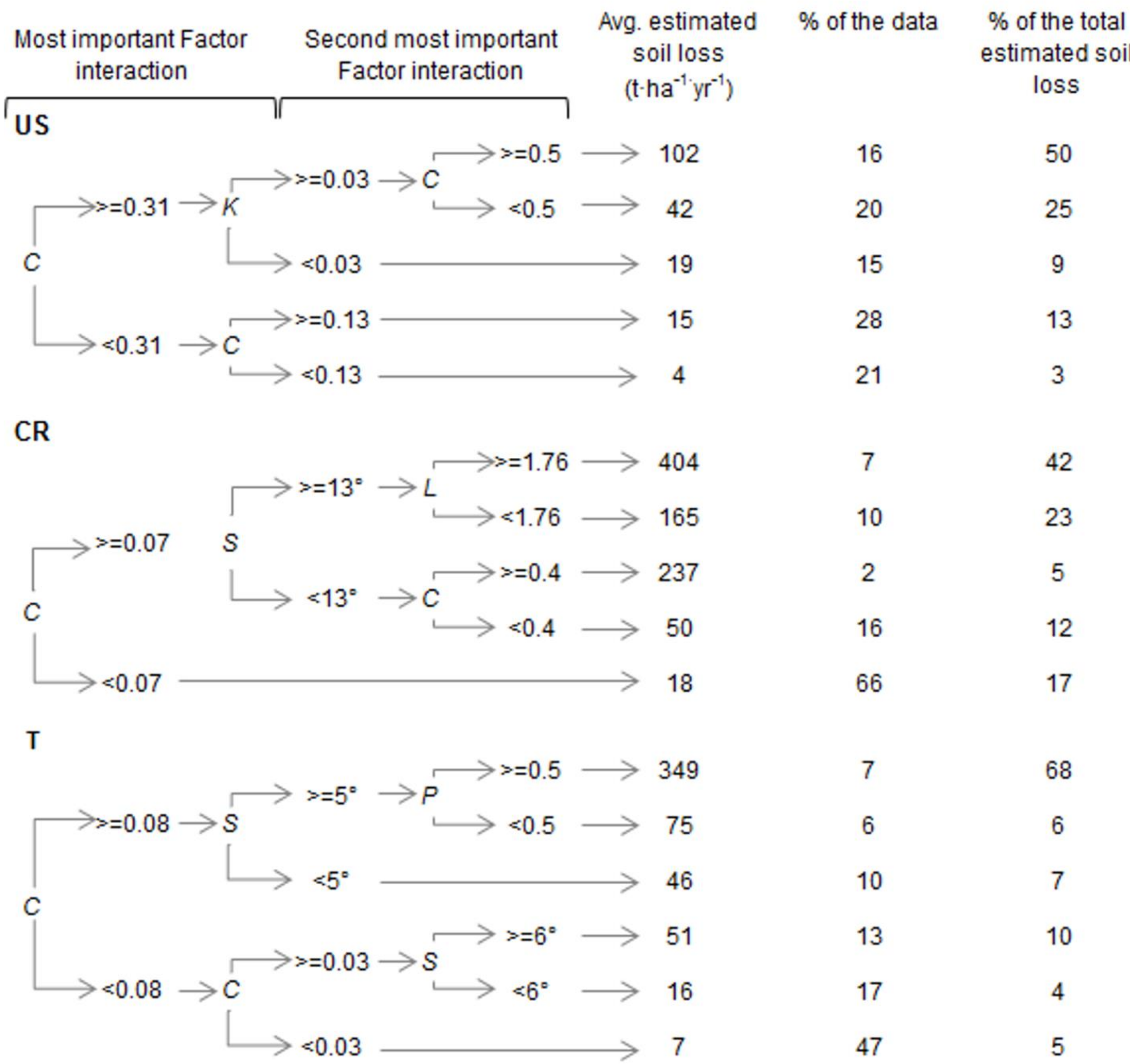
Figure 12. Factor importance order for US, CR and T (theoretical) datasets for structured and unstructured datasets at factor and parameter level (see Table 2 for factor and parameter descriptions). Relative importance is the normalized factor node impurity metric obtained from the Random Forest statistical procedure and indicates the relative importance of each factor/parameter in influencing model predictions.



Factor estimation procedures (ground collected data versus GIS proxies) or factor range estimates in each dataset (mountainous, high rainfall versus plains, less rainfall) may cause differences in the less important factors (Figure 10 and Figure 11). After the *C* factor, no clear pattern of factor importance emerged other than soil erodibility (*K* factor) being ranked in the three last positions across all analyses (Figure 12). *L* and *S* factors are the second and third most sensitive factors (respectively) in the CR dataset (Figure 12) despite the greater rainfall-runoff erosivity (*R* factor) estimates (Figure 10). Results between structured and unstructured data were consistent (Figure 12), implying that correlations among factors have a weak or null effect on model factor importance.

Higher order factor interactions, illustrated by the CART analysis, indicated that the interaction between the *C* and *K* factors was the most important in determining greater magnitudes of soil loss, despite the low *K* factor order for the US dataset (Figure 12 and Figure 13, US). Here, crops with mean *C* values above 0.31 (rye, potatoes, fallow or cotton) lost soil at a mean rate between 19 and 102 $t \cdot ha^{-1} \cdot yr^{-1}$, depending on soil type (Figure 13, US). This is contrasted with the CR dataset where the greater *C* and slope steepness (*S* factor) estimates indicate greater erosive loss (Figure 13, CR). Annual crops or bare soil with a mean *C* value above 0.4, produced erosion rates between 50-237 $t \cdot ha^{-1} \cdot yr^{-1}$ when located on slopes below 13°, however, perennial crops (i.e. coffee) with C value above 0.07 can be also highly erosive when located on slopes above 13° (Figure 13, CR). The theoretical dataset behaves similar to the CR dataset, where the interaction between *C* and *S* determined greater soil loss. The *C* factor threshold that defined low and medium soil loss was similar *C*~0.08 - 0.07 for the theoretical (within original equation factor estimates) and CR datasets (outside original equation factor estimates) (Figure 13, CR and T).

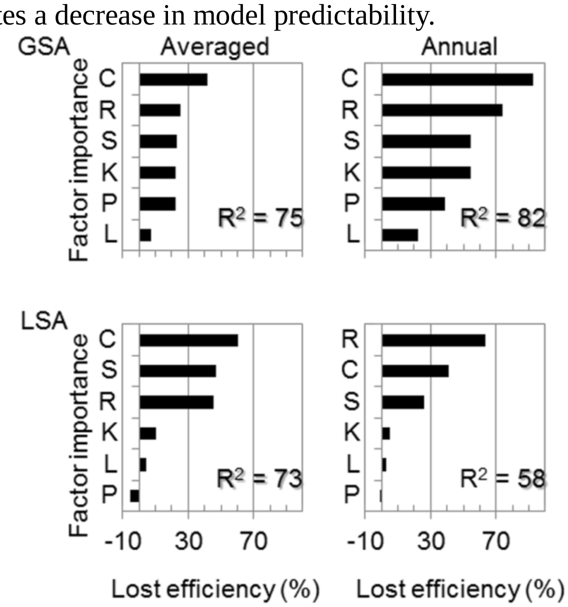
Figure 13. Factor interactions for US, CR and T (theoretical) datasets obtained from the CART analysis. Each dataset is represented as a tree, the left side of the tree represents factors combinations and the right side represent the end of the tree with the averaged soil loss, the percentage of data that follow each specific factor combination (or tree branch) and the percentage of the total estimated soil loss. Factor interactions importance is from left to right, and the value next to each factor is the factor threshold value at which the data are split and combined with the next factor.



Magnitudes of soil loss across datasets follow a similar pattern despite the different factor and parameter estimates. The CART analysis shows that greater magnitudes of soil loss come from a limited proportion of the area and from a limited combination of factors (Figure 10 and Figure 12). For example, soil loss estimated above 20 $t \cdot ha^{-1} \cdot yr^{-1}$ comes from 36% of the US parcels, 34% of the CR pixels and 36% of the theoretical runs, but account for 75%, 83% and 91% of the total estimated soil loss respectively (Figure 13).

The GSA and LSA similarly explained average plot-level soil loss in the US study site (LSA 73% and GSA 75%, Figure 14). However, the GSA explained more of the measured annual plot-level soil loss (82%) than the LSA (58%) (Figure 14). Both LSA and GSA indicated that the *C* factor is the most important factor determining soil loss when averaged plot-level data are used. The LSA results were highly affected by the difference in data variability between the averaged versus annual plot data, since the order of the three most important factors was different (Figure 14). The LSA and GSA on averaged plot-level data distinctly disagreed on the role of the support practice (*P* factor). The GSA ranked this factor as more important than slope length (*L* factor), a factor with narrower range of estimates (Figure 10and Figure 13).

Figure 14. RUSLE efficiency and factor importance order for global and local sensitivity analyses of the average and annual US datasets. Model efficiency corresponds to a pseudo R^2 from estimated and measured soil loss. Loss of efficiency value indicates the contribution of each factor to model error. The negative value indicates a decrease in model predictability.



6. Discussion

Our results indicate that cover management is the most important factor driving soil loss in RUSLE, across both the scale of data resolution and environmental context. In other words, the *C* factor produces the greatest degree of variation in model predictions. This illustrates the need to focus on *C* factor estimation over other factors to improve the accuracy of model predictions. In addition, this result suggests that the *C* factor in RUSLE could be further improved to reduce uncertainty in model predictions. This is not surprising considering the complex processes in which vegetation influences soil loss (Schwilch, Hessel, & Verzandvoort,2012). The results also underline the importance of understanding the complex interactions among vegetation, topography and soil type in determining soil loss and the high spatial variability in soil loss rates.

6.1. Model uncertainty under different environmental conditions

Our modeling efforts illustrate the importance of C factor estimation because across datasets the *C* factor is the main contributor to model uncertainty regardless of factor parameterization. For example, the CR dataset had four factor estimate ranges outside the theoretical estimates (*K*, *R*, *L*, *S* factors), yet still the *C* factor was the most important factor controlling soil loss. For this reason, we suggest that applications pay close attention to *C* factor parameterization regardless of the method used or the scale of the data source. Other factor contributions to model uncertainty were dataset or context dependent. Level landscapes require more accurate parameterization of the *C* and *K* factors, whereas estimation of the *C* and the *S* factors require greater focus on steeper landscapes. This particular result differs compared to other studies at the watershed scale. Zhang et al. (2013) highlighted the importance of the *R* factor in mountainous areas, while Falk et al. (2010) highlighted the *S* factor in flatter areas in contributing to model uncertainty. These differences are potentially explained by the higher order interactions considered when a GSA approach is used.

Our discussion here is not intended to support or refute the application of RUSLE outside the original factor and parameter estimates. We understand that RUSLE's wide use and acceptance for management (Eslinger et al., 2012) is due to its relatively easy calibration and lack of data requirements compared to more mechanistic models (Mueller et al., 2005; Bewket & Tefari, 2009). We do suggest, however, that parameter estimation of the *C* factor should be a main focus during model calibration and continued improvement of the RUSLE. We also recommend the implementation of the GSA approach in improving model parameterization by assessing factor importance, including interactions.

6.2. GSA versus LSA.

We show that a GSA approach provides a more detailed analysis of model uncertainty than LSA. GSA is not highly affected by data variability, and factor interactions are explicitly considered and visible. Assessing data that are naturally highly variable in space and time such as soil loss (Nearing et al., 1999), with statistical methods sensitive to data variability may lead to inaccurate results. Finally, consistent results obtained in the GSA were due to the method's capacity to capture a broader range of model sensitivities and interactions among model factors and parameters (Wagner, 1995). Both of these are key characteristics to understand better and parameterize empirical models (Harper et al. 2011).

6.3. Management implications.

Our GSA results further underline two key points in soil loss management across environments. The cover management factor is the most important factor in RUSLE and much of the soil loss occurs in a limited area of the watershed. These findings are important because cover management is the only factor that can be easily manipulated to reduce soil loss from agricultural lands (Shi et al., 2012) and reduce sediment accumulation in downstream reservoirs (Estrada-Carmona and DeClerck, 2011). The consistency across databases on most of the soil loss coming from a small portion of the landscape, reinforces the need to implement targeted soil conservation interventions where the location and the rate of soil control can be assessed to improve ecosystem service-based interventions (Fremier et al., 2013).

Finally, the creation of a theoretical dataset might help to provide information about the most important factor interactions, and even information at the parameter level, particularly in those areas with poor or no site specific data. This will help to provide insights on the most important parameters to guide management changes. For example, our results from the theoretical dataset indicate that the mass density of live and dead roots found in the upper centimeters of soil and the percentage of land area with surface cover as the most important parameters in determining soil loss. Multiple studies report similar findings where an increase of the root density and surface cover were demonstrated to be particularly efficient in controlling soil loss (Linse et al., 2001; Gyssels et al., 2005; De Baets et al., 2006).

7. Conclusion

We assessed RUSLE behavior and factor contributions to model uncertainty under different environmental conditions and compared global and local sensitivity analyses. The GSA approach is an informative procedure for identifying sources of model uncertainty, mainly because it captures interactions amongst factors and it is little affected by data variability. The application of a GSA before final model parameterization will help constrain model uncertainty and focus resources and efforts on parameterizing the most important factors. Our datasets from different environmental conditions indicate that the cover management factor is the most important factor in RUSLE and much of the soil loss occurs on a limited area of the watershed. However, the importance of other RUSLE factors varies across environmental contexts.

8. References

Benkobi, L., Trlica, M.J., Smith, J.L., 1994. Evaluation of a Refined Surface Cover Subfactor for Use in RUSLE. Journal of Range Management 47 (1), 74-78.

Bewket, W., Teferi, E., 2009. Assessment of soil erosion hazard and prioritization for treatment at the watershed level: case study in the Chemoga Watershed, Blue Nile Basin, Ethiopia. Land Degradation & Development 20, 609–622.

Biesemans, J., Van Meirvenne, M., Gabriels, D., 2000. Extending the RUSLE with the Monte Carlo error propagation technique to predict long-term average off-site sediment accumulation. Journal of Soil and Water Conservation 55 (1), 35-42.

Bilotta, G.S., Grove, M., Mudd, S.M., 2012. Assessing the significance of soil erosion. Transactions of the Institute of British Geographers 37, 342–345.

Boix-Fayos, C., Martínez-Mena, M., Arnau-Rosalén, E., Calvo-Cases, A., Castillo, V., Albaladejo, J., 2006. Measuring soil erosion by field plots: Understanding the sources of variation. Earth-Science Reviews 78, 267–285.

Breiman, T., Cutler, A., 2012. Package " randomForest ", p. 29 (http://cran.r-project.org/web/packages/randomForest/randomForest.pdf).

Bryan, R.B., 2000. Soil erodibility and processes of water erosion on hillslope. Geomorphology 32, 385–415.

Burke, L., Sugg, Z., 2006. Hydrologic Modeling of Watersheds Discharging Adjacent to the Mesoamerican Reef, Development. World Resources Institute (WRI), p.40 (http://eprints.eriub.org/24/1/MAR_Hydrologic_Model_Results_-_English.pdf).

Cutler, D.R., Edwards, T.C., Beard, K.H., Cutler, A., Hess, K.T., Gibson, J., Lawler, J.J., 2007. Random forests for classification in ecology. Ecology 88(11), 2783–2792.

De Baets, S., Poesen, J., Gyssels, G., Knapen, A., 2006. Effects of grass roots on the erodibility of topsoils during concentrated flow. Geomorphology 76, 54–67.

Eslinger, D. L., Carter, H. J., Dempsey, E., VanderWilt, M., Wilson, B., Meredith, A. 2005. The Nonpoint Source Pollution and Erosion Comparison Tool (NSPECT). Systems Research. Charleston, South Carolina: NOAA Coastal Services Center, p. 42 (http://www.csc.noaa.gov/digitalcoast/tools/opennspect).

Estrada-Carmona, N., Declerck, F., 2012. Payment for Ecosystem Services for Energy , Biodiversity Conservation , and Poverty Reduction in Costa Rica. In: J.C. Ingram, F. Declerck, and C. Rumbaitis-del Rio, (Eds.), Integrating Ecology and Poverty Reduction: The Application of Ecology in Development Solutions. Springer, New York, pp. 191–210.

Falk, M.G., Denham, R.J., Mengersen, K.L., 2009. Estimating Uncertainty in the Revised Universal Soil Loss Equation via Bayesian Melding. Journal of Agricultural, Biological, and Environmental Statistics 15(1), 20–37.

FAO. 1989. Evaluación de los estados de la erosión hídrica de los suelos en Costa Rica (Assessment of soil erosion by water in Costa Rica). Informe técnico Nº2. Programa de cooperación FAO/Italia. Roma.

Ferreira, V.A., Weesies, G.A., Yoder, D.C., Foster, G. R., Renard, K.G., 1995. The site and condition specific nature of sensitivity analysis (RUSLE). Journal of Soil and Water Conservation 50(5), 493.

Flanagan, D.C., Nearing, M.A., 1995. USDA-Water Erosion Prediction project: Hillslope profile and watershed model documentation. NSERL Report no. 10, USDA-ARS National Soil Erosion Research Laboratory. West Lafayette, IN 47097- 1196 (http://www.ars.usda.gov/Research/docs.htm?docid=18073).

Fremier, A.K., DeClerck F.A.J., Bosque-Pérez, N.A., Estrada-Carmona, N, Hill, R, Joyal, T, Keesecker, , L., Klos, P.Z. , Martínez-Salinas, A., Niemeyer, R., Sanfiorenzo, A. , Welsh, K., and Wulfhorst, J.D. 2013. Understanding spatiotemporal lags in ecosystem services to improve incentives. BioScience 63(6): 472-482.

Gaffer, R.L., Flanagan, D.C., Denight, M.L., Engel, B. A., 2008. Geographical information system erosion assessment at a military training site. Journal of Soil and Water Conservation 63(1), 1–10.

Gardiner, E.P., Meyer, J.L., 2001. Sensitivity of RUSLE to data resolution: modeling sediment delivery in the upper little Tennessee river basin. In: Hatcher, K.J. (Ed.), Water Resources Conference. Institute of Ecology. University of Georgia, Georgia, pp. 561–565.

Gómez Delgado, F., 2002. Evaluación de la erosión potencial y producción de sedimentos en tres cuencas de Costa Rica (Assessment of the potential erosion and sediment production in three Costa Rican watersheds). Engineer Degree, Costa Rican University, Costa Rica.

Gyssels, G., Poesen, J., Bochet, E., Li, Y., 2005. Impact of plant roots on the resistance of soils to erosion by water: a review. Progress in Physical Geography 29(2), 189–217.

Harper, E.B., Stella, J.C., Fremier, A.K., 2011. Global sensitivity analysis for complex ecological models: A case study of riparian cottonwood population dynamics. Ecological Applications 21(4), 1225–1240.

Hoyos, N., 2005. Spatial modeling of soil erosion potential in a tropical watershed of the Colombian Andes. Catena 63, 85 – 108.

Lal, R., 2001. Soil degradation by erosion. Land Degradation & Development 12(6), 519–539.

Linse, S.J., Mergen, D.E., Smith, J.L., Trlica, M.J., 2001. Upland Erosion under a Simulated Most Damaging Storm. Journal of Range Management 54(4), 356.

Lu, D., Li, G., Valladares, G.S., Batistella, M., 2004. Mapping soil erosion risk in Rondônia, Brazilian Amazonia: using RUSLE, remote sensing and GIS. Land Degradation & Development 15(5), 499–512.

Marchamalo Sacristian, M., 2004. Ordenación del territorio para la producción de servicios ambientales hídricos . Aplicación a la cuenca del Río Birrís (Costa Rica) (Land planning for the provisioning of hydrological environmental services: An application in the Birrís River, Costa Rica). PhD Dissertation. Escuela Técnica Superior de Ingenieros de Montes, Spain.

McCool, D.K., Foster, G.R., Yoder, D.C., 1997. Slope length and steepness factor (LS). In: K.G. Renard, G.R. Foster, G.A. Weesies, D.K. McCool, and D.C. Yoder, Predicting soil erosion by water: a guide to conservation planning with the Revised Universal Soil Loss Equation (RUSLE). U. S. Department of Agriculture, Agriculture Handbook No. 703. Washington, D.C., pp. 404.

Morgan, R.P.C., Quinton, J., Smith, R.E., Govers, G., Poesen, J.W.A., Auerswald, K., Chisci, G., Torri, D., Styczen, M.E., 1998. The European Soil Erosion Model (EUROSEM): A dynamic approach for predicting sediment transport from fields and small catchments. Earth Surface Processes and Landforms 23, 527–544.

Mueller, T.G., Cetin, H., Fleming, R.A., Dillon, C.R., Karathanasis, A.D., Shearer, S.A., 2005. Erosion probability maps : Calibrating precision agriculture data with soil surveys using logistic regression. Journal of Soil and Water Conservation 60(6), 462-468.

Mutua, B.M., Klik, A., Loiskandl, W., 2006. Modeling soil erosion and sediment yield at a catchment scale: the case of Masinga catchment, Kenya. Land Degradation & Development 17, 557–570.

Nash, J.E., Sutcliffe, J.V., 1970. River flow forecasting through conceptual models part I — A discussion of principles. Journal of Hydrology 10, 282-290.

Nearing, M.A., Govers, G., Norton, L.D., 1999. Variability in Soil Erosion Data from Replicated Plots. Soil Science Society of America Journal 63, 1829–1835.

Nearing, M.A., Romkens, M.J.M., Norton, L.D., Stott, D.E., Rhoton, F.E., Laflen, J.M., Flanagan, D.C., Alonso, C. V, Binger, R.L., Dabney, S.M., Doering, O.C., Huang, C.H., Mcgregor, C., Simon, A., 2000. Measurements and Models of Soil Loss Rates of Soil Loss. Science New Series 290(5495), 1300–1301.

Nelson, E., Mendoza, G., Regetz, J., Polasky, S., Tallis, H., Cameron, Dr., Chan, K.M., Daily, G.C., Goldstein, J., Kareiva, P.M., Lonsdorf, E., Naidoo, R., Ricketts, T.H., Shaw, M.R., 2009. Modeling multiple ecosystem services, biodiversity conservation, commodity production, and tradeoffs at landscape scales. Frontiers in Ecology and the Environment 7(1), 4–11.

Pang, H., Lin, A., Holford, M., Enerson, B.E., Lu, B., Lawton, M.P., Floyd, E., Zhao, H., 2006. Pathway analysis using random forests classification and regression. Bioinformatics (Oxford, England) 22(16), 2028–36.

Pedroni, L., 2003. Improved classification of Landsat Thematic Mapper data using modified prior probabilities in large and complex landscapes. International Journal of Remote Sensing 24(1), 91–113.

Pelacani, S., Märker, M., Rodolfi, G., 2008. Simulation of soil erosion and deposition in a changing land use: A modeling approach to implement the support practice factor. Geomorphology 99, 329–340.

Pimentel, D., Harvey, C., Resosudarmo, P., Sinclair, K., Kurz, D., McNair, M., Crist, S., Shpritz, L., Fitton, L., Saffouri, R., Blair, R., 1995. Environmental and economic costs of soil erosion and conservation benefits. Science 267, 1117–23.

R Core Team, 2012. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0 (http://www.R-project.org/).

Ranzi, R., Le, T.H., Rulli, M.C., 2012. A RUSLE approach to model suspended sediment load in the Lo river (Vietnam): Effects of reservoirs and land use changes. Journal of Hydrology 422-423, 17–29.

Rapp, J.F. 1994. Error assessment of the Revised Universal Soil Loss Equation using natural runoff plot data. M.S. Thesis. School of Renewable Natural Resources, Univ. of Arizona, Tucson, AZ.

Renard, K.G., Ferreira, V.A., 1993. RUSLE Model description and database sensitivity. Journal of environmental quality 22(3), 458–466.

Renard, K.G., Foster, G.R., Weesies, G.A., McCool, D.K., Yoder, D.C., 1997. Predicting soil erosion by water: a guide to conservation planning with the Revised Universal Soil Loss Equation (RUSLE) U. S. Department of Agriculture, Agriculture Handbook No. 703. Washington, D.C., pp. 404.

Risse, L.M., Nearing, M.A., Nicks, A.D., Laflen, J.M., 1993. Error assessment in the Universal Soil Loss Equation. Soil Science Society of America Journal 57(3), 825–833.

Saltelli, A., Tarantola, S., Chan, K., 1999. A Quantitative Model-Independent Method for Global Model Sensitivity Analysis of Model Output. Technometrics 41(1), 39–56.

Schuler, J., Sattler, C., 2010. The estimation of agricultural policy effects on soil erosion—An application for the bio-economic model MODAM. Land Use Policy 27, 61–69.

Schwilch, G., Hessel, R., & Verzandvoort, S. (Eds.). (2012). Desire for Greener Land. Options for sustainable land management in drylands. Bern, Switzerland adn Wageningen, The Netherlands: SRIC - World Soil Information and CTA - Technical Centre for Agricultural and Rural Cooperation. Retrieved from https://www.wocat.net/fileadmin/user_upload/documents/Books/DESIRE_BOOK_low_resolution.pdf

Shi, Z.H., Ai, L., Fang, N.F., Zhu, H.D., 2012. Modeling the impacts of integrated small watershed management on soil erosion and sediment delivery: A case study in the Three Gorges Area, China. Journal of Hydrology 438-439, 156–167.

Sobol′, I., 2001. Global sensitivity indices for nonlinear mathematical models and their Monte Carlo estimates. Mathematics and Computers in Simulation 55, 271–280.

Therneau, T.M., Atkinson, B., 2011. Package “ rpart ” Source (http://cran.r-project.org/web/packages/rpart/rpart.pdf).

Tiwari, A.K., Risse, L.M., Nearing, M.A., 2000. Evaluation of WEPP and its comparison with USLE and RUSLE. American Society of Agricultural Engineers 43(5), 1129–1135.

Van Remortel, R., Maichle, R.W., Hickey, R.J., Remortel, R.D. Van, 2004. Computing the LS factor for the Revised Universal Soil Loss Equation through array-based slope processing of digital elevation data using a C ++ executable. Computers & Geosciences 30, 1043–1053.

Wagner, H.M., 1995. Global sensitivity analysis. Operations research 43(6), 948–969.

Wang, G., Gertner, G., Anderson, A.B., Howard, H., Gebhart, D., Althoff, D., Davis, T., Woodford, P., 2007. Spatial variability and temporal dynamics analysis of soil erosion due to military land use activities : uncertainty and implications for land management. Land Degradation & Development 18, 519–542.

Waylen, P.R., Quesada, M.E., Caviedes, C.N., 1996. Temporal and Spatial Variability of Annual Precipitation in Costa Rica and the Southern Oscillation. International Journal of Climatology 16, 173–193.

Wischmeier, W.H., Smith, D.D., 1978. Predicting rainfall erosion losses a guide to conservation planning. U. S. Department of Agriculture, Agriculture Handbook No. 537, pp. 69.

Yang, D., Kanae, S., Oki, T., Koike, T., Musiake, K., 2003. Global potential soil erosion with reference to land use and climate changes. Hydrological Processes 17, 2913–2928.

Zhang, R., Liu, X., Heathman, G.C., Yao, X., Hu, X., Zhang, G., 2013. Assessment of soil erosion sensitivity and analysis of sensitivity factors in the Tongbai–Dabie mountainous area of China. Catena 101, 92–98.

CHAPTER 4: PREVENTION IS BETTER THAN CURE: IMPLEMENTING SOIL CONSERVATION PRACTICES MAY BE CHEAPER THAN DREDGING

Natalia Estrada-Carmona, Fabrice DeClerck, Alexande K. Fremier

1. Abstract

Assessing changes in the provisioning of ecosystem services (ES) due to changes in agroecosystem management will better inform Costa Rican PES escheme. This scheme is recognizing the role of agroecosystem as ES providers, still an assessment of the provisioning of ES by implementing ideal cropping systems (combination of at least two or three soil conservation practices) rather than only spread trees is missing. One of the most critical ES provided in agroecosystems is soil retention, this ES have on-site benefits for the farmer and off-site benefits for downstream consumers such as hydropower companies. We estimated changes on soil retention ES by implementing ideal cropping systems in three of the most important basins for hydropower and agricultural production in the Upper-Middle Reventazon watershed in Costa Rica. We tested three targeting strategies, four budgets allocations and compared the avoided cost of dredging the retained soil with current dredging cost. We quantified the provision of the soil retention ES using the Integrated Valuation of Environmental Services (InVEST). We used the Tradeoffs and the Resources Investment Optimization System (RIOS) to test our three targeting strategies: (1) RIOS default optimization, (2) RIOS constrained to current land uses in conflict with soil legislation and (3) RIOS constrained to erosive crops and crops on steep slopes. The tested budget included the lowest budget allocated in the watershed for soil conservation programs in the past up to the maximum amount it will be requiered to implement ideal cropping systems across all the agricultural land. Our results indicate that targeting efforts on erosive crops or crops on steep slopes will likely provide the highest cost-effectiveness investment scenario, or in other words, the highest soil retention per dollar spent. Under this particular targeting strategy, investments in ideal cropping systems may be more cost effective than dredging sediment from the downstream

reservoirs, given our modeling assumptions. Our modeling strategy, offers a conservative and simple but robust first approximation to a methodology that can be adapted and modeled iteratively to assess ES provisioning due to changes in agroecosystems management.

2. Introduction

Agroecosystems production and sustainability along with forest conservation should be top priorities for Costa Rica (Hall et al., 2000). Approximately 35% of Costa Rica land for food production has poor management practices (Vignola et al., 2010; CADETI, 2004). Poor management practices impacts the national economy with an estimated reduction of 7.7% of the agriculture gross domestic product due to soil erosion and nutrient depletion (MINAE 2002). Costa Rica consumes 4-8 times more fertilizers, particularly nitrogen and potash, than the average Latin America country (FAO, 2013). High amounts of fertilizers are required to compensate for the high erosion rates that probably are exceeding soil formation rates in most of the agricultural land (Rubin & Hyman, 2000). In addition to the loss of crop productivity from soil loss, the transport and accumulation of sediment has further economic implication for downstream reservoirs for hydropower (Vignola et al., 2008). Hydropower is the main source of energy in Costa Rica, constantly challenged by the high sediment loads and pollution into upstream reservoirs (Haun et al., 2013; Brandt & Swenning, 1999). Besides, high sediment loads reduce the life span of dams by rapid infilling (Haun et al., 2013). Pollution (source and non-source) from agriculture production affects water quality, riparian habitats and aquatic communities (Echeverría-Sáenz et al., 2012).

Efforts to protect soil (and the services it provides) are weaker than the efforts to protect forest cover (and the services it provides) in Costa Rica. Forest cover area in Costa Rica is slightly increasing (FAO, 2013) while soil is being depleted (MINAE 2002). The increase of forest cover is due to a combination of factors such as the creation and enforcement of the Forestry Law 7575 in 1997 which forbids deforestation while promotes incentive-based conservation via payment for environmental services (PES) schemes; besides other external factors such as the increase of ecotourism and the reduction of cattle ranch profitability (Robalino & Pfaff, 2013). The Soil Law 7779 created in 1998 has a poor enforcement that has led to poor conditions, law inconsistencies and constrained budgets that weakened agricultural extension offices, key organizations transmitting information, technology and sustainable soil conservation practices (Vignola et al., 2013; Vignola et al., 2010). Hydropower companies, an industry highly dependent and affected by water quality, has been also promoting environmental education (Blackman & Woodward, 2010), supporting soil conservation management (Vignola et al., 2012) and supporting watershed management plans (PREVEDA, 2008) to increase soil retention at the source. Also, major voluntary or non-voluntary (tax payments) investments to fund the PES scheme comes from hydropower companies to improve the provision of hydrological services and extend the life span of the dams: but most importantly to improve their relationship with local stakeholders (Blackman & Woodward, 2010).

Payment for ecosystem services (PES) scheme goals is to increase national forest cover to generate multiple ecosystem services (ES), such as hydrological services (particularly water quality), scenic beauty, carbon sequestration, and biodiversity (Pagiola, 2008). The PES scheme provides funds for forest protection, forest management, reforestation, and, recently, agroforestry. The recognition of agroforestry (only trees within agricultural land) in the Costa Rican PES scheme was an important step towards recognizing the role agroecosystems as ES providers. The total land area covered with PES for agroforestry has increased from 2% in 2003 to 12% in 2011 (FONAFIFO, 2014). Despite this increase, we still lack a quantified understanding of which practices guarantee ES provisioning at the site level and how site level implementations across a watershed improve larger scale services in agroecosystems, such as soil retention. Design efficacy and site prioritization of agroforestry practices becomes key component in designing PES programs that get what they pay for.

To curb soil loss from agroecosystems, many conservation practices (not only spread trees as current PES scheme) have proven to increase farm productivity while improving soil retention and water quality (Dogliotti et al., 2013; Lenka et al., 2012; WOCAT, 2012; Cocchi & Bravo-Ureta, 2007; Alegre, & Rat, 1996). In Honduras, ground-cover technologies such as crop-mulch/residue management, green manure and conservation tillage led to an increase of farm income up to 20% (Cocchi & Bravo-Ureta, 2007). While in Chile, multi-year planning and farm redesign halved soil erosion rates (Dogliotti et al., 2013). Past experiences studying a PES scheme on degraded pastures in Costa Rica, Nicaragua and Colombia, indicated that implementing both, high density of trees and shrubs, improved rangeland productivity, biodiversity, carbon sequestration and water quality (Pagiola et al., 2005; Garbach et al., 2012). However, potential negative effects such as competition for nutrients and light, increase of diseases and seedlings suppression should also considered in full cost-benefit analyses (Alegre, & Rat, 1996). Vegetative conservation practices offer diverse ES and are as effective as physical or structural practices (particularly retaining soil) but are more cost-effective and more flexible (Bravo-Ureta et al., 2006; Maetens et al., 2012).

Farmer's voluntary implementation of conservation practices is limited by short-term needs, lack of information and lack of resources (Vignola et al., 2010). In addition, masking factors such as external inputs, soil deposition, deep soils and everyday contact also limits voluntary implementation (Lal, 2001, Vignola et al., 2012). However, a recent research in one of the most erosive and hydrological important watershed in Costa Rica indicated that farmers (ES providers) and hydropower companies (ES consumers) agreed on the need to change existent conditions in terms of land use and management towards a more sustainable (Vignola et al., 2008). Local stakeholders highlighted that efforts to promote the desired change should be targeted to high priority areas (Vignola et al., 2012).
To define which targeting strategy will be the most cost-effective, we used a coupled economic and soil loss model to evaluate multiple strategies for reducing soil loss and compared these estimates to the costs of dredging three reservoirs in the upper and middle part of the Reventazon River, Costa Rica. We estimated the effect of implementing soil conservation practices as a strategy to provide the ES soil retention under three targeting strategies and three budget levels. We were particularly

interested on two key questions. First, which targeting strategies, investment distribution and budget is the most effective to provide the ES soil retention? Second, at which point investments to provide the ES soil retention are cheaper than the cost dredging? To answer both questions, we conducted a literature review to select the most suitable practices according to the agroecological and productive conditions of the study area. We also conducted a meta-analysis to estimate the efficacy of each practice retaining soil. The Integrated Valuation of Environmental Services and Tradeoffs (InVEST) help us to estimate soil retention under current and the different targeting strategies at the watershed scale. And, we used the Resources Investment Optimization System (RIOS) tool to test three targeting strategies. Though excluded from our analysis all the transaction costs associated with implementation, we focused on establishment and maintenance cost of the soil conservation practices.

3. Methodology

3.1. Study area

The upper and middle part of the Reventazon watershed has an area of 139,644 ha and generates approximately 38% of the national energy, 25% of the consumed water in San José and 11% of the agricultural products for exportation (ProDUS, 2011). Our analysis covers the drainage area of three of the most important dams within the Reventazon: Cachi, Angostura and Birris (Table 4; Figure 15). In 2000, the government created legislation (Law Nº 8023, 2000) to regulate and promote the sustainable management of the watershed due to its importance to the national economy. The upper and middle part of the watershed developed a management plan to improve local capacity, risk management, environmental education and soil conservation particularly on highly erosive basins (PREVEDA, 2008). These efforts to reduce soil loss have had only marginal impacts and the watershed still has high level of erosion and pollution (PREVEDA, 2008).

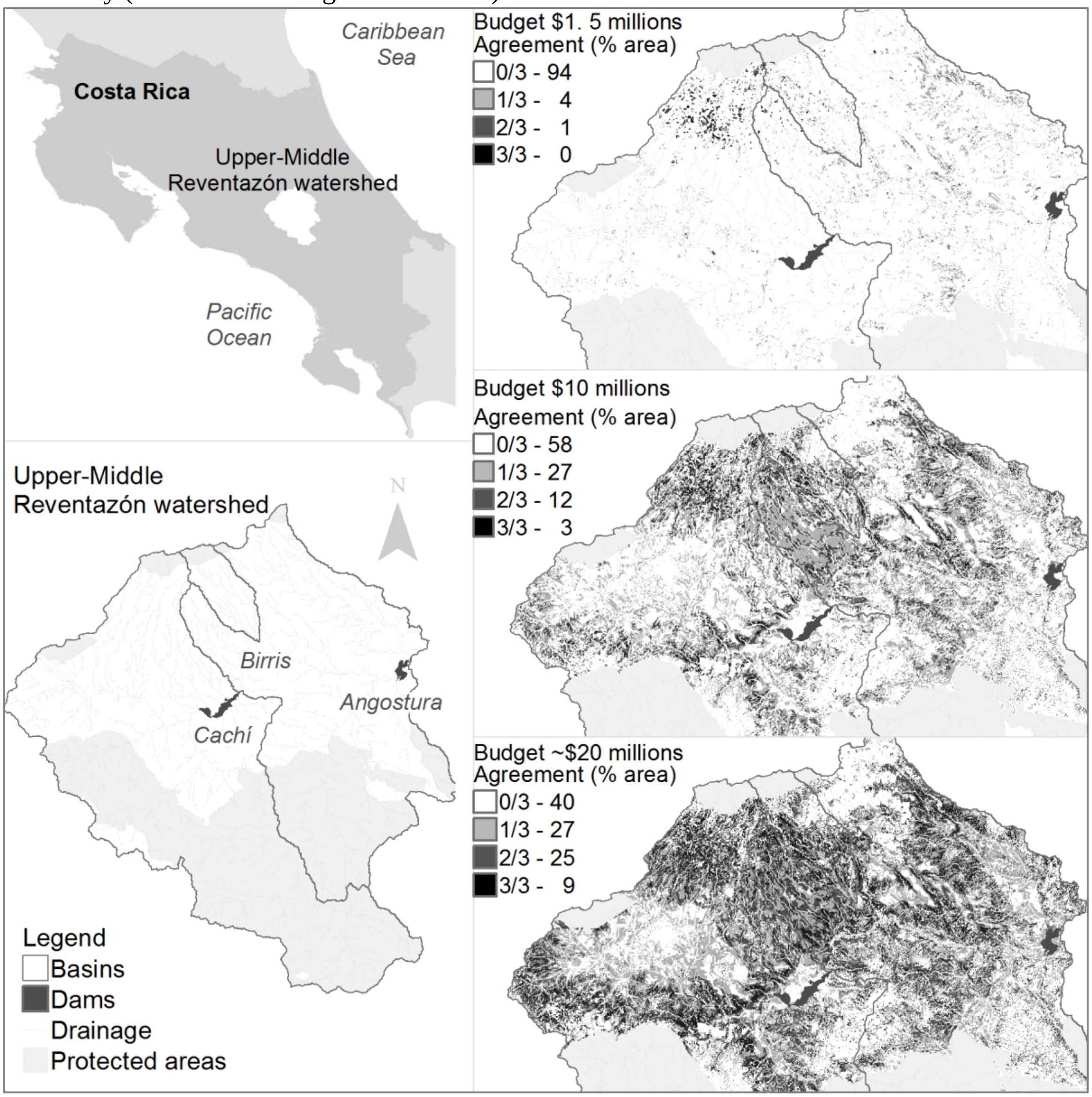
Table 4. Characteristics of the assessed dams in the Reventazon watershed. Assessment accuracy based on the comparison between the reported sediment yield to each reservoirs and the estimated exported sediment with InVEST.

	Starting	Current production (projected)	Capacity	Removal cost	Sediment yield	InVEST Exported Sediment	Accuracy Assessment		
							Sediment delivery ratio	Reported Soil loss	Estimated Soil loss
Dam/ Reservoir	year	MW	$millions \cdot m^3$	$\$millions \cdot y^{-1}$	$\$millions \cdot y^{-1}$	$\$millions \cdot y^{-1}$		$t \cdot ha^{-1}$	$t \cdot ha^{-1}$
Cachi/ ICE	1966	100 (160)	48*		1,1	3.5	0.32	26***	14
Birris/ JACEC	1990	4.3(13.6)			0.2	0.6	0.28	42***	42
Angostura/ ICE	2000	177	10.7**		1,5**	5.5	0.27	26****	26
Total				>2-4	2.8				

JASEC: Junta Administrativa del Servicio Eléctrico Municipal de Cartago
ICE: Instituto Costarricense de Electricidad
*The original volume is $54Mm^3$, however, the latest estimation in 1993 indicated a volume loss of 11% of the original volume (Jiménez-Ramírez and Rodríguez-Mesa, 1992)
**The original volume is $11Mm^3$, however, after two years of functioning the dam lost 2.5% of the original volume (Jiménez-Ramírez and Rodríguez-Mesa, 1992)
***Marchamalo (2004); Abreu (1994)
**** Vignola et al., (2010)

The Reventazon watershed is located on the Caribbean side of the Costa Rica mountain range (Figure 15), with annual precipitations ranging from 1,551 to 6,303 mm·y-1 with an average of 2,955 mm·y-1. The watershed is characterized by steep slopes in the upper and middle part of the watershed of altitudes ranging from 449 to 3,475 m.a.s.l and with an average slope of 21° (slope 37.5%). The watershed is largely covered with forest (51% of the total area), perennial crops (25%), pasture (16%) and semi-perennial and annual crops (5%). Coffee and sugarcane are the dominant perennial and semi-perennial crops. Forest cover has been constant through time the Reventazon watershed, but pastures, urban and sugarcane areas are increasing by replacing coffee and shrubland areas (Brenes, 2009).

Figure 15. The left panel shows the location of the Upper – Middle Reventazon watershed and the drainage area of the dams. The right panel shows the distribution of the targeted areas and the level of agreement across the three targeting strategies: 1) RIOS, 2) RIOS&Legislation and 3) RIOS&C-S. The level of agreement indicates which areas were targeted (or not) by the strategies. For example, with a budget of $1.5 millions, ninenty four percent of the area was excluded from all three targetting strategies to implement ideal croping systems and, all the three strategies allocated the budget differently (3/3 – 0% of the agricultural land).

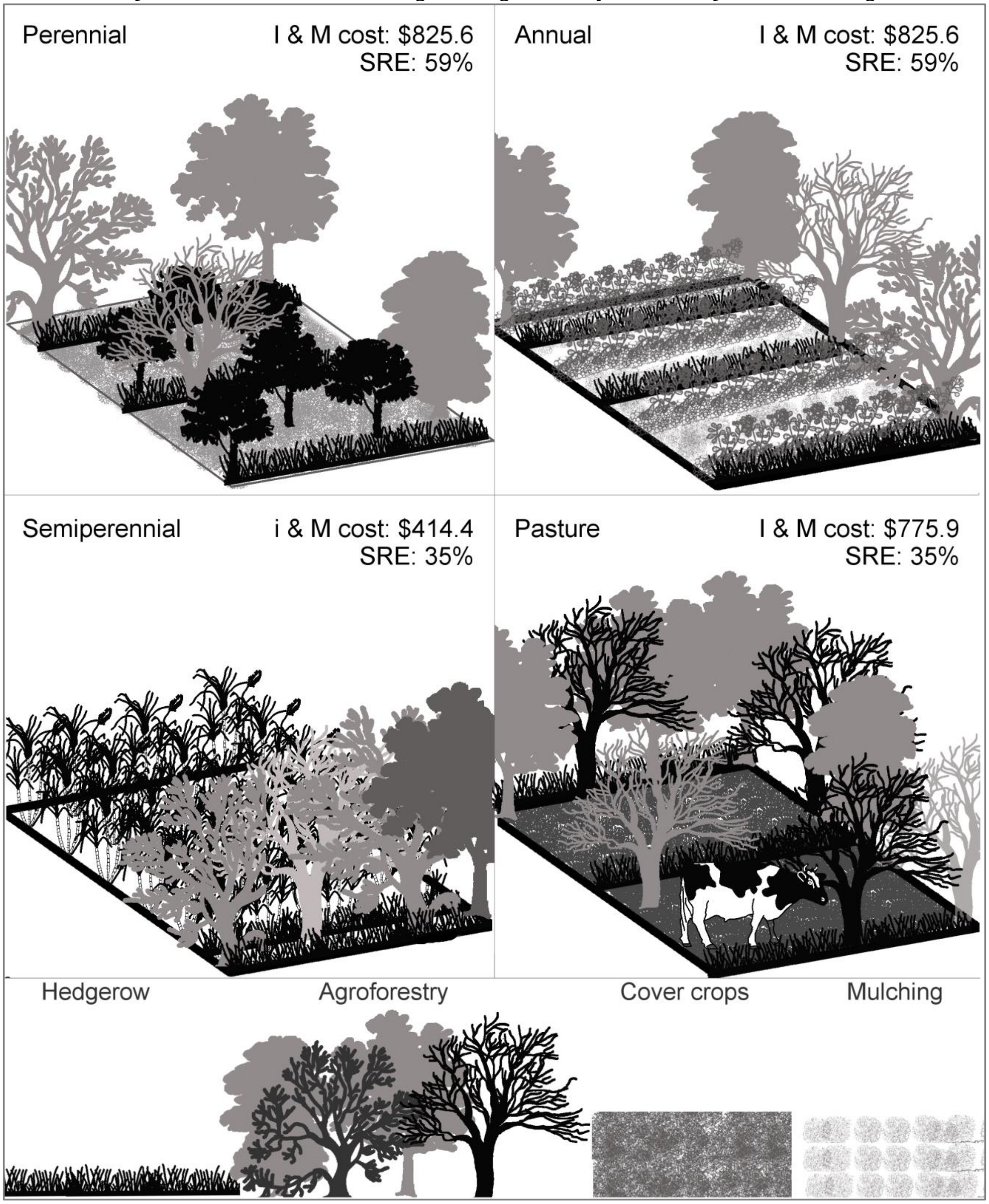


3.2. Activities: Ideal cropping systems – coupled soil conservation practices

Agroforestry is supported by the PES scheme to increase the number of trees within agricultural land (FONAFIFO, 2014). Spread trees can particularly provide ES such as scenic beauty, carbon sequestration and biodiversity (Harvey et al., 2006; Perfecto et al., 2008). However, to particularly provide hydrological services, other soil conservation practices should be considered. In this modeling effort, we incorporated other vegetative soil conservation practices that minimize soil loss and maintain agricultural production, with lower implementation cost than engineered structures (Bravo-Ureta et al., 2006; Maetens et al., 2012). For each selected soil conservation practice we completed a literature review to list the pros and cons (Supplemental Material I) and to estimate the cost of implementation and the soil retention efficiency (Figure 16).

The Program for Sustainable Agriculture in Steep-lands in Central America (PASOLAC) systematized, revised and validated promising soil conservation practices using Honduras, Nicaragua and El Salvador farmers, technicians and organizations' knowledge and experience (PASOLAC, 2000). We used this dataset and selected the most suitable soil conservation practices for the agroecological and production conditions of the Reventazon. Four main soil conservation practices were selected: mulch, herbaceous hedgerows, agroforestry systems (low and high density) and cover crops or intercropping (Figure 16). In the Reventazon watershed farmers are already familiar with these selected practices (Vignola et al., 2010) which are actively being promoted by the watershed management plan (COMCURE, 2009). In our analysis we also assessed the combined effect of coupling multiple of the soil conservation practices (termed ideal cropping systems). Coupled practices were based on previous research (WOCAT, 2012; Vignola et al., 2010; Raudes & Sagastume 2009; COMCURE, 2009; FAO 2000 and 2001,) (Figure 16).

Figure 16. Ideal cropping systems or activities implementation and maintenance cost per hectare (I & M) estimated as the sum of each soil conservation practices implementation and maintenance cost (**¡Error! No se encuentra el origen de la referencia.**). Soil retention efficacy (SRE) estimated as the sum of the minimum reported efficacy for each soil conservation practice. Legend of the soil conservation practices at the bottom: Hedgerow, agroforestry, cover crops and mulching.



Each soil conservation practice has important pros and cons, and factors that limit their efficacy trapping soil and the adoption by individual farmers (**¡Error! No se encuentra el origen de la referencia.**). For example, soil conservation practices might limit the ability of machinery to enter the field or a practice could increase crop management complexity or increase shade area thereby increase pest risk (Raudes & Sagastume 2009). In addition, the specific crop, be it annual, perennial or semi-perennial, impacts the possible combinations of soil conservation practices. For example, burning is practiced in the region to harvest sugar cane (semi-perennial); therefore, hedgerows with trees in lineal arrangement are advocated over intermixed plantings. We considered these factors to design our ideal cropping systems and to model the effect of implementing those as a strategy to minimize soil loss. For example, cover crops or mulch will protect the soil from detachment, but if detached, hedgerows downslope will potentially retain it and agroforestry systems will promote deeper roots and grater infiltration rates (Supplemental Material I). We implemented ideal cropping systems on current perennial, annual, semi-perennial and pasture land cover types. But, we implemented reforestation with endangered tree species on bare soil cover type rather ideal cropping systems.

Implementation and maintenance cost for each one of the soil conservation practices were adopted from PASOLAC (2000) and updated to Costa Rican wages and prices (**¡Error! No se encuentra el origen de la referencia.**). Seed costs were obtained from a tropical research center in Costa Rica (CATIE) seed bank prices and the cost of the tree seed species correspond to the tree endangered species promoted according to Costa Rican legislation. The cost of implementing hedgerow increases with the slope steepness, so we estimated the total cost for each ideal cropping as the sum of each soil conservation practice cost on level (<15%), moderate (15-30%) and steep (>30%) slopes and used the averaged total cost across slope steepness (**¡Error! No se encuentra el origen de la referencia.**). The cost of reforestation with endangered tree species equals the payment that FONAFIFO is currently (2014) assigning to this activity ($1,470). Our cost of implementing and maintaining ideal cropping systems do not include cost associated with running and maintaining a PES program. This includes transaction, training and opportunity costs. Targeting efforts to a small portion of the landscape will decrease transaction and monitoring costs, yet without a quantification of these costs, this analysis should not be considered a complete program analysis (Garrick et al., 2013).

The soil retention efficacy by each conservation practice and coupled practices were estimated from a meta-analysis. We searched in ScienceDirect using keywords such as "mulch" & "soil loss", “cover crops" & "soil loss", "hedgerow" & "soil loss" and "agroforestry" & "soil loss". We found 30 articles and 105 observations that reported the soil retention efficacy of specific soil conservation practices (the difference in measured soil loss with and without the soil conservation practice; 0% no retention and 100% maximum retention) (**¡Error! No se encuentra el origen de la referencia.**). We performed an analysis of variance (ANOVA) to test differences in soil retention efficacy between practices across slope ranges. The ANOVA indicated that agroforestry and agroforestry combined with hedgerow have significantly lower soil retention efficacy (36% and 43%, respectively) (p-value = 0.042). There were no significant differences between the other practices and at the different slopes categories.

We use a conservative method to estimate the soil retention efficacy of each soil conservation practices and ideal cropping systems due to the high variability among experiments and the lack of clear trends. We used the minimum reported value across the 105 observations for each practice (**¡Error! No se encuentra el origen de la referencia.**). We assumed that the interaction and retention efficacy among soil conservation practices in the ideal cropping system was additive; and therefore, we estimated the total soil retention efficacy of each ideal system as the sum of the minimum reported soil retention for each soil conservation practice (Figure 16, **¡Error! No se encuentra el origen de la referencia.**). In this study we only assessed soil retention as an ES; however, vegetative practices can also improve water regulation, nutrient cycling and biological control among other ES at the plot scale (Comerford et al., 2013). At larger scales, increase forest cover can improve habitat connectivity (Martínez-Salinas

& DeClerck, 2010), food security and human nutrition (DeClerck et al., 2011) and reduce vulnerability to extreme events (Altieri, 2002; Holt-Giménez, 2002).

3.3. Tools: Integrated Valuation of Environmental Services and Tradeoffs (InVEST) and Resources Investment Optimization System (RIOS)

Our metric for ecosystem service provision was soil retention, or in other words, the reduction of the exported soil off site by implementing the ideal cropping systems, estimated with InVEST and RIOS. InVEST and RIOS were developed by the Natural Capital Project and are complementary tools to assess ecosystem services. InVEST determines the quantity or presence of an ecosystem service; while RIOS identifies priority areas where changes on land use management to protect or restore an ecosystem service are potentially more cost-effective (Sharp et al., 2013; Vogl, et al., 2013). Soil retention was estimated as the difference between the estimated exported soil with InVEST under current conditions and the three targeting strategies we explored using also three budget levels with RIOS, over the current conditions' exported soil. Our analysis only included agricultural lands available to ideal cropping systems (53% of the watershed [73,441 ha] area). For instance we excluded protected areas, forest, urban, or water bodies, as well as areas classified as clouds or shadows.

RIOS identifies the areas that are more cost-effective retaining soil by combining information about the user desired activities (i.e. soil conservation practices), the cost of implementing each activity, the user´s available budget and the critical factors determining potential effectiveness retaining soil such as the contributing area, crop management (Factor C), riparian continuity restoration among others (Table 5) (Vogl et al., 2013). The critical factors determining soil loss come from a detailed review of literature and hydrological experiments and models; however, the user can modify the goal and weight of each critical factor according to local conditions (maximize or minimize), exclude factors from the analysis or use the defaults values as we did (Table 5) (Vogl et al., 2013). RIOS scores each pixel potential effectiveness for retaining soil as the weighted sum of each one of the critical factors values per activity (i.e. Figure 16), then, the cost of an activity is assigned to each pixel for all the included activities. This is done to allocate the budget yielding the biggest return on investment; therefore, the priority areas for an activity will potentially yield the greatest benefit at the lowest cost (Vogl et al., 2013).

Table 5. Critical factors consider by RIOS to score each pixel's potential effectiveness retaining soil.

Category	Factors determine effectiveness	Goal	Weight	Description	Calculated from (by who):
Upslope Source Index	Upslope retention index	Maximize	1	Estimates the contributing area to a pixel and the magnitude of the contribution	Flow accumulation, pixels sediment export coefficients, retention factors, slope (RIOS)
Downslope Retention Index	Downslope index	Minimize	1	Estimates potential retention downslope of a pixel	Flow length, slope, retention factors (RIOS)
On-pixel source:	Sediment export coefficient	Maximize except for transition keep native veg (Minimize)	0.25	Factor C in USLE. Indicates the impacts of previous cropping systems, the protection offered to the soil surface by vegetative canopy, erosion reduction due to surface cover, and surface roughness	Obtained from literature review or by measuring surface cover, mass density of superficial roots, effectiveness of surface cover; mass density of incorporate surface residue, surface soil consolidation factor, surface roughness; canopy height, surface roughness, fraction of land surface covered by canopy impacts of the subsurface residues (USER)
On-pixel source:	Erosivity factor	Maximize	0.25	Factor R in USLE. Indicates the effect of raindrop impact and rate of runoff associated with rain of moderately sized storms with occasional large storms	No events per year, erosive rain Intensity (USER)
On-pixel source:	Erodibility factor	Maximize	0.25	Factor K in USLE. Reflects soil profile reaction to hydrologic processes (e.g. raindrop impact, surface flow, roughness (topographic or induced), and rain water infiltration).	Soil structure; soil permeability, organic matter, %Silt , %Very fine sand, %Clay (USER)
On-pixel source:	Soil depth	Maximize	0.25		(USER)
On-pixel retention	Sediment retention	Minimize except for transition keep native vegetation (Maximize)	0.5	Reflects the efficacy of a pixel trapping sediment and holding it	From literature review. Factor affected by land cover type and management, geomorphology, climate. (USER)
On-pixel retention	Riparian continuity	Maximize	0.5	Indicated the continuity riparian areas	DEM and land use map (RIOS)
	Beneficiaries	Maximize	1	Indicate priority areas based on the number of beneficiaries of the ES (no people) or by the amount of the service (energy produced)	(USER)

InVEST models soil retention using the Universal Soil Loss Equation - USLE (Wischmeier & Smith 1978). The USLE is an empirical but robust model that combines the effect of the characteristics of the soil (K factor), the intensity of the precipitation (R factor), conservation practices (P factor), slope steepness (S factor), slope length (L factor) and cover management (C factor) (Wischmeier & Smith 1978). The empirical equation has important limitations (Sharp et al., 2013; Estrada-Carmona et al., in review); however, it has shown to be applicable across a wide range of conditions to indicate areas of greater risk to soil erosion by water (Gaffer et al., 2008).

We parameterized the USLE using available data for the area. The K values were obtained from FAO surveys at a national level and soil type classification at a scale of 1:200,000 (FAO, 1989). The R factor was estimated using the total storm energy (E) and a maximum 30 minute intensity (I30) for each erosive storm (i.e. storms with total accumulated rainfall greater than 13 mm and separated by at least six hours) for 148 station years of measurements in 54 meteorological stations of the Costa Rican Institute of Electricity– (ICE; Gómez-Delgado, 2002). InVEST estimates the L and S factors using Desmet and Govers (1996) methodology for the watershed's digital elevation model with a 28.5 m resolution (Imbach, 2006). Land uses were defined by a 1996 LandSat image classification (Pedroni, 2003), the most accurate land use classification with the best spatial and thematic resolutions for our analysis to our knowledge. The C factor and the crop soil retention values for each the current land use were obtained from RIOS's extensive literature review (Vogl et al., 2013). The P factor was assumed to be 1.0 for current conditions since no detailed information about the support practices in the watersheds exists. But, we incorporated the effectiveness of the ideal cropping systems retaining soil by modifying the practices factor (P factor). The P factor was estimated as one minus the soil retention efficacy for each cropping system.

The USLE is better at estimating long term average erosion and it only estimates erosion by water (sheet and rill) (Wischmeier & Smith 1978). Therefore, other erosive processes such as bank erosion, landslides or even other types of erosion such as wind erosion are not considered (Wischmeier & Smith 1978). This is particularly true in the Cachi drainage area where there is a greater frequency of landslides within the basin (Ramírez et al., 2008). Yet, this source of sediment is not directly related to land use decisions (afforestation is unlikely to stop land sliding) and should be considered background variability. A potential larger unquantified land use impact is the construction of unpaved roads (Gómez-Delgado et al., 2011).

We calculated the sediment delivery ratio, the proportion of the gross sediment exported per each pixel that actually reaches the reservoirs, to assess the accuracy of the USLE estimations. The delivery ratio was estimated as the ratio between the measured sediment yield in each reservoir (Table 4) and the gross sediment for each dam's drainage area (Bhattarai & Dutta, 2006). Our estimated average sediment per hectare was calculated as the total gross sediment exported per pixels divided by the drainage area multiplied by the sediment delivery ratio.

3.4. Targeting strategies

Defining priority areas to target efforts can be based using different criteria. For this reason, we tested the effectiveness of implementing cropping systems using three targeting strategies: RIOS default optimization (named RIOS), RIOS constrained to areas in conflict with current legislation (named RIOS&Legislation) and RIOS constrained to areas with erosive crops or crops on steep lands (named RIOS&C-S). RIOS optimization uses the pre-determined critical factors (Table 5) to find the most cost-effective areas to implement ideal cropping systems as we discussed in section 2.3. However, we also tested if enforcing current land use capability legislation is the most effective strategy or if using verifiable criteria's in field and key drivers of soil erosion is the most effective.

We determined the targeting strategy RIOS&Legislation by overlapping the land use capability developed for the Reventazon management plan (PREVDA, 2008) with the land use from 1996 (Pedroni, 2003). Costa Rica established in 1994 the land use capability for the national territory according to local conditions such as soil nutrients, soil depth, relieve, rockiness, floodable (Act N°

23214-MAG-MIRENEM, 1994). The land use capability classifies the land into eight categories, from null restrictions for productive activities (i.e. class I) to high restrictions (i.e. class VIII). We defined conflict areas as those areas that corresponds to 1) any productive activity occurring in areas that should be dedicated to forest protection (i.e. classes VII, VIII), 2) other agricultural activities than perennial crops in areas with severe limitations (i.e. class VI) and 3) other agricultural activities than semi-perennial and perennial crops occurring in areas with strong limitations (i.e. classes IV). We constrained RIOS to run and prioritize using only the areas in conflict (33,693 ha, ~41% of the upper Reventazon watershed area).

We determined the targeting strategy RIOS&C-S by overlapping the land use map and the slope. Estrada-Carmona et al., (in review), identified for the same watershed using a global sensitivity analysis, that the interaction between cover management and slope steepness is what mainly drives soil erosion in the region. Therefore, we used Estrada-Carmona et al. (in review) results and identify those areas located on 1) steep areas (steepness >23%) with productive uses (C factor > 0.07) and 2) erosive crops (C factor >0.4) on level landscapes (steepness <23%). We constrained RIOS to run and prioritize using only the areas where C and S factors interacts generating greater soil loss in the upper Reventazon watershed area (36,009 ha, ~44%).

3.5. Budget allocation

We assessed the changes on the provision of the ecosystem service soil retention across different budget levels. Low budget allocations correspond to the amount ($0.3 million USD) the Reventazon watershed plan assigned to invest on soil loss control and to implement agroforestry systems during 2008-2010 (PREVDA, 2008). The medium budget allocations correspond to the lowest and larger reported yearly dredging cost for both, Angostura and Cachi reservoirs. The national hydropower company, ICE, spent between $2-4 million dredging the dams (Vignola et al., 2012, Vignola et al., 2010). These costs exclude the financial support the ICE contributed to the Reventazon management plan (PREVDA, 2008). Finally, the largest budget corresponds to the maximum amount ($7million) that would be needed to allocate to cover the maximum extent of agricultural land available for ideal cropping systems. We assumed an adoption rate of 100% during the first five years of implementing and maintaining ideal cropping systems.

We assumed that at least a five year of continuous budget allocation would be needed for two reasons. First, this period is approximately what it will take to fully establish ideal cropping systems (maximum soil retention) and to potentially increase yield production (Alegre, & Rat, 1996). Second, FONAFIFO distributes the payments for agroforestry in a five-year period (FONAFIFO, 2014).

We estimated the avoided cost as the cost of dredging the retained soil by each targeting strategy at the different budget allocations for the life span of the dams. Then we compared both, the cost of implementing ideal cropping systems (budget allocation) and the avoided cots. The cost of dredging one ton of sediment in the area is $1.3t-1 according to Vignola et al. (2010), who reported that ICE dredges every year 1.5millions·tonnes of sediment from the reservoirs (Angostura and Cachi) with a cost of at least $2 million USD. Approximately 70% of the sediment yield in the reservoirs is removed during the dredging. For instance, the life span of the dams was estimated as the sum of the accumulated sediment (30% of the sediment yield) through time until the reservoir capacity was full. The total retained soil is the cumulative throughout the life span of the dams. The avoided cost is estimated then as the dredging cost multiplied by the extended life span of the dam and the total retained soil up-stream due to the implementation of the ideal cropping systems. We excluded the first five years after of implementation to account for the time it will take to the practices to fully establish. The avoided cost is estimated only for Cachi and Angostura's dams. Birris was incorporated into the Angostura drainage area in this analysis since we lacked information about the volume of the reservoir (Table 4.). We assumed constant conditions (i.e. sediment yield in the reservoirs, land cover) through time to estimate the avoided cost and the extension of the life span of the dams since we lack of historical data for all the dams. Measurements in Angostura indicates a high yearly variability with reported extremely high sediment yields in the reservoirs up to five times greater than the average yields (Jiménez-Ramírez et al., 2004).

4. Results

Modeling results indicated a wide range of ES provisioning rates across targeting and budget allocation. InVEST (particularly the USLE) accuracy assessment indicated that model predictions are consistent with reported values for the study area. Our comparisons across targeting strategies and budget allocations indicated that the most cost-effective (highest soil retention per dollar) strategy is to target lands with erosive crops and crops on steep lands (RIOS&C-S) using medium budgets ($10-16.4million). Low budget allocations ($1.5million) yielded similar results across targeting strategies. And, the benefits of investing on ideal cropping systems exceeded the dredging cost using RIOS&C-S targeting strategy across budgets, given our modeling assumptions.

4.1. Universal Soil Loss Equation accuracy assessment

The soil retention ES provision rate was estimated as the relative change between current condition and each targeting strategy across the three budgets (Figure 17 and 18). We used this rate to estimate the reduction in sediment yield reaching the reservoirs and its effect extending the life span of the dams (Table 6), rather than the gross estimates of cumulative sediment. As a simple accuracy assessment of the gross estimates we compared our estimated average sediment per hectare with reported values. The estimated average sediment per hectare for the Birris and Angostura dams correspond to the values reported in other studies. The USLE underestimated measured values for the Cachi drainage area in which the frequency of landslides is higher (Table 4).

Figure 17. Covered area and retained soil by the implemented ideal cropping systems in each drainage area (Angostura, Cachi and Birris) under three targeting strategies (RIOS, RIOS constrained to areas in conflict with legislation and RIOS constrained to areas with erosive crops on steep slopes) and at different budget levels. The percentage of the cover area corresponds to the total area of each one of the drainage area of each dam.

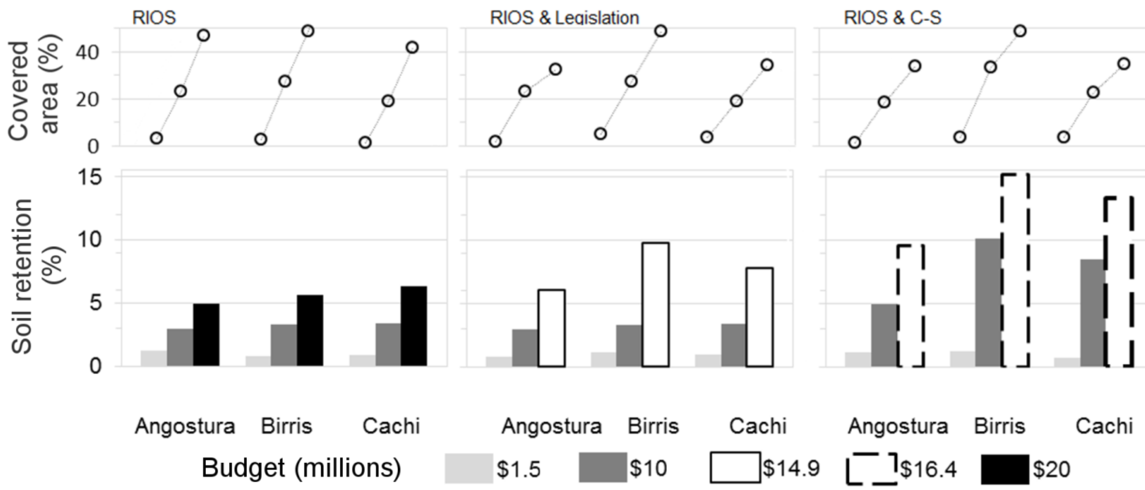


Figure 18. Covered area and retained soil in the upper and middle part of the Reventazon watershed by using three strategies to target ideal cropping systems (RIOS, RIOS constrained to areas in conflict with legislation and RIOS constrained to areas with erosive crops on steep slopes) at different budget levels. One-hundred percent of the area refers to the 73,441ha in the watershed where ideal cropping systems can be implemented.

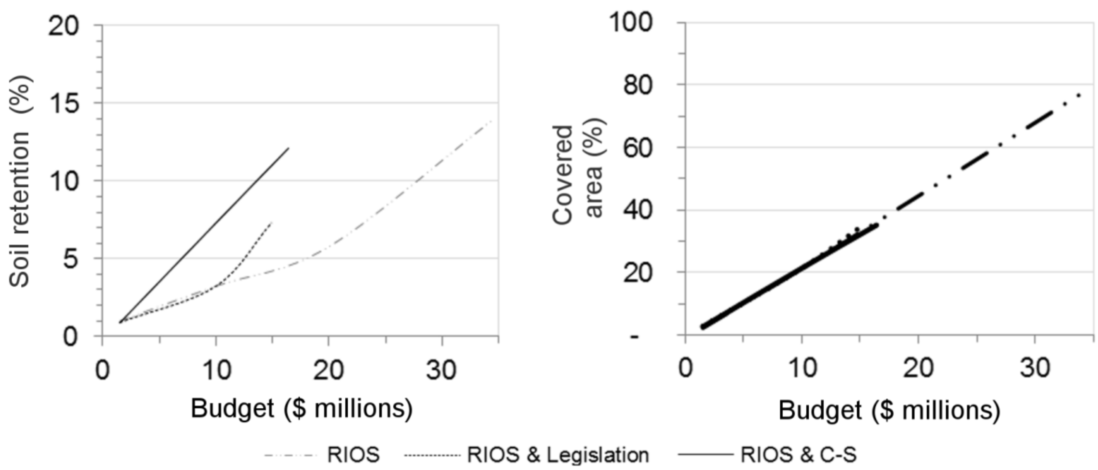


Table 6. Dams lifespan extension and avoided cost if ideal cropping systems (ICS) are implemented using different targeting strategies at different budgets levels.

	Implementation cost ($millions)		Life span (y)		Sediment yield (millions·t·y^{-1})		Up-stream retention (millions·t·y^{-1})	Total retained (millions·t)	Avoided cost ($millions)
Targeting strategies	Budget	Dam	No ICS	ICS	No ICS	ICS	ICS	ICS	ICS
RIOS&Legislation	1.5	Angostura	24	24	1.5	1.49	0.01	0.3	0.4
	1.5	Cachi	145	147	1.1	1.09	0.01	1.2	1.6
Total									1.9
RIOS&C-S	1.5	Angostura	24	24	1.5	1.49	0.01	0.2	0.3
	1.5	Cachi	145	147	1.1	1.09	0.01	1.8	2.3
Total									2.6
RIOS	1.5	Angostura	24	24	1.5	1.49	0.01	0.3	0.3
	1.5	Cachi	145	147	1.1	1.09	0.01	1.9	2.6
Total									2.9
RIOS&Legislation	10	Angostura	24	25	1.5	1.45	0.05	1.0	1.3
	10	Cachi	145	150	1.1	1.07	0.03	4.7	6.3
Total									7.6
RIOS&C-S	10	Angostura	24	26	1.5	1.37	0.13	2.7	3.6
	10	Cachi	145	153	1.1	1.05	0.05	8.1	10.8
Total									14.4
RIOS	10	Angostura	24	25	1.5	1.45	0.05	1.0	1.3
	10	Cachi	145	150	1.1	1.07	0.03	4.7	6.3
Total									7.6
RIOS&Legislation	14.9	Angostura	24	25	1.5	1.41	0.09	1.8	2.4
	14.9	Cachi	145	155	1.1	1.03	0.07	9.9	13.2
Total									15.7
RIOS&C-S	16.4	Angostura	24	26	1.5	1.36	0.14	3.0	4.1
	16.4	Cachi	145	161	1.1	1.00	0.10	16.3	21.8
Total									25.9
RIOS	20	Angostura	24	25	1.5	1.43	0.07	1.5	2.0
	20	Cachi	145	153	1.1	1.05	0.05	8.0	10.7
Total									12.7
RIOS	34.5	Angostura	24	27	1.5	1.34	0.16	3.5	4.7
	34.5	Cachi	145	163	1.1	0.98	0.12	18.8	25.0
Total									29.7

4.2. Targeting strategies and budget allocation comparison

The Birris dam has smallest drainage area yet has the highest erosion rates (Figure 15). This basin occupies only 3% of the upper and middle Reventazon, still both targeting strategies RIOS&C-S and RIOS&Legislation covered more area in this basin with ideal cropping systems yielding slightly higher soil retention rates, particularly at the higher budget levels (Figure 17). Cachi and Angostura’s dams have the largest drainage area, occupying 55% and percent 42% of the Reventazon watershed, respectively. In these two dams, both targeting strategies RIOS and RIOS&Legislation tended to cover the same proportion of area at the medium budgets yielding similar soil retention rates. Modeling results show similar soil retention rates across targeting strategies with the lowest budget allocation

(Figure 17). Finally, RIOS&C-S yielded the highest soil retention rates across dams when medium and larger budgets were available (Figure 17 and 18).

The targeting strategy with RIOS and the maximum budget ($34.5million) yielded the maximum soil retention rate (14%). However, the targeting strategy RIOS&C-S yielded similar results (12%) using half of the budget ($16.4millions) and covering half of the area (Figure 18). The RIOS & Legislation targeting strategy is only more effective than RIOS when larger budgets were available (Figure 18). With low budgets ($1.5millions), all the different targeting strategies had low effectiveness since they only reduced ~1% of the total exported sediment and changed less than 3% of the area. The targeting strategies of RIOS & C-S and RIOS & Legislation used partially the $20millions budgeted ($16.4millions and $14.9millions, respectively), indicating that the most effective areas retaining soil can be covered with lower budgets (Figure 18).

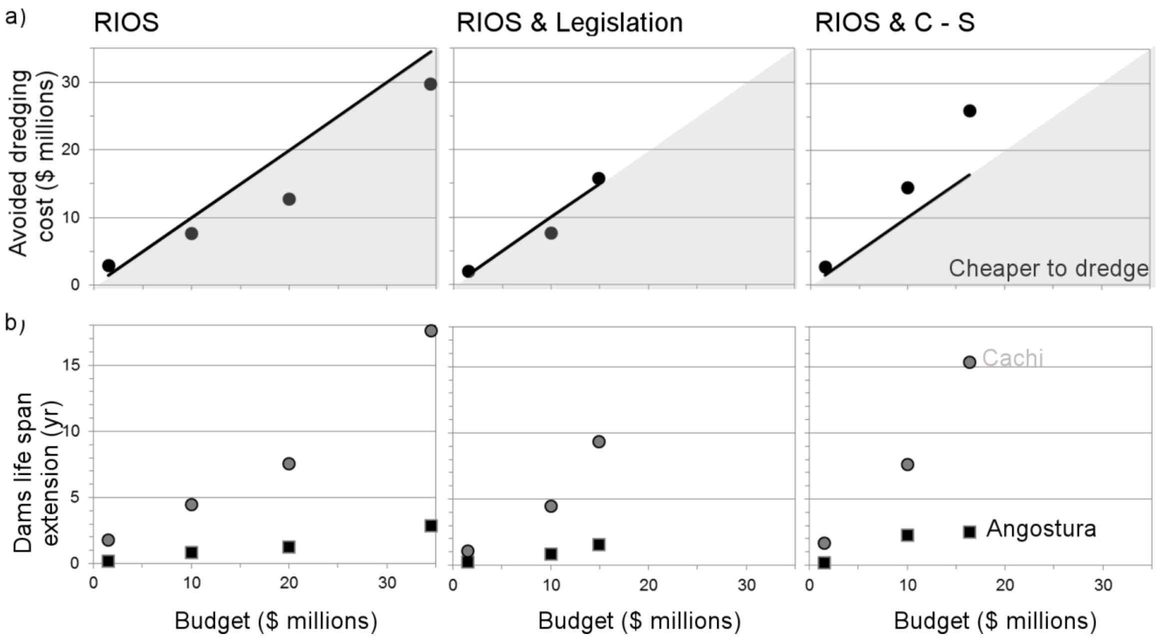
The slope of both the covered area and the soil retention at different budgets indicates a marginal benefit (Figure 18). Modeling results indicates that on average, every million invested may cover with ideal cropping systems 2.3% (1,689 ha) of the agricultural land; however, every extra million invested will only reduce exported soil in a magnitude of 0.4, 0.5 and 0.8 percent using RIOS, RIOS & Legislation and RIOS & C-S targeting strategies, respectively. The marginal benefit across budgets was constant for RIOS & C-S, but it increased for RIOS (from 0.3 to 0.6) and RIOS & Legislation (from 0.3 to 0.8) when budget was increased from $10 to $20 million (Figure 18).

Budget allocation across cropping systems (i.e. annual, perennial, semi-perennial, pasture or reforestation) was consistent with the current land use distribution. The largest proportion of the budget (approximately 75%) across targeting strategies and budgets was designated to support perennial and pasture ideal cropping systems. Bare soil, although occupying low proportion in the watershed (1.2% of the area), was the third most invested activity across targeting strategies and budgets, despite the highest implementation and maintenance cost (Supplemental Material II). This means that investing on bare soil is effective in comparison to other activities.

4.3. Benefit of implementing soil conservation practices (avoided cost)

Avoided cost is the cost the hydropower companies would have to spend dredging if the retained soil by the cropping systems entered the reservoir. Here, we assumed a constant sediment yield through the life span of each dam. We also assumed a constant soil retention rate through time after five years of cropping system establishment (Table 6). The estimated rates indicated that the targeting strategy RIOS & C-S is the only strategy that consistently retained enough soil up-stream across budgets allocations to make the investment on cropping systems cheaper than to remove the sediment from the reservoirs (Figure 19a). The targeting strategy RIOS & C-S also extended the dams' life span close to the maximum that could extended with RIOS and the highest budget ($34.5), which covers 78% of the watershed area where ideal cropping systems can be implemented (Figure 18). RIOS targeting strategy with a budget of $34.5millions extended the life span of the Angostura and Cachi dams, 2.9 years and 17.6 years, respectively. RIOS&C-S targeting strategy and with half of the budget ($16.5millions) extended both dams life span, 2.5 years and 15.3 years, respectively (Figure 19b).

Figure 19. Panel a) shows the avoided cost by the hydropower companies estimated as the cost of removing the sediment retained up-stream by the cropping systems (black dots) at the different budget levels and targeting strategies. The black line represents the implementation cost of the cropping systems, below this line (gray area), the implementation and maintenance cost of the ideal cropping systems is more expensive than the dredging cost of the retained soil by the ideal cropping systems. Panel b) shows the extension of the dams' life span across targeting strategies and budgets.



Other targeting strategies avoided costs was similar or lower than the implementation cost of the ideal cropping systems, potentially due to a low soil retention rate (Table 7). Still, almost all targeting strategies extended the life span of the dams between 0.8y and 1.5y for Angostura's dam and between 4.5y and 9.3y for Cachi's dam with budgets greater than $1.5millions (Figure 19b and Table 7). Comparing the total retained soil accumulated up-stream by the ideal cropping systems with the reported sediment yield in each reservoir offered a non-monetary assessment of the benefits. We found that targeting strategies RIOS&C-S (budgets $10 and $16.4 million) and RIOS (budget $34.5 million) retained up-stream during the whole dam's life span, the equivalent to two years of the current sediment yield in Angostura's dam (1.5millions·t·y·r-1, Table 4 and 7). The same targeting strategies retained up-stream what is the equivalent amount to 7, 15 and 17 years, respectively, of the annual sediment yield (1.1millions·t·y·r-1, Table 4) in Cachi's dam.

5. Discussion

Our application of InVEST and RIOS tools to assess the provisioning of the soil retention ES is an initial attempt to better assess the role of agroecosystems as ES providers in Costa Rica. Our results indicate that targeting efforts to implement ideal cropping systems (combination of at least two or three soil conservation practices) on erosive crops or crops on steep slopes will likely provide the highest cost-effectiveness investment scenario, or in other words, the highest soil retention per dollar spent. Under this particular targeting strategy, investments in ideal cropping systems may be more cost effective than dredging sediment from the downstream reservoirs, given our modeling assumptions.

5.1. Role of agroecosystems as ES providers

The Costa Rican PES scheme is becoming more supported by local ES consumers such as hydropower companies, industry, tourisms among others (Pagiola et al., 2008; Blackman & Woodward, 2010). These consumers may demand a higher provision of ES at this local scale such as water quality. Improving water quality will require the provision of ES not only from the forested areas or spread trees but also from a proper agroecosystem management and planning.

ICE previous efforts in the upper-middle Reventazon watershed such as raising awareness, trainings, nurseries to foment agroforestry and technological transfer (i.e. vermicomposting or biodigestors) improved in agricultural lands the management of natural resources (Sims & Sinclair, 2008). Still, the benefits of those efforts in terms of the reduction of sediment loads and pollution in the reservoirs are marginal (PREVEDA, 2008). Marginal benefits on reducing sediment yield may be due to a poor monitoring strategy of the on-site and off-site effects of the efforts, to a spatiotemporal lag (e.g. Fremier et al., 2013) or to a low budget allocation. Low budget allocation ($1.5 million) in our analysis indicates low rate of ES provisioning (less than 2% increase on soil reduction) regardless the targeting strategy. Yet, these investments might be profitable by the hydropower company as they not only reduce soil transport into the reservoir, but also for public relations. When considering higher investments, the amount of soil retained by investments in ideal cropping systems using the RIOS&C-S method might be enough to make investments more cost effective than remediating the effects of dredging (e.g. implementation and maintenance cost $16.4millions versus estimated dredging cots $23.3millions; Figure 4). Investments in soil conservation practices might also extend dam life span, which is one of the most critical concerns of hydropower companies with high sedimentation rates (Haun et al., 2013).

5.2. Targeting strategies

The majority of ES are spatially explicit as well as the pressure or threats (e.g. deforestation, soil erosion) to ecosystems and the services they provide. Targeting efforts, incentive or policy based, rather than "first-come first-served" guarantees the additionality and efficiency of the efforts (Robalino & Pfaff, 2013; Pfaff & Robalino, 2012; Wünscher et al., 2008). The Costa Rican PES scheme prioritizes PES for agroforestry systems based on land use capability (FONAFIFO, 2014), similarly to our RIOS&Legislation targeting strategy yet less aggressive at targeting erosive lands. However, our results indicate that targeting efforts to increase the provision of the ES soil retention on erosive crops and crops on steep slopes (> 23%) (RIOS&C-S) potentially will yield the highest benefits per dollar invested. Particularly, with the medium and larger budgets we tested for this targeting strategy ($10 or $16.4 million). Another advantage of the RIOS&C-S targeting strategy is that both, the slope steepness and cover management factors, are verifiable on the field. Using verifiable factors on the field to determine participation criteria in the PES scheme may add a sense of fairness to the program (Vignola et al., 2010) and decrease negative behavioral spillovers (Alpízar et al., 2013) such as reducing current voluntary implementation of conservation practices or reducing aversion to participate.

We tested three targeting strategies using an empirically based approach, USLE, to quantify the provisioning of the soil retention ES. Our modeling strategy, offers a simple but robust and conservative first approximation to a methodology that can be adapted and modeled iteratively to assess the potential contribution that changes in agroecosystems management has on providing ES. This first approximation also contributes to move beyond the assumption that spread trees will provide the demanded hydrological services by local consumers and contributes to improve spatial planning, one of the weaknesses of the Costa Rican PES scheme (Robalino & Pfaff, 2013). Also, this modeling exercise offers an opportunity to quantify the approximate benefits of investing on provisioning ES and, particularly private sector, may get more engage with more clear and direct benefits (Ruckelshaus et al., 2012). Higher engagement of the private sector in conservation is currently an important challenge in agricultural landscape planning across Latin America and the Caribbean (Estrada-Carmona et al., 2014). Future efforts with more complete available data may include more comprehensive hydrological and calibrated models to assess hydrological services (e.g. Gómez-Delgado et al., 2011).

6. Conclusion

Our results indicate that the cost of implementing ideal cropping systems (combination of at least two or three soil conservation practices) is potentially similar or cheaper than dredging. Particularly, we estimated that the highest soil retention per dollar spent is obtained by targeting efforts on erosive crops (C factor >0.4) or crops (C factor > 0.07) on steep lands (>23%) using medium budget allocations such as ~$10-20 millions. Low budget allocations yielded marginal benefits providing an increase of soil retention ES lower than 3%. However, all targeting strategies extended the life span of the dams by reducing sediment yields in the reservoirs, given our modeling assumptions. Our estimation of the provisioning of the soil retention ES due to changes in agroecosystem management is an empirical-based and conservative methodology that can be adapted and modeled iteratively to improve PES spatial planning in agroecosystems. Our methodology may also improve private or industry sector long-term and strong engagement with more clear and direct benefits of their investments. Future research should incorporate transaction cost and explore other strategies to boost the voluntary implementation of ideal cropping systems through training, experimental farms or farmer scientist.

7. References

Abreu, H.M. 1994. Adoption of soil conservation in Tierra Blanca, Costa Rica. In Lutz E, Pagiola S, Reiche C. 1994. Economic and institutional analysis of the soil conservation projects in Central America and the Caribbean. World Bank Development paper No. 8, Washington DC, USA. 207 pp.

Alegre, J. C., & Rat, M. R. (1996). Soil and water conservation by contour hedging in the humid tropics of Peru. Agriculture, Ecosystems and Environment, (57), 17–25.

Alpízar, F., Nordén, A., Pfaff, A., & Robalino, J. (2013). Effects of Exclusion from a Conservation Policy : Negative Behavioral Spillovers from Targeted Incentives (p. 29). Retrieved from http://sites.nicholasinstitute.duke.edu/environmentaleconomics/files/2013/11/WP-EE-13-06-Pfaff-et-al._full-pdf.pdf

Altieri, M. a. (2002). Agroecology: the science of natural resource management for poor farmers in marginal environments. Agriculture, Ecosystems & Environment, 93(1-3), 1–24. doi:10.1016/S0167-8809(02)00085-3

Bhattarai, R., & Dutta, D. (2006). Estimation of Soil Erosion and Sediment Yield Using GIS at Catchment Scale. Water Resources Management, 21(10), 1635–1647. doi:10.1007/s11269-006-9118-z

Blackman, A., & Woodward, R. T. (2010). User financing in a national payments for environmental services program: Costa Rican hydropower. Ecological Economics, 69(8), 1626–1638. doi:10.1016/j.ecolecon.2010.03.004

Brandt, S. A., & Swenning, J. (1999). Sedimentological and geomorphological effects of reservoir flushing: The Cahí reservoir, Costa Rica. Geografiska Annaler, 81, 391–407.

Bravo-Ureta, B. E., Solís, D., Cocchi, H., & Quiroga, R. E. (2006). The impact of soil conservation and output diversification on farm income in Central American hillside farming. Agricultural Economics, 35, 267–276.

Brenes, C. (2009). Análisis multitemporal de cambio de uso de suelo y dinámica del paisaje en el Corredor Biológico Volcánica Central Talamanca, Costa Rica. CATIE.

CADETI. (2004). Programa de Acción Nacional de Lucha contra la Degradación de Tierras en Costa Rica (2 ed., p. 122). San Jose, Costa Rica: Comisión Asesora sobre Degradación de Tierras (CADETI) y Ministerio del Ambiente y Energía (MINAE).

Cocchi, H., & Bravo-ureta, B. E. (2007). On-site cost and benefits of soil conservation among hillside farmers in El Salvador (p. 45). Washington, D.C. Retrieved from http://ove/oveIntranet/DefaultNoCache.aspx?Action=WUCPublications@ImpactEvaluations

Comerford, N. B., Franzluebbers, A. J., Stromberger, M. E., Morris, L., Markewitz, D., & Moore, R. (2013). Assessment and Evaluation of Soil Ecosystem Services. Soil Horizons, 54(3), 1–14. doi:10.2136/sh12-10-0028

Comisión para el Ordenamiento y Manejo de la Cuenca Alta del Río Reventazón (COMCURE). 2009. Manual Técnico de Incentivos. Retrieved from: http://comcure.go.cr/nosotros/normativa

Declerck, F. A. J., Fanzo, J., Palm, C., & Remans, R. (2011). Ecological approaches to human nutrition. Food and Nutrition Bulletin, 32(1), S41–S50.

Desmet, P., and G. Govers (1996) A GIS procedure for automatically calculating the USLE LS factor on topographically complex landscape units. Journal of Soil and Water Conservation, vol. 51, no. 5, pp. 427-433.

Dogliotti, S., García, M. C., Peluffo, S., Dieste, J. P., Pedemonte, A. J., Bacigalupe, G. F., … Rossing, W. a. H. (2013). Co-innovation of family farm systems: A systems approach to sustainable agriculture. Agricultural Systems. doi:10.1016/j.agsy.2013.02.009

Echeverría-Sáenz, S., Mena, F., Pinnock, M., Ruepert, C., Solano, K., Cruz, E. de la, … Barata, C. (2012). Environmental hazards of pesticides from pineapple crop production in the Río Jiménez watershed (Caribbean Coast , Costa Rica). Science of the Total Environment, 440, 106–114.

Estrada-Carmona, N., Harper, H., Declerck, F. A. J., & Fremier, A. In review. Global sensitivity analysis of RUSLE illustrates importance of cover management across environments in predicting soil erosion rates. Geomorphology.

Estrada-Carmona, N., Hart, A. K., DeClerck, F. A. J., Harvey, C. A., & Milder, J. C. (2014). Integrated landscape management for agriculture, rural livelihoods, and ecosystem conservation: An assessment of experience from Latin America and the Caribbean. Landscape and Urban Planning, 129, 1–11. doi:10.1016/j.landurbplan.2014.05.001

FAO. (1989). Evaluación de los estados de la erosión hídrica de los suelos en Costa Rica (Assessment of soil erosion by water in Costa Rica). Informe técnico Nº2. Programa de cooperación FAO/Italia. Roma.

FAO. (2000). Manual on integrated soil management and conservation practices (1st ed., p. 228). Rome, Italy: Food and Agriculture Organization of the United Nationas. Retrieved from ftp://ftp.fao.org/agl/agll/docs/lw8e.pdf

FAO. (2001). Lessons learned and farmer-to-farmer transfer of technologies (p. 86). FAO. Retrieved from ftp://ftp.fao.org/agl/agll/docs/sb76e.pdf

FAO. (2013). Statistical Yearbook: World food and agriculture (p. 307). Roma, Italia.

Fondo Nacional de Financiamiento Forestal (FONAFIFO). 2014. Estadísticas del Pago por Servicios Ambientales. Retrieved from: http://www.fonafifo.go.cr/psa/estadisticas_psa.html

Fremier, A. K., Declerck, F., Bosque-Pérez, N., Estrada-Carmona, N., Hill, R., Joyal, T., … Wulfhorst, J. D. (2013). Understanding spatiotemporal lags in ecosystem services to improve incentives. BioScience, 63(6), 472–482. doi:10.1525/bio.2013.63.6.9

Gaffer, R. L., Flanagan, D. C., Denight, M. L., & Engel, B. A. (2008). Geographical information system erosion assessment at a military training site. Journal of Soil and Water Conservation, 63(1), 1–10. doi:10.2489/63.1.1

Garbach, K., Lubell, M., & DeClerck, F. A. J. (2012). Payment for Ecosystem Services: The roles of positive incentives and information sharing in stimulating adoption of silvopastoral conservation practices. Agriculture, Ecosystems & Environment, 156, 27–36. doi:10.1016/j.agee.2012.04.017

Garrick, D., McCann, L., & Pannell, D. J. (2013). Transaction costs and environmental policy: Taking stock, looking forward. Ecological Economics, 88, 182–184. doi:10.1016/j.ecolecon.2012.12.022

Gómez Delgado, F. (2002). Evaluación de la erosión potencial y producción de sedimentos en tres cuencas de Costa Rica (Assessment of the potential erosion and sediment production in three Costa Rican watersheds). Costa Rican University.

Gómez-Delgado, F., Roupsard, O., le Maire, G., Taugourdeau, S., Pérez, A., van Oijen, M., … Moussa, R. (2011). Modelling the hydrological behaviour of a coffee agroforestry basin in Costa Rica. Hydrology and Earth System Sciences, 15(1), 369–392. doi:10.5194/hess-15-369-2011

Hall, C.A.S, Levitan, L., & Schlichter, T. 2000. Land, energy and agricultural production in Costa Rica. In: Quantifying Sustainable Development, The future of tropical economics. (eds) Hall, C.A.S. Academic Press. San Diego, CA. 121-156.

Harvey, C. A, Medina, A., Sánchez, D. M., Vílchez, S., Hernández, B., Saenz, J. C., … Sinclair, F. L. (2006). Patterns of animal diversity in different forms of tree cover in agricultural landscapes. Ecological Applications, 16(5), 1986–1999. Retrieved from http://www.jstor.org/stable/40061768

Haun, S., Kjærås, H., Løvfall, S., & Olsen, N. R. B. (2013). Three-dimensional measurements and numerical modelling of suspended sediments in a hydropower reservoir. Journal of Hydrology, 479, 180–188. doi:10.1016/j.jhydrol.2012.11.060

Holt-Giménez, E. (2002). Measuring farmers’ agroecological resistance after Hurricane Mitch in Nicaragua: a case study in participatory, sustainable land management impact monitoring. Agriculture, Ecosystems & Environment, 93(1-3), 87–105. doi:10.1016/S0167-8809(02)00006-3

Imbach P, 2006. Modelo de Elevación Digital (Digital Elevation Model). Grupo Cambio Global CATIE

Jiménez-Ramírez, O., Rodríguez-Mesa, C. R., & Olsen, N. (2004). Sedimentación del embalse del p.h. angostura, estudios y experiencias. In 9th International Symposium on River Sedimentation (Vol. 2). Yichang, China.

Lal, R. (2001). Soil degradation by erosion. Land Degradation & Development, 12(6), 519–539. doi:10.1002/ldr.472

Lenka, N. K., Dass, A., Sudhishri, S., & Patnaik, U. S. (2012). Soil carbon sequestration and erosion control potential of hedgerows and grass filter strips in sloping agricultural lands of eastern India. Agriculture, Ecosystems & Environment, 158, 31–40. doi:10.1016/j.agee.2012.05.017

Maetens, W., Poesen, J., & Vanmaercke, M. (2012). How effective are soil conservation techniques in reducing plot runoff and soil loss in Europe and the Mediterranean? Earth-Science Reviews, 115(1-2), 21–36. doi:10.1016/j.earscirev.2012.08.003

Marchamalo, M. (2004). Ordenación del territorio para la producción de servicios ambientales hídricos. Aplicación a la cuenca del Río Birrís, Costa Rica. (Territory management for hydrological environmental services. An application to the Birris basin, Costa Rica). Universidad Politecnica de Madrid.

Martínez-Salinas, M.A. & DeClerck, F. (2010). The role of Agroecosystems and forests in the conservation of birds within biological corridors. Mesoamericana 14(3). Retrieved from http://biblioteca.catie.ac.cr:5151/repositoriomap/bitstream/123456789/127/3/224.pdf

Ministerio de Medio Ambiente y Energía (MINAE), 2002. GEO Costa Rica: una perspectiva sobre el medio ambiente. Observatorio de Desarrollo de la Universidad de Costa Rica, San Jose, 162 pp

Pagiola, S. (2008). Payments for environmental services in Costa Rica. Ecological Economics, 65(4), 712–724. doi:10.1016/j.ecolecon.2007.07.033

Pagiola, S., Agostini, P., Gobbi, J., de Haan, C., Ibrahim, M., Murgueitio, E., … Ruíz, J. P. (2005). Paying for Biodiversity Conservation Services. Mountain Research and Development, 25(3), 206–211. doi:10.1659/0276-4741(2005)025[0206:PFBCS]2.0.CO;2

PASOLAC. (2000). Guía téctica de conservación de suelos y agua (1st ed., p. 205). San Salvador, El Salvador: Programa para la Agricultura Sostenible en Laderas de América Central, PASOLAC.

Pedroni, L. (2003). Improved classification of Landsat Thematic Mapper data using modified prior probabilities in large and complex landscapes. International Journal of Remote Sensing, 24(1), 91–113. doi:10.1080/01431160110115005

Perfecto, I., Vandermeer, J., & Paradigm, A. N. C. (2008). Biodiversity conservation in tropical agroecosystems: a new conservation paradigm. Annals of the New York Academy of Sciences, 1134, 173–200. doi:10.1196/annals.1439.011

Pfaff, A., & Robalino, J. (2012). Protecting forests, biodiversity, and the climate: predicting policy impact to improve policy choice. Oxford Review of Economic Policy, 28(1), 164–179. doi:10.1093/oxrep/grs012

PREVDA. (2008). Plan de cuenca del Río Reventazón - Parismina (p. 196). San Jose, Costa Rica.

ProDUS. (2011). Base teórica para la construcción de planes reguladores en la cuenca alta y media del Río Reventazón (No. Tomo II) (p. 312). San José, Costa Rica.

Ramírez, L., Alvarado, A., Pujol, R., & Brenes, L. G. (2008). Caracterización física de la cuenca media del río Reventado, Cartago, Costa Rica. Agronomía Costarricense, 32(2), 73–92.

Raudes, M., & Sagastume, N. (2009). Manual de Conservación de Suelos. Programa para la Agricultura Sostenible en Laderas de América Central (p. 75). El Zamorano, Honduras.

Robalino, J., & Pfaff, A. (2013). Ecopayments and Deforestation in Costa Rica : A Nationwide Analysis of PSA ' s Initial Years. Land Economics, 89(3), 432–448.

Robalino, J., Pfaff, A., Sánchez-azofeifa, G. A., Alpízar, F., León, C., & Rodríguez, C. M. (2008). Environment for Development Deforestation Impacts of Environmental Services Payments, (August).

Rubin, B. D. & Hyman, G. G. 2000. Soil erosion's economic impacts on Costa Rica. In: Quantifying Sustainable Development, The future of tropical economics. (eds) Hall, C.A.S. Academic Press. San Diego, CA. 121-156.

Ruckelshaus, M., McKenzie, E., Tallis, H., Guerry, A., Daily, G., Kareiva, P., … Bernhardt, J. (2013). Notes from the field: Lessons learned from using ecosystem service approaches to inform real-world decisions. Ecological Economics. doi:10.1016/j.ecolecon.2013.07.009

Sharp, R., Tallis, H. T., Ricketts, T., Guerry, A. D., Wood, S. A., Chaplin-Kramer, R., … Hamel, P. (2013). InVEST tip User's Guide (p. 324). Palo Alto, CA. Retrieved from http://ncp-dev.stanford.edu/~dataportal/nightly-build/release_tip/release_tip/InVEST_tip_Documentation.pdf

Sims, L., & Sinclair, a. J. (2008). Learning Through Participatory Resource Management Programs: Case Studies From Costa Rica. Adult Education Quarterly, 58(2), 151–168. doi:10.1177/0741713607309802

Vignola, R., Koellner, T., Scholz, R. W., & McDaniels, T. L. (2010). Decision-making by farmers regarding ecosystem services: Factors affecting soil conservation efforts in Costa Rica. Land Use Policy, 27(4), 1132–1142. doi:10.1016/j.landusepol.2010.03.003

Vignola, R., McDaniels, T. L., & Scholz, R. W. (2012). Negotiation analysis for mechanisms to deliver ecosystem services: The case of soil conservation in Costa Rica. Ecological Economics, 75, 22–31. doi:10.1016/j.ecolecon.2012.01.004

Vignola, R., McDaniels, T. L., & Scholz, R. W. (2013). Governance structures for ecosystem-based adaptation: Using policy-network analysis to identify key organizations for bridging information across scales and policy areas. Environmental Science & Policy, 31, 71–84. doi:10.1016/j.envsci.2013.03.004

Vignola, R., Otárola, M., & Calvo, G. (2008). Defining ecosystem-based adaptation strategies for hydropower production: stakeholders' participation in developing and evaluating alternative land use scenarios and the strategies to achieve desired goals. In C. Marínez-Alonso, B. Locatelli, R. Vignola, & P. Imbach (Eds.), Seminario Internacional sobre Adaptación al Cambio Climático: el Rol de los Servicios Ecosistémicos (SIAASE (pp. 68–79). Turrialba, Costa Rica: Serie técnica. Manual técnico / CATIE ; no. 99.

Vogl, A., Tallis, H., Douglass, J., Sharp, R., Veiga, F., Benitez, S., … Sebastián Lozano, J. (2013). Resource Investment Optimization System (RIOS). Palo Alto, CA. Retrieved from http://ncp-dev.stanford.edu/~dataportal/rios_releases/RIOSGuide_Combined_8-22-13.pdf

Wischmeier, W. H., & Smith, D. D. (1978). Predicting rainfall erosion lossess a guide to conservation planning. 1978. Washington, D.C.

WOCAT. (2012). Desire for Greener Land. Options for sustainable land management in drylands. (G. Schwilch, R. Hessel, & S. Verzandvoort, Eds.). Bern, Switzerland and Wageningen, The Netherlands: SRIC - World Soil Information and CTA - Technical Centre for Agricultural and Rural Cooperation. Retrieved from https://www.wocat.net/fileadmin/user_upload/documents/Books/DESIRE_BOOK_low_resolution.pdf

Wünscher, T., Engel, S., & Wunder, S. (2008). Spatial targeting of payments for environmental services: A tool for boosting conservation benefits. Ecological Economics, 65(4), 822–833. doi:10.1016/j.ecolecon.2007.11.014

APPENDIX A

Internet Search Terms (in English, Spanish and Portuguese)

Terms (English)
1. Agrobiodiversity
2. Agroecology
3. Agroforestry
4. Biological corridor
5. Buffer zone
6. Community-based forest management
7. Community-based natural resource management
8. Conservation agriculture
9. Food security and conservation
10. Initiative
11. Integrated landscape management
12. Integrated management
13. Integrated watershed management
14. Landscape initiative
15. Landscape management
16. Landscapes and livelihoods
17. Livelihoods
18. Multi-stakeholder
19. Natural resource management
20. Participatory
21. Program
22. Project
23. Socio-ecological
24. Territorial development
25. Territorial management
26. Territory

Plus names of each of the countries in Latin America and the Caribbean (23 Countries).

APPENDIX B

Survey to assess Integrated Landscape Management for agriculture, rural Livelihoods, and ecosystem conservation in Latin America and The Caribbean.

Continental Review Survey (LPFN)- English

1. Welcome!

Dear colleague,

Thank you for responding to this survey. By sharing your experiences, you will be contributing to a global effort to document and share lessons learned from landscape-scale initiatives to support food production, ecosystem conservation, and human wellbeing in rural landscapes ("ecoagriculture" initiatives). These results, in turn, will contribute to a strategic, international action and advocacy program to expand the use of sustainable landscape management approaches around the world. For more information on this program, please visit http://landscapes.ecoagriculture.org.

This questionnaire includes 7 pages, and should take about 20 minutes to complete. The survey asks questions about a landscape initiative in which you have been involved, and about the landscape where this initiative is located. A landscape initiative is defined as a multi-stakeholder project, program, or community-led effort to increase food production, ecosystem conservation, and rural livelihoods through integrated planning, decision-making, and management at a landscape scale. Landscape initiatives can include community-led efforts, government projects or programs, or initiatives supported by organizations from outside the landscape.

In appreciation of your contribution, you will receive an electronic copy of the final review study, highlighting key lessons learned, resources, and opportunities for supporting and expanding ecoagriculture initiatives. We will send this document to the e-mail address that you provide us in your survey response. Also, upon completion of the full questionnaire, you will be automatically entered to win one of three Apple iPad computers, which will be awarded to three randomly-selected respondents.

If you have any questions about the survey, please contact Abby Hart at ahart@ecoagriculture.org. Thank you very much for your valuable contribution to this research and to supporting the sharing of knowledge about sustainable landscape management!

Sincerely,
The Ecoagriculture Global Review Team

Continental Review Survey (LPFN)- English

2. Part 1: Respondent Information

Please provide the following basic information about yourself and your role in the landscape or landscape initiative.

Title:

First name:

Middle name:

Last name:

Email address:

What is the name of your organization?

Telephone number (please include any country or regional codes)

What is your position or title within the organization?

What is your role in the landscape or landscape initiative? (please describe)

Continental Review Survey (LPFN)- English

3. Part 2: Basic information on the landscape

Please describe the landscape where you were involved in promoting integrated activities to benefit food production, ecosystem conservation, and rural livelihoods.

On which continent is the initiative located?

Where is the landscape located? (please fill in as many as relevant)

Country:

State, province or region:

Locality (please list the districts, municipalities or towns within the landscape):

If the landscape has a name, please provide it here:

Approximately how large is the landscape (area)? (please answer in hectares or in square kilometers)

Hectares

Square kilometers

Do you know approximately how many people live in the landscape? (an estimate is OK)

☐ Yes: ☐ No:

How many people?

Continental Review Survey (LPFN)- English

Please provide a general characterization of land use/land cover in the landscape by checking the boxes that apply:

	Major landscape component (occupy more than 5% of the area)	Minor landscape component (present, but occupy less than 5% of the area)	Does not exist in the landscape
Tropical moist forest	○	○	○
Tropical dry forest	○	○	○
Temperate, upland, or montane forest	○	○	○
Grassland or savanna (without livestock)	○	○	○
Pasture (grassland for livestock)	○	○	○
Lakes and other water bodies	○	○	○
Annual grain crops	○	○	○
Other annual crops (horticulture, etc.)	○	○	○
Perennial crops in agroforestry systems (e.g., shade-grown cocoa or coffee)	○	○	○
Other sun-grown perennial crops (e.g., fruit orchards, coffee)	○	○	○
Wetland	○	○	○
Forestry plantations	○	○	○
Villages / towns / urban	○	○	○
Industry, mining, oil/gas development	○	○	○

Please list any other land use/land cover that is

a major landscape component (occupy more than 5% of the area)

a minor landscape component (occupy less than 5% of the area)

Continental Review Survey (LPFN)- English

4. Part 3: Basic information on the landscape initiative

Please tell us about the landscape initiative in which you have been involved.

In your responses, please describe the landscape initiative as it is currently organized and managed, even though it may have a longer history under previous organization and management.

Initiative name (or brief description):

Initiative dates:

Starting date (year only):

End date (year, if applicable):

State of the project (beginning, in process, ending, permanent):

Which organizations lead the initiative? (please provide the complete name of the organization if possible)

Please list key organization(s) within the landscape (e.g., farmers' associations, community or indigenous groups, local government, local NGOs):

Please list key organization(s) outside the landscape (e.g., donors, international organizations or NGOs):

Is this initiative a continuation of a previous project or effort?

☐ Yes ☐ No ☐ I do not know

If so, please provide the name of the previous effort:

Continental Review Survey (LPFN)- English

Which of the following issues were the main motivations for the landscape initiative? Indicate the level of importance of each issue that is trying to be improved with the landscape initiative.

	Very important	Important	Moderate important	No important	N/A
Enhance food security	○	○	○	○	○
Improve crop productivity	○	○	○	○	○
Diversify food production	○	○	○	○	○
Conserve biodiversity	○	○	○	○	○
Conserve soil or increase soil fertility	○	○	○	○	○
Stop or reverse natural resource degradation	○	○	○	○	○
Enhance sustainable land management	○	○	○	○	○
Reduce conflict among different resource users in the landscape	○	○	○	○	○
Increase farmer incomes	○	○	○	○	○
Improve livestock productivity	○	○	○	○	○
Improve health or nutrition	○	○	○	○	○
Conserve or increase water quality or water flow	○	○	○	○	○
Reduce the environmental impacts of agriculture	○	○	○	○	○
Mitigate climate change or obtain carbon credits	○	○	○	○	○
Reduce vulnerability to extreme weather events	○	○	○	○	○

There were other issues that motivated the establishment of the initiative? (Indicate the level of importance)

What percentage of the landscape has been directly affected by the initiative's activities, programs or policies?

☐ Yes: ☐ No:

What percentage (0-100%)?

Continental Review Survey (LPFN)- English

How many people has the initiative sought to benefit? (please provide either the number of people benefited or the percent of the landscape population benefited by the initiative)

☐ Number of beneficiaries: ☐ Percent of total landscape population: ☐ I do not know:

How many?

At the beginning of the initiative, was a baseline study, pre-project assessment, project document, or similar material prepared?

○ Yes: ○ No: ○ I don't know:

Does the initiative have cartographic information, aerial photographs or imagery of the landscape?

○ Yes ○ No ○ I don't know

If so, has this cartographic information been used for analysis and planning at landscape scale?

○ Yes: ○ No: ○ I am not sure:

Continental Review Survey (LPFN)- English

5. Part 4: Initiative activities and investments

Please tell us about the major activities, investments, or other changes that were included as part of the initiative.

Which of the following investments in agriculture were actively promoted by the landscape initiative?

	Was actively promoted	Was not actively promoted, but it occurred simultaneously in the landscape	Was not actively promoted and did not occurred in the landscape	N/A or Don't know
Promotion or introduction of new crops or crop varieties	○	○	○	○
Crop intensification with increased mechanization or application of fertilizers, pesticides, or herbicides	○	○	○	○
Crop intensification with agroecological methods (e.g., organic production, conservation agriculture, no-till, integrated pest management, improved fallows, etc.)	○	○	○	○
Livestock intensification with agroecological methods (e.g. improved grass and browse supply, management of water availability, etc.)	○	○	○	○
Establishment or improvement of irrigation systems	○	○	○	○
Adoption or expansion of agroforestry	○	○	○	○
Programs to adopt or improve home gardens	○	○	○	○
Implementation of laws or incentives to reduce the environmental impacts of agriculture	○	○	○	○
Implementation of soil conservation practices	○	○	○	○
Extension or capacity building programs to support agriculture	○	○	○	○
Establishment of new supply chain or marketing channels (including value addition and certification) for agricultural products	○	○	○	○
Promotion of native food species and agrobiodiversity	○	○	○	○

Other investment in agriculture (please specify)

Continental Review Survey (LPFN)- English

Which of the following investments in forestry, conservation, and natural resource management were actively promoted by the landscape initiative?

	Was actively promoted	Was not actively promoted, but it occurred simultaneously in the landscape	Was not actively promoted and did not occurred in the landscape	N/A or Don't know
New protected areas established	○	○	○	○
New management plans for existing protected areas	○	○	○	○
Other new reserves or community-based conservation areas (including areas that allow sustainable harvest and use of natural resources)	○	○	○	○
Other community-based natural resource management activities	○	○	○	○
Improved forestry management	○	○	○	○
Extension or capacity building programs to support forestry or natural resource management	○	○	○	○
Watershed management program or activities (e.g., restoration of riparian areas)	○	○	○	○

Other investment in forestry, conservation, or natural resource management (please specify)

Continental Review Survey (LPFN)- English

Which of the following investments in livelihoods and human wellbeing were actively promoted by the landscape initiative?

	Was actively promoted	Was not actively promoted, but it occurred simultaneously in the landscape	Was not actively promoted and did not occurred in the landscape	N/A or Don't know
Programs to reduce malnutrition and hunger	○	○	○	○
Programs for improving human health (e.g., improved access to health services)	○	○	○	○
Programs for improving gender equity	○	○	○	○
Programs to help secure land tenure and resource access rights	○	○	○	○
Preservation of traditional knowledge, values, or cultural resources	○	○	○	○
Programs to support enterprise development, savings and investment, or financial education	○	○	○	○
Activities to promote income generation and diversification outside of agriculture or forestry (e.g., handicrafts, ecotourism)	○	○	○	○
Efforts to reduce migration out of the landscape	○	○	○	○

Other investment in livelihoods and human wellbeing (please specify)

Continental Review Survey (LPFN)- English

Which of the following investments in multi-sectoral coordination and planning were actively promoted by the landscape initiative?

	Was actively promoted	Was not actively promoted, but it occurred simultaneously in the landscape	Was not actively promoted and did not occurred in the landscape	N/A or Don't know
Activities to strengthen existing coordination bodies (e.g., inter-jurisdictional councils, public-private partnerships)				
Creation of new landscape coordinating bodies				
Dialogue and mediation of conflicts among local communities or resource users				
Dialogue and mediation of conflicts between local, national and international communities or resource users				
Capacity building activities to help communities and stakeholders conduct integrated, landscape-scale management				
Technical assistance to support integrated, landscape-scale management				

Other investment in livelihoods and human wellbeing (please specify)

Please list any other activities or investments that were

actively promoted

not actively promoted, but it occurred simultaneously in the landscape

Continental Review Survey (LPFN)- English

6. Part 5: Stakeholders' roles in the initiative

Please tell us about the roles of different local and external groups in the initiative.

Which of the following types of groups have participated in designing or implementing the initiative? Please list only those groups that played a role in creating or carrying out the initiative or its component activities. Do not include groups that were merely informed or consulted about the initiative as affected stakeholders. Please check all that apply:

	Active participation designing the landscape initiative	Active participation implementing the landscape initiative	N/A
Local farmers' or producers' association	☐	☐	☐
Womens' association	☐	☐	☐
Indigenous group	☐	☐	☐
Group representing rural landless people	☐	☐	☐
Local government leaders (village leaders, mayors, chiefs, etc.)	☐	☐	☐
Government extension officers	☐	☐	☐
Other local or district government offices or staff	☐	☐	☐
State or provincial government offices or staff	☐	☐	☐
National ministries or national-level government staff	☐	☐	☐
Local non-governmental organization (NGO)	☐	☐	☐
Sub-national or national NGO	☐	☐	☐
International NGO	☐	☐	☐
Local or national university or research center	☐	☐	☐
Foreign or international university or research center	☐	☐	☐
In-country agribusiness (e.g., large plantation or ranch owners, agricultural land investors, etc.)	☐	☐	☐
Foreign agribusiness (e.g., large plantation or ranch owners, agricultural land investors, etc.)	☐	☐	☐
Logging/forest products industry	☐	☐	☐
Mining, oil, gas, or other industry	☐	☐	☐
Bi-lateral or multi-lateral donor(s)	☐	☐	☐
International organization focused on agriculture	☐	☐	☐

Continental Review Survey (LPFN)- English

International organization focused on conservation	☐	☐	☐

Other (please specify the name and if the organization is local, national or international)

Which sectors have been directly involved in the initiative? Direct involvement could include, for example, providing funding or staff resources, carrying out activities on the ground, or providing extension or capacity building services. Please check all that apply, but do not check sectors that were not directly involved in the initiative, even if they were conducting other activities in the landscape.

- ☐ Agriculture
- ☐ Livestock
- ☐ Forestry
- ☐ Natural resources, conservation, or environment
- ☐ Tourism
- ☐ Health
- ☐ Education
- ☐ Energy
- ☐ Roads, transportation, or infrastructure

Others (please specify)

Was any new institution or mechanism established to support the initiative?

○ Yes: ○ No: ○ I do not know:

If so, what type of institutions or mechanisms were established to support integrated landscape management?

- ☐ New cross-jurisdictional planning or governance entity (e.g., council of governments or territorial development group)
- ☐ Other organization that plays the role of supporting landscape-wide planning and coordination
- ☐ Mechanism or process to coordinate plans and investments proposed by different sectors (e.g., agriculture, forestry, infrastructure, irrigation)
- ☐ Mechanism or platform to allow different groups of land and resource users to resolve conflict

Other institutions or mechanisms? (specify)

Continental Review Survey (LPFN)- English

7. Part 6: Initiative outcomes/results

Please tell us about the initiative's outcomes and results.

Does this initiative include a monitoring and evaluation component?

- ○ Yes
- ○ No

Does the initiative use an adaptive management approach? (Note: adaptive management an iterative process that involves monitoring the results and effectiveness of project activities, reflecting on lessons learned from this experience, and then adjusting strategies to respond to this new information or to changing conditions.)

- ○ Yes
- ○ No
- ○ I am not sure

Which of the following outcomes or changes took place within the ten years following the start of the initiative? (If the initiative started less than ten years ago, please indicate changes since the start of the initiative.) For each change, please indicate if the change took place as a result of the initiative or not as a result of the initiative. Please check the most appropriate box for each line:

Effects on agriculture:

	This change took place as a result of the initiative	This change took place, but not as a result of the initiative	This change did not take place	I am not sure if this change took place, or it is too early to tell
Agricultural yield per unit of land area (e.g., tons per hectare) increased	○	○	○	○
Agriculture became more profitable	○	○	○	○
Total area under agriculture and pasture increased	○	○	○	○
Environmental impacts of agriculture were reduced	○	○	○	○
Agricultural biodiversity (agrobiodiversity) was protected or enhanced	○	○	○	○

Other benefit (please specify)

Continental Review Survey (LPFN)- English

Effects on conservation and ecosystem services

	This change took place as a result of the initiative	This change took place, but not as a result of the initiative	This change did not take place	I am not sure if this change took place, or it is too early to tell
Rare, threatened, or endangered species were better protected	○	○	○	○
Overall biodiversity of the region was better protected	○	○	○	○
The amount or connectivity of natural habitats was increased	○	○	○	○
Water quality, quantity, or regularity improved	○	○	○	○
Ecosystem services that support agriculture (e.g., irrigation water supply, pollination, soil fertility) were restored or protected	○	○	○	○
Other ecosystems services (e.g., urban water supplies, flood control, carbon storage) were restored or protected	○	○	○	○

Other benefit (please specify)

Effects on livelihoods and the poor:

	This change took place as a result of the initiative	This change took place, but not as a result of the initiative	This change did not take place	I am not sure if this change took place, or it is too early to tell
Food security or nutrition for landscape inhabitants were improved	○	○	○	○
Household cash income for low-income residents was increased	○	○	○	○
Non-cash measures of livelihoods (e.g., greater material assets, cleaner or more reliable water, better educational resources) were improved	○	○	○	○
Communities became less vulnerable to shocks and disasters (e.g., landslides, floods, droughts, epidemics)	○	○	○	○
Access to health services improved	○	○	○	○

Other benefit (please specify)

Continental Review Survey (LPFN)- English

Effects on governance, institutions, and social capital:

	This change took place as a result of the initiative	This change took place, but not as a result of the initiative	This change did not take place	I am not sure if this change took place, or it is too early to tell
Local communities gained capacity to sustainably manage agriculture and natural resources	○	○	○	○
Local communities became more empowered to negotiate and participate in political decisions	○	○	○	○
Coordination and cooperation among stakeholders (e.g., local communities, district government, private sector, NGOs) improved	○	○	○	○
Coordination and cooperation among sectors (e.g., agriculture, environment, health) improved	○	○	○	○
Women gained power or capacity to improve their wellbeing	○	○	○	○
Traditional and local knowledge on agriculture and natural resources has been preserved and used	○	○	○	○

Other benefit (please specify)

What has been the most successful aspect of the initiative?

What has been the least successful aspect of the initiative?

Would you be willing to participate in a more in depth interview regarding your experiences with this landscape initiative?

○ Yes ○ No

Continental Review Survey (LPFN)- English

Do you know of any other ecoagriculture initiatives in Latin American that might be willing to share about their experiences?

Name of the initiative(s):

Country:

Region:

Contact person:

Telephone:

Email:

Help us improve our survey. Please leave your comments about the survey - Did you have any difficulty understanding the questions? Was the survey too long or difficult? Did you have any technical difficulties completing the survey? Thank you for your thoughtful comments!

Continental Review Survey (LPFN)- English

8. Thank you!

Thank you very much for completing this questionnaire! In appreciation of your contribution, we will send you an electronic copy of the final review study to the e-mail address that you provided. You have also been entered to win one of three Apple iPad computers, which will be awarded to three randomly-selected respondents.

For more information about the Landscapes for People, Food and Nature Initiative that is supporting this study, please visit http://landscapes.ecoagriculture.org.

APPENDIX C

Interview to assess Integrated Landscape Management for agriculture, rural Livelihoods, and ecosystem conservation in Latin America and The Caribbean

NOTAS SOBRE LA ENTREVISTA DEL TIER 2

LOGISTICA

Verifique que la conexión entre el skype y el callnote está activa. Este segura de comenzar la grabación antes de llamar.

Leer las respuestas del TIER 1 para estar un poco contextualizada con la iniciativa

Antes de llamar verifique cuáles pregunta le hará al entrevistado

ESTRUCTURA ENCUESTA

Las preguntas están divididas con base en los HECHOS o las INTERPRETACIONES, y con base en quién/cuántos entrevistados deben responder las preguntas. Estas clasificaciones tienen los siguientes significados:

HECHOS –básicamente preguntan sobre una información objetiva (basada en hechos) que debe ser verificable independientemente. Cualquier entrevistado(a) bien informado(a) debe proveer básicamente la misma respuesta para cuestiones basadas en HECHOS. Así, no es necesario preguntar cuestiones de HECHOS para todos(as) los(as) entrevistados(as).

INTERPRETATIVA – la pregunta incluye un elemento de subjetividad, interpretación y percepción personal. Inclusive donde existe una realidad objetiva (e.g., que tan efectiva ha sido una iniciativa con relación a indicadores variados), diferentes personas pueden tener percepciones distintas de esa realidad. Cuando estamos interesados en entender esas diferentes percepciones, es cuando hacemos las preguntas INTERPRETATIVAS.

SOLO 1 – la entrevistadora debe preguntar la pregunta a solamente un(a) entrevistado(a), él(la) cual se considera ser él(la) mayor conocedor(a) del asunto en cuestión. Las preguntas SOLO1 son basadas en HECHOS, y una vez que obtenemos la información necesaria, no hay necesidad de hacer la pregunta a otras personas.

TRIANGULAR – la entrevistadora debe hacer la pregunta a cuantos(as) entrevistados(as) crea necesario para establecer una respuesta confiable. Preguntas TRIANGULARES generalmente son preguntas basadas en HECHOS, en relación a las cuales es posible que algunos(as) entrevistados(as) no tengan la información completa o precisa y entonces nos podrían proveer una respuesta engañosa. La entrevistadora debe empezar haciendo la pregunta al primer entrevistado(a) que se considere conocedor del asunto. Si hay duda respecto a la confiabilidad de la respuesta, la entrevistadora debe continuar haciendo la pregunta a entrevistados(as) adicionales hasta que ella esté satisfecha y con información consistente y precisa.

PREGUNTE A TODOS(AS) – esas son generalmente preguntas INTERPRETATIVAS cuyo objetivo es comprender cómo distintos actores perciben la iniciativa y sus resultados. Tales cuestiones deben ser hechas a todos(as) los(as) entrevistados(as).

Objetivo: cerca de 15 preguntas; no más que 20

Tamaño de la muestra (# de paisajes): seleccionar 12-14 paisajes de alta prioridad que estamos seguros de incluir, además de 6-8 adicionales que intentaremos incluir si tenemos tiempo.

Intensidad de la muestra (# de entrevistados por paisaje): mínimo de 4, máximo de 6.

Entrevistados(as) deben representar distintos sectores, niveles y perspectivas. Debe haber al menos alguna representación del sector de conservación y del sector de agricultura. Entrevistados(as) deben incluir al menos una organización local, una representación rural o de comunidades, y, cuando aplique, un actor externo (donante, organización nacional o internacional, etc.) para cada iniciativa.

La mayoría, si no la totalidad, de los entrevistados(as) deben tener una perspectiva de todo el paisaje. No queremos respuestas que sean informadas solamente por el conocimiento del entrevistado(a) respecto a su finca o pueblo. Una posible excepción es cuando algunos actores ubicados en comunidades estén familiarizados principalmente con un área local, pero no con todo el paisaje. Esto está OK en la medida que sus perspectivas parezcan temáticamente anchas (i.e., consciente de las cuestiones de agricultura, medios de vida y conservación, además de las instituciones, políticas y estrategias relacionadas a ellas).

Presentación nuevo contacto en el TIER 2

Introducción: Actualmente Amigos de la Ecoagricultura en asocio con el CATIE estamos llevando a cabo una sistematización o búsqueda de experiencias de ecoagricultura en América Latina. La finalidad de este estudio es conocer y aprender sobre el contexto o bajo qué condiciones de dan este tipo de manejo de integral de paisajes. Nosotros definimos una iniciativa de ecoagricultura como aquella iniciativa que busca al mismo tiempo mejorar la producción agropecuaria, la conservación de los recursos naturales, la calidad y medio de vida de las comunidades y la gobernanza o empoderamiento de las comunidades sobre sus RN a una escala de paisaje.

Descripción proyecto: La primera etapa del proyecto consistió en contactar a las personas líderes o personas contacto de un conjunto de iniciativas, proyectos o programas que buscamos a través del internet. En el caso del [INICIATIVA] contactamos al Sr. / Sra. [NOMBRE CONTACTO], al cual le solicitamos su colaboración con el llenado de una encuesta. Después de analizar las encuetas que fueron diligenciadas, seleccionamos unas iniciativas las cuales estamos interesados en conocer más detalladamente. Para lograr esto queremos entrevistar a varios actores o líderes claves en el paisaje que han venido trabajando con la iniciativa [INICIATIVA] y tienen un buen conocimiento del paisaje. Lo estamos contactando porque [NOMBRE CONTACTO] nos indicó que usted nos podría colaborar.

La entrevista: La entrevista que le vamos a hacer, dura aproximadamente una hora. En esta entrevista le haremos preguntas sobre el paisaje donde se encuentra ubicada la iniciativa [INICIATIVA], sobre la iniciativa misma, la participación de diferentes actores o grupos en la iniciativa, las instituciones y la gestión de la iniciativa, políticas y gobernanza, y finalmente sobre las inversiones y los logros de la misma. No dude en interrumpirme o preguntarme si alguna pregunta o concepto no es claro. Algunas veces usamos terminología que es muy específica y que puede ser confusa, así que por favor no dude en preguntarme. De igual manera si no tiene conocimiento o información para responder alguna pregunta no hay ningún problema y solo pasamos a la siguiente pregunta.

Antes de comenzar me gustaría agradecerle de antemano por su tiempo y colaboración, y también me gustaría saber si tiene alguna duda o comentario.

Presentación contacto del TIER 1

De antemano le agradezco por su colaboración y participación, en días anteriores estuvimos revisando y analizando las diferentes encuestas que fueron llenadas por las diferentes iniciativas en América Latina, y seleccionamos la iniciativa [XXXX] para conocerla más detalladamente.

En esta segunda etapa de nuestra búsqueda de iniciativas ecoagrícolas, nos gustaría poder entrevistar a varios actores o líderes del paisaje que tiene buen conocimiento sobre la iniciativa y que ha estado involucrado con la iniciativa durante un buen tiempo. Lo ideal sería si me puede brindar los nombres y teléfonos de otras 5 o 6 personas que usted considera pueden participar en la entrevista y que han estado trabajando en los diferentes componentes como el agropecuario, conservación, calidad de vida de las comunidades, gobernanza, educación, etc. y/o que hace parte de organizaciones locales, gobiernos, ONG, universidades, etc. [ANOTAR CONTACTOS].

La entrevista:

La entrevista durará aproximadamente una hora y cubriremos temas similares a la encuesta que ya diligenció pero en más detalle. No dude en interrumpirme o preguntarme si alguna pregunta o concepto no es claro. Algunas veces usamos terminología que es muy específica y que puede ser confusa, así que por favor no dude en preguntarme. De igual manera si no tiene conocimiento o información para responder alguna pregunta no hay ningún problema y solo pasamos a la siguiente pregunta.

Antes de comenzar me gustaría agradecerle de antemano por su tiempo y colaboración, y también me gustaría saber si tiene alguna duda o comentario.

SECCION 1: INFORMACIÓN SOBRE LA PERSONA ENTREVISTADA

Por favor, provea la siguiente información básica sobre usted mismo y su papel en el paisaje y/o en la iniciativa de paisaje.

*Primer nombre:

Segundo nombre:

*Apellidos:

*Dirección correo electrónico:

*Nombre de su organización:

Teléfono (Por favor incluir el código del país - región):

*Su posición o cargo dentro de la organización:

¿Cuál es su papel en el paisaje o en la iniciativa de paisaje? (por favor describa):

SECCION 2: INFORMACIÓN SOBRE EL PAISAJE

POR FAVOR USE EL CUADRO PARA INGRESAR LA INFORMACIÓN ¿? 2.1, 2.11.
ESTE SEGURA QUE **INDICA LA IMPORTANCIA**. 1: más importante, 4: menos

En orden de importancia, cuáles son las cuatro sectores económicos (p.e. *agropecuario, forestal, pesquero, turismo, extracción, industria y otros*) más importantes en el paisaje?
(HECHOS/TRIANGULAR)

Si la agricultura es mencionada, por favor clasifique si es:

Sector		Pequeña escala			Mediana escala		Gran escala	
		Subsistencia	Comercial		Comercial		Comercial	
			Mercados locales / nacionales	Mercados internacionales / Exportación	Mercados locales / nacionales	Mercados internacionales / Exportación	Mercados locales / nacionales	Mercados internacionales / Exportación
Agropecuario								
Forestal								
Pesca								
Turismo								
Extracción								
Industria								
Otro:								
Otro:								

Es posible que varias de esas categorías agrícolas sean prioritarias

POR FAVOR USE EL CUADRO PARA INGRESAR LA INFORMACIÓN ¿? 2.2, 2.2.1.
ESTE SEGURA QUE **INDICA LA IMPORTANCIA**. 1: más importante, 4: menos importante

En orden de importancia, cuáles son los cultivos u otros productos agropecuarios / forestales más importantes en el paisaje?
(HECHOS / ¿? SOLO A 1)
Nota entrevistador: *Esto puede incluir cultivos, ganadería, fibras, cultivos para biocombustible, otros productos maderables y no maderables, etc.*
Se debe especificar el cultivo o el producto, *por ejemplo, maíz, banano, café, leche, puercos, teca o piscícolas.*
"Más importantes" *en términos de su contribución económica (para el caso de cultivos orientados a mercados) o contribución para suplir los mercados locales (para el caso de los cultivos de subsistencia)*

Cuál es el mercado principal o usos para cada uno de esos cinco cultivos o productos:
(HECHOS / ¿? SOLO A 1)

p.e cultivos (cuáles?), ganadería, fibras, cultivos para biocombustible, otros productos maderables y no maderables, etc.	Subsistencia	Mercados locales / nacionales	Mercados internacionales / Exportación
Prod1:			

Prod2:			
Prod3:			
Prod4:			
Prod5:			

Cuál es el tipo de tenencia de la tierra más común en el paisaje?
(HECHOS / ¿? SOLO A 3)
Nota entrevistador: *La meta es entender los principales tipos de propiedad y tenencia de la tierra en el paisaje.*

Ejemplos de las categorías de tenencia	**Solo las más importantes:** abarcan más del 10-20% del paisaje
a) tierras públicas o del estado	
b) tierras comunales	
c) propiedad privada manejada por los propietarios	
d) propiedad privada manejada por compañías	
e) propiedad privada aprovechada o manejada por arrendatarios	
Otro:	
Otro:	

Cómo considera usted que el paisaje donde se encuentra la iniciativa es definido o delimitado geográficamente?
(INTERPRETATIVA / ¿? TODOS) aclarar
Nota entrevistador: *De pronto es necesario hacer la misma pregunta de diferentes maneras para garantizar que el entrevistado la entienda. Básicamente queremos saber cómo el entrevistado ve la extensión geográfica del paisaje, y cómo ésta es delimitada. La pregunta* ***NO*** *pretende preguntar sobre el proceso de delineación del paisaje.*

Queremos saber si el entrevistado piensa que los límites corresponden a:	Si	No
Jurisdicciones (p.e. villas, municipalidades, cantones)		
Límite legal (p.e. áreas protegidas y sus zonas de amortiguamiento)		
Cuencas		
Río, lago, divisoria de aguas, u otro elemento geográfico mayor		
Ecosistema (p.e. un humedal grande)		
Rango de una o más especies de interés para la conservación		
Límite cultural o grupo étnico		
Un problema que debía ser resuelto		
Usaron otro criterio? Cuál?		
Otro:		
Otro:		

Los límites originales del paisaje han cambiado? Cómo y por qué?
(INTERPRETATIVA/ ¿? TODOS)

Hubo eventos (naturales, políticos, sociales, económicos, conflictos) que afectaron el paisaje y generaron cambios importantes en los últimos 25 años. Por favor, mencionar los más importantes.

(INTERPRETATIVA/ ¿? TODOS)

Nota entrevistador: *Esta debe ser una pregunta abierta. Queremos saber si hay un entendimiento común del paisaje y sus dinámicas. La pregunta también debe revelar algunos de los retos que la iniciativa pretende resolver. Si el entrevistado necesita o quiere ayuda para entender la pregunta, se pueden dar algunos ejemplos de cambios importantes, como los cambios mayores en el uso de la tierra o las actividades económicas (p.e. deforestación, nuevas plantaciones), conflictos/guerras, e importantes designaciones de tierras como áreas protegidas.*

SECCION 3: INFORMACIÓN SOBRE LA INICIATIVA

Cuáles fueron los retos principales o problemas que motivaron la creación de la iniciativa de paisaje?

(INTERPRETATIVA/ ¿? TODOS)

Nota entrevistador: *Hacer como pregunta abierta. Esperamos que en algunos casos habrá un reto o un problema principal, mientras que en otros casos habrán más. Queremos que el entrevistado identifique los retos/problemas **más importantes** - no una lista inservible. Si se ve que el entrevistado se esta desviando, hacerlo que mencione **máximo tres o cuatro** de los retos claves.*

1)
2)
3)
4)

Cuáles cree usted son los objetivos más importantes de la iniciativa?

(INTERPRETATIVA/ ¿? TODOS)

Nota entrevistador: *De nuevo, puede haber solo un objetivo o varios. Si el entrevistado piensa que hubo varios objetivos, déjelo listarlos y anótelos. Pero asegúrese al final que tiene claro **los tres o cuatro objetivos más importantes**, ya que se preguntará más adelante sobre la efectividad de la iniciativa en relación a esos objetivos.*

1)
2)
3)
4)

Cuáles fueron las 3 o 4 actividades o inversiones principales de la iniciativa?

(INTERPRETATIVA/ ¿? TODOS)

Nota entrevistador: *Queremos obtener dos cosas de esta pregunta.*

La primera, *es entender qué hizo la iniciativa y si esto incluyó un conjunto de actividades “balanceadas” para alcanzar los múltiples objetivos de la iniciativa. Por lo tanto, l**a pregunta debe ser abierta** para dejar que la persona mencione las 3 o 4 principales actividades, inversiones, o intervenciones, a pesar del sector u objetivo en la que esta caiga.*

Lo Segundo*, es entender si la iniciativa realmente incluyó actividades relacionadas a la agricultura (cultivos/ganado), conservación, medios de vidas rurales, y fortalecimiento institucional - inclusive si el entrevistado no identifica estas en las tres o cuatro actividades. Por lo tanto, si las tres o cuatro actividades no incluyen las actividades o inversiones relacionadas a las categorías, hacer la siguiente pregunta.*

1)
2)
3)
4)

La iniciativa incluyó alguna actividad relacionada con X?
(INTERPRETATIVA/ ¿? SI ES NECESARIO)
Nota entrevistador: *X puede ser agricultura (cultivos/ganado), conservación, medios de vidas rurales, y fortalecimiento institucional, si no fue mencionada en las tres o cuatro más importantes.*

Cuáles fueron las principales fuentes de financiamiento para las actividades o componentes?
(HECHOS / TRIANGULAR)
Nota entrevistador: *Esta pregunta debe ser hecha varias veces,* ***una para cada una de las tres o cuatro actividades*** *o inversiones que fueron mencionadas en la pregunta 3.3.*

Actividades mencionadas 3.3 y 3.3.1	*apoyo local en especie / directo (p.e. plantación árboles, terrazas hechas por los finqueros o grupos comunitarios, esfuerzos de los trabajadores de los gobiernos)*	*apoyo externo (p.e. donante o fondos del gobierno)*

<u>SECCION 4</u>: PARTICIPACIÓN EN LA INICIATIVA
Cuáles fueron los principales grupos involucrados en el **diseño** de la iniciativa? Cuál fue el papel de cada uno de estos grupos?
(INTERPRETATIVA/ ¿? TODOS)
Nota entrevistador: *Esta es una pregunta abierta.* ***Estamos interesados en ver si los entrevistados identifican los grupos locales y externos, y cuáles sectores son considerados <u>los más influyentes</u>.*** *Los grupos pueden ser. Los entrevistados puede que mencionen varios grupos de actores del paisaje, como grupos que no son actores del paisaje pero que están involucrados en el financiamiento/desarrollo/facilitación de la iniciativa.*

Grupos (p.e *organizaciones locales/comunitarias, gobiernos locales, gobiernos regionales/nacionales, sociedad civil, sector privado, donantes, organizaciones internacionales, academia u otros)*	Papel	Externo o local

Grupos (p.e *organizaciones locales/comunitarias, gobiernos locales, gobiernos regionales/nacionales, sociedad civil, sector privado, donantes, organizaciones internacionales, academia u otros)*	Papel	Externo o local

Se involucraron los grupos marginados del paisaje en el **diseño** de la iniciativa?
(INTERPRETATIVA/ ¿? TODOS SI NO SALIÖ EN LA PREGUNTA 4.1, sino obviar)
Nota entrevistador: *"Grupos marginalizados" puede incluir minorías étnicas, campesinos sin tierra y mujeres. De todas maneras, sin definir el término, le permitimos al entrevistado interpretar la pregunta basado en los grupos que él piensa son marginalizados dentro del paisaje.*

Se involucraron a los pequeños productores o las asociaciones de productores [nota entrevistador: incluir si aplica a los gestores forestales de pequeña escala] del paisaje en el **diseño** de la iniciativa?
(INTERPRETATIVA/ ¿? TODOS SINO SALIO EN LA PREGUNTA 4.1)

Se involucraron a los grandes productores o agronegocios [nota entrevistador: incluir si aplica a los gestores forestales de gran escala] del paisaje en el **diseño** de la iniciativa?
(INTERPRETATIVA/ ¿? TODOS SINO SALIO EN LA PREGUNTA 4.1)

Considera que se debió incluir algún grupo de actores en el **diseño** de la iniciativa y que no fue incluido? Cuáles grupos?
(INTERPRETATIVA/ ¿? TODOS)

Cuáles fueron los principales grupos involucrados en la **implementación** de la iniciativa? Cuál fue el papel de cada uno de estos grupos?
(INTERPRETATIVA/ ¿? TODOS)
Nota entrevistador: *Esta es una pregunta abierta.* ***Estamos interesados en ver si los entrevistados identifican los grupos locales y externos, y cuáles sectores son considerados <u>los más influyentes</u>.*** *Los entrevistados puede que mencionen varios grupos de actores del paisaje, como grupos que no son actores del paisaje pero que están involucrados en el financiamiento/desarrollo/facilitación de la iniciativa.*

Grupos (p.e *organizaciones locales/comunitarias, gobiernos locales, gobiernos*	Papel	Externo o local

regionales/nacionales, sociedad civil, sector privado, donantes, organizaciones internacionales, academia u otros)		

Se involucraron los grupos marginados del paisaje en la **implementación** de la iniciativa?
(INTERPRETATIVA/ ¿? TODOS SINO SALIO EN LA PREGUNTA 4.2)
Nota entrevistador: *s. Preguntar sin definir el término "marginado", le permitimos al entrevistado interpretar la pregunta basado en los grupos que él piensa son marginado dentro del paisaje. Si el entrevistado no entiende el concepto o se desvía, dar ejemplos: "Grupos marginados" puede incluir minorías étnicas, campesinos sin tierra y mujeres*

Se involucraron a los pequeños productores o las asociaciones de productores [nota entrevistador: incluir si aplica a los gestores forestales de pequeña escala] del paisaje en la **implementación** de la iniciativa?
(INTERPRETATIVA/ ¿? TODOS SINO SALIO EN LA PREGUNTA 4.2)

Se involucraron a los grandes productores o agronegocios [nota entrevistador: incluir si aplica a los gestores forestales de gran escala] del paisaje en la **implementación** de la iniciativa?
(INTERPRETATIVA/ ¿? TODOS SINO SALIO EN LA PREGUNTA 4.2)

Considera que se debió incluir algún grupo de actores en la **implementación** de la iniciativa y que no fue incluido? Cuáles grupos?
(INTERPRETATIVA/ ¿? TODOS)

<u>SECCION 5</u>: INSTITUCIONES Y GESTION DE LA INICIATIVA

Al comienzo de la iniciativa existían grupos en el paisaje que estaban liderando o facilitando actividades para apoyar el manejo integrado del paisaje (p.e. evaluaciones de paisaje, planeación, procesos multi-actores, etc)? Si fue así, cuáles fueron esos grupos y qué estaban haciendo?
(HECHOS/ TRIANGULACIÓN)

Grupos que existían	*<u>aspectos técnicos(</u> p.e. que tipo de información, datos, o análisis fueron usados para hacer la evaluación del paisaje)*	*<u>aspectos sobre el proceso</u> (p.e. cómo los grupos fueron ayudados para guiar o construir las decisiones sobre el manejo del paisaje, quién estuvo involucrado en el procesos de toma de decisiones, y si el proceso fue más tecnocrático o participativo)*

En el transcurso de la iniciativa se crearon nuevos grupos para liderar o facilitar las actividades del manejo integrado del paisaje?, o fueron grupos existentes que antes no cumplían estas funciones pero que después de la iniciativa tomaron este papel?. Si fue así, cuáles fueron esos grupos y qué hacen?
(HECHOS/ TRIANGULACIÓN)

Grupos creados	*<u>aspectos técnicos(</u> p.e. que tipo de información, datos, o análisis fueron usados para hacer la evaluación del paisaje)*	*<u>aspectos sobre el proceso</u> (p.e. cómo los grupos fueron ayudados para guiar o construir las decisiones sobre el manejo del paisaje, quién estuvo involucrado en el procesos de toma de decisiones, y si el proceso fue mas tecnocrático o participativo)*

Como son financiados los nuevos o existentes grupos? El financiamiento tiene un tiempo limitado o es contínuo?
(HECHOS/ TRIANGULACIÓN)

<u>SECCION 6</u>: POLÍTICAS Y GOBERNANZA

***<u>Nota entrevistador</u>*:** Provea una breve transición "Ahora, me gustaría preguntarle sobre el papel de las políticas apoyando o limitando el desarrollo de la iniciativa".

Hubo algunas políticas públicas, leyes, o procedimientos que fueron especialmente útiles para apoyar e incentivar desarrollo de la iniciativa?

(INTERPRETATIVA/ TRIANGULACIÓN)
Nota entrevistador: *Acá estamos preguntando específicamente sobre las políticas que apoyaron el proceso integrado o participativo del manejo del paisaje. Por lo tanto, eso puede incluir políticas de descentralización, políticas que reconocen a las entidades locales como administradores de los recursos, procesos a nivel regional para la planeación de los usos de la tierra o desarrollo territorial, etc.* ***NO*** *estamos preguntado a los entrevistadores que identifiquen las políticas que tienen el propósito de incrementar la compatibilidad entre la agricultura y el ambiente, o apoyar paisajes multifuncionales como los pagos por servicios ambientales, leyes para la protección ambiental, etc.*

Hubo alguna política pública, ley o procedimiento que especialmente obstaculizó el desarrollo de la iniciativa?
(INTERPRETATIVA/ TRIANGULACIÓN)
Nota entrevistador: *Similar a la pregunta anterior, acá estamos preguntando específicamente sobre las políticas que inhibieron el proceso integrado o participativo del manejo del paisaje. Por lo tanto, esta puede incluir estructuras de gobierno que fallaron en devolver el poder a las autoridades locales o entidades administradoras de los recursos naturales. De nuevo,* ***NO e****stamos preguntando al entrevistado identificar las políticas relacionadas a la agricultura y el ambiente, p.e subsidios perversos a la agricultura.*

La iniciativa resultó en algún cambio importante en la política o gobernanza en relación a uso tierra, el manejo de los recursos naturales, o la regulación de actividades económicas? Si fue así, por favor describa según su percepción los cambios más importantes y explique como la iniciativa lo logró.
(HECHOS/ TRIANGULACIÓN)
Nota entrevistador: *Similar a las preguntas 6.1 y 6.2, cuál es el contexto político para el proceso del manejo integrado del paisaje, acá se pregunta sobre el nivel en que la iniciativa incluyó el cambio de políticas como una estrategia para alcanzar los paisajes integrales y multifuncionales.* ***Por lo tanto, si la iniciativa resultó en nuevas leyes de protección ambiental, subsidios o incentivos para la agricultura sostenible, etc., esos pueden ser mencionados.*** *Igualmente estamos interesados en aprender sobre* ***nuevos sistemas de gobernanza o políticas,*** *por lo tanto cambios en la tierra o tenencia de la tierra, procesos de toma de decisiones, nuevas entidades de gobernanzas como mancomunidades, etc.*

Hay algunos cambios adicionales en las políticas o gobernanza que usted considera se deberían de crear o implementar para apoyar los objetivos de la iniciativa?
(INTERPRETATIVA/ TRIANGULACIÓN)

SECCION 7: RESULTADOS Y EFECTIVIDAD DE LA INICIATIVA
Al comienzo de la conversación, usted identificó tres [O la cantidad que mencionó en la pregunta 3.2] objetivos de la iniciativa de paisaje. Ahora nos gustaría conocer su opinión sobre la efectividad de la iniciativa en alcanzar cada objetivo. Me gustaría preguntarle en una escala del 1 al 7 cual fue el nivel de efectividad de cada objetivo, siendo. Luego me gustaría conocer por que les dio esa calificación (indicadores y/o resultado de la iniciaitva. Vamos a comenzar con el primer objetivo [mencionarlos].
(INTERPRETATIVA/ ¿? TODOS)

Objetivo (ver ¿? 3.2)	Nivel efectividad (**7** cuando se logró totalmente el objetivo, **4**	Por qué / cómo les asignó ese valor? Usó indicadores o percepción?. (trate de comprobar si los resultados son claramente atribuibles

	cuando se logró parcialmente y **1** cuando no hubo ningún progreso)	propiamente a la iniciativa)
4)		

Que tan efectiva ha sido la iniciativa reuniendo a los diferentes actores para incrementar la cooperación y resolver los conflictos para alcanzar los múltiples objetivos en el paisaje?
(INTERPRETATIVA/ ¿? TODOS)
Nota entrevistador: *Esta es una pregunta abierta. Buscamos entender de igual manera la parte exitosa y no exitosa del proceso del manejo del paisaje con múltiples actores. Queremos conocer si la iniciativa ayudó a incrementar la coordinación y colaboración entre sectores (p.e. agricultura, forestal, agua, salud) y a diferentes escalas (p.e. finca, villas, distritos, cuenca, región)*

Me gustaría preguntarle sobre los beneficios e inconvenientes de trabajar a escala de paisaje. De qué manera el enfoque de paisaje de la iniciativa ayudó a los actores a entender y a abordar mejor diferentes temáticas, problemas y retos en el paisaje? [Pausa para la persona responder, continuar con:] De qué manera el enfoque de paisaje dificultó el logro de objetivos claves?
(INTERPRETATIVA/ ¿? TODOS)
Nota entrevistador: *Estamos tratando de entender si el enfoque de manejo integral de paisajes (p.e. reuniendo personas de diferentes sectores y en diferentes escalas) ayuda a los actores a encontrar un sentido común entre los diferentes intereses, o áreas de negociación de discordia o conflicto?. Igualmente queremos entender si el enfoque de paisaje pudo haber distraído la atención de puntos claves locales, si este enfoque es considerado irrelevante por algunos actores que están más preocupados por asuntos sectoriales o locales, o si el enfoque de paisaje creó problemas muy grandes o complejos de resolver.*

Finalmente, me gustaría preguntarle sobre el impacto de la iniciativa en algunos grupos comunitarios en el paisaje. Me podría decir si la iniciativa benefició, no tuvo ningún efecto, o perjudicó a cada uno de los siguientes grupos? [Omitir los que no aplican para paisaje]
(INTERPRETATIVA/ ¿? TODOS)

Grupos	Benefició	No tuvo ningún efecto	Perjudicó
Pequeños productores y/o ganaderos			
Medianos productores y/o ganaderos			
Grandes productores y/o ganaderos beneficio			
Personas sin tierra (p.e como los trabajadores de las fincas, arrendatarios, “parceros”, “tala y quema”)			
Comerciantes e industriales agropecuarios.			
Responsables / administradores del bosque			
Comunidades nativas dependientes del bosque			

Grupos	Benefici ó	No tuvo ningún efecto	Perjudi có
Mujeres.			
Comunidades viviendo en los pueblos y/o ciudades (no involucradas con la agricultura / forestería).			
Más ricos:			
Más pobres:			
Otros:			

<u>SECCION 8</u>: LECCIONES APRENDIDAS Y REFLEXÓN GENERAL

Finalmente, nos gustaría solicitarle reflexionar críticamente sobre la iniciativa y compartir algunas de las lecciones que usted aprendió, y pensamientos sobre cómo las iniciativas de paisaje, como la actual, pueden ser más efectivas en el futuro.

Cuál fue el aspecto más exitoso de la iniciativa?
(INTERPRETATIVA/ ¿? TODOS, menos al que llenó la encuesta del TIER 1)

Cuál fue el aspecto menos exitoso de la iniciativa?
(INTERPRETATIVA/ ¿? TODOS, menos al que llenó la encuesta del TIER 1)

Si tuviera más plata para diseñar e implementar esta iniciativa qué haría diferente?
(INTERPRETATIVA/ ¿? TODOS, menos al que llenó la encuesta del TIER 1)
Realizaría un monitoreo y control más eficientes

De acuerdo a su experiencia, qué consejo le daría a sus colegas que están comenzando una iniciativa de paisaje?
(INTERPRETATIVA/ ¿? TODOS)
<u>Nota entrevistador:</u> *Esta pregunta está hecha para combinar las dos preguntas anteriores en términos de las lecciones aprendidas y los aspectos de la iniciativa que son replicables en cualquier lugar. Si el entrevistado no parece responder la pregunta de esta manera, siéntase libre de redirigirlo.*

[Termine agradeciendo a la persona por su participación y déjele saber que recibirá una copia del estudio cuando éste termine]

APPENDIX D

Description of each factor and its parameters, including the maximum values, minimum values and equations used to create the theoretical dataset. HB: handbook·

RUSLE (S=C•R•K•L•S) ($tonf \cdot acre^{-1} \cdot year^{-1}$)*			
Factors / Parameters	**Max**	**Min**	**Equations / Max and min values sources**
Cover - Management factor C (dimensionless)			
C factor	1	0	C= PLU•CC•SC•S
PLU (Prior Land Use)	1	0	PLU=Cf•Cb•EXP[(-Cur•Bur)+(Cus•Bus/Cf^Cuf)]
Cf: surface soil consolidation factor (decay exponentially when soil is left undisturbed)	1	0.05	"The value of Cf for freshly tilled conditions is 1. If the soil is left undisturbed, this value decays exponentially to 0.45 over 7 yr, or over some other length of time specified by the user". HB 703
Bur: Mass density of live and dead roots found in the upper inch of soil ($lbacre^{-1}in^{-1}$)	1,750	345	Based on the RUSLE2 CROP dataset and HB 703 tables
Bus: mass density of incorporate surface residue in the upper inch of soil ($lbacre^{-1}in^{-1}$)	1,700	0	Based on the RUSLE2 CROP dataset and HB 703 tables
Cuf: impact of soil consolidation on the relative effectiveness of incorporated residue		0.5	Describe the relative effectiveness of subsurface biomass in reducing erosion. The values were calibrated using information from Van Liew and Saxton (1983), values from table 5 and 5d in
Cb: relative effectiveness of subsurface residue in consolidation		0.951	Agricultural Handbook 537 (Wischmeier and Smith, 1978), and an extensive data set collected from a broad series of no-till experiments. hb 703
Cur: calibration coefficient indicating the impacts of the subsurface residues (acre in lb^{-1})	0.00398	0.00199	
Cus: calibration coefficient indicating the impacts of the subsurface residues (acre in lb^{-1})	0.000832	0.00042	
CC (Canopy cover)	1	0	CC= 1-Fc•exp(-0.1•H)
Fc: Fraction of land surface covered by canopy	1	0.05	HB 703
H: distance that rain drops fall after striking the canopy (ft)	33	0.5	Data based on the listed crops on the HB 703
SC (Surface cover)			SC=exp[-b•Sp•(0.24/Ru)^0.08]
b: empirical coefficient. indicate the effectiveness of surface cover in reducing soil loss	0.07	0.024	Extreme values from the different b values reported by several authors: Laflen et al., (1980) and Laflen and Colvin (1981) b=0.030 to 0.070 for row crops; Dickey et al., (1983) b=0.024-0.032 for small grains; b>0.05 small grains in northwestern wheat and range region; Simanton et al., (1984) b= 0.039 for rangeland. HB 703
Sp: Percentage of land area covered by surface cover (crop residue, rocks, cryotogams and other no erodible material that is in direct contact with the soil surface	100	0.1	HB 703

Ru: surface roughness in in	1.9	0.25	From table 5-5 in HB 703, In Figure 4-3 it is indicated that a Ru =4 indicate more roughness than from most primarily tillage operations. It is kept the value of 2 because Wischmeier and Smith (1978) affirms that the USLE equation estimate accurately soil loss for consistent cropping and management systems that have been represented in the erosion plot studies
SR (Surface roughness)	1	0.9	SR=exp[-0.66(Ru-0.24)]
Rainfall-runoff erosive factor R (100 foot•tonf•inch•acre^{-1} •hour^{-1}•year^{-1})**			
R factor			R = ∑(j=1 to j=n)E•I30
I30 (in/hr): Erosive rain Intensity	3.00	0.50	The limit of 3in/h is because median drop size does not continue to increase when intensities exceed this threshold (Carter et al., 1974). The limit for rain showers less than 0.5in and separated from other rain periods by more than 6 h are omitted, because these light rains are usually too small for practical significance and that, collectively, they have little effect on the distribution of the annual EI or erosion. Also reduce time consuming processing EI. HB 703
E (100ft tonf acre^{-1} in^{-1}): Kinematic Energy	10.81	6.80	E = (1099•(1-0.72•EXP($^{-1}$.27•I)))/100
j (no storm / yr): No events per year	50.00	5.00	HB 703
Soil - erodibility factor K (tonf•acre•hour•100^{-1}acre^{-1} foot^{-1} tonf^{-1} inch^{-1})***			
K factor			K= [2.1•〚10〛^(-4) (12-OM) M^1.14+3.25• (s-2)+2.5• (p-3)]/100
OM%: Organic matter	4.00	-	Based on the nomograph HB 537
Clay% (<0.002 mm)	40.00	10.00	
Silt% (0.002 - 0.1 mm)	70.00	10.00	Based on the nomograph HB 537
Sand% (0.1 - 2 mm)	70.00	10.00	Based on the nomograph HB 537
p: Permeability	5	2	Wischmeier and Smith (1978) affirms that the
s: Structure class	4	1	USLE equation estimate accurately soil loss “for medium – textured soil”
M			M=(%Silt +%Very fine sand)(100-%Clay);
Topographic factor (dimensionless)			
Slope length			L= (λ/72.6)^m
Slope steepness	10	2	S= IF(θ<5, (10.8•sinθ+0.03), (16.8•sinθ-0.5)) θ: slope angle in degrees
λ: Slope length (ft). Horizontal projection	400	10	Soil runoff will usually concentrate in less than 400ft, which is a practical slope length limit in many situations, although longer slope lengths of up to 1,000 ft are occasionally found. The equation for S can’t be applied to slopes shorter than 15 ft
m: a variable slope length exponent	0.44	0.17	m=β/(1+β)
β: ratio of rill erosion to inter-rill erosion	0.80	0.21	β=(sinθ/0.0896)/[3•(sinθ)^0.8+0.56]

*Conversion to SI system: 2.242 metric ton•ha^{-1}•yr^{-1}

**Conversion to SI system: 17.02 megajoule•millimeter•ha^{-1}•hour^{-1}•year^{-1}

*** Conversion to SI system: 0.1317 metric ton•ha•hour•ha^{-1}•megajoule^{-1}•millimeter^{-1}

APPENDIX E

Description of the selected soil conservation practices in terms on the mechanism to retain soil, pros and cons, and factors that limit the efficacy of the practices.

	Mulch	Cover crops	Hedgerow	Agroforestry
Mechanism	Mitigates the impact of the rain drops, reduction soil detachment and increase water infiltration (Donjadee & Chinnarasri, 2012).	The root system offers resistance to the overland flow (Edwards & Burney, 2005) Also, offers same protection as Mulch	Reduce Runoff, promotes deposition and water infiltration	Mitigates the impact of the rain drops, protect soil and return nutrients via litter or mulch material Deep roots favors water infiltration and reduce runoff (Niemeyer et al., 2013)
Pros	Reduce soil loss and runoff (Adekalu, Okunade, & Osunbitan, 2006) Mulch may form dams and build up hollows which delays the afterflow (Döring et al., 2005) Finer mulch texture cover higher land with not to moderate effects on soil moisture nor crop yield (Döring et al., 2005) Improves soil moisture, moderate soil thermal regime, improves soil aeration, promotes biological activity, improves soil structure, add organic matter and nutrients, reduction N loss (Acharya, Hati, & Bandyopadhyay, 2005)	Incorporate organic matter and nutrients to the soil (Edwards & Burney, 2005) Prevent nutrient loss (Ruiz-Colmenero, Bienes, & Marques, 2011) May form positive associations with crops providing key nutrients and improving main crop yield (i,e, total N content) (Armecin et al, 2005) Protect soils from extreme climatic fluctuations, improves soil aggregates (Armecin et al., 2005) In the long-run it facilitates water infiltration, increases soil organic carbon and aggregate stability, (Ruiz-Colmenero et al., 2013) Result in higher macrofauna density and biomass, higher density of facultative phytophagous, bacterial-feeding and predatory nematodes, and lower density of obligatory (Blanchart et al., 2006) Helps to solve weed management (Erenstein, 2003)	Facilitates terraces formation through time (Lin et al., 2009) Provides fodder for ruminants, mulch or grains (Angima et al., 2002; Dinh et al., 2014) Increase crop yields due to the control of soil loss and the improvement of soil bulk density, gravimetric moisture content and infiltration parameters (Oshunsanya, 2013) Increase soil organic matter, total nitrogen and total phosphorus contents (Bu et al., 2009)	More profitable than conventional agriculture (Neupane & Thapa, 2001) Deep-rooted trees reduce the environmental risk by NO3-N pollution and increased water retention capacity of subsurface soil (Wang, Zhang, Lin, & Zepp, 2011)
Cons	Low levels of mulch may have no effect on weeds, weed cover and above ground biomass of weeds (Döring et al., 2005) If poor planned it can affect sowing or tillage, increase diseases or pest, and limit seedling emergence (Acharya, Hati, Bandyopadhyay, 2004)	Competition with the main crop for water and nutrients may reduction main crop yields (Ruiz-Colmenero, Bienes, & Marques, 2011)	After long periods the portions below of the plant hedgerows can also suffer severe erosion (Chaowen et al., 2007) Can compete with main crop for nutrients and light (Dinh et al., 2014; Oshunsanya, 2013), Cutting cost to avoid crop competition increase farm labor (Kinama et al., 2007)	Lower trunk biomass and slower tree growth due to competition with crops during establishment (Ong et al., 2000) Superficial roots and high demand for water affect crop yields (Ong et al., 2000)
Efficacy reduced by	Slope gradient, soil type, mulch type and dominant soil process (Smets, Poesen, & Knapen, 2008) Dislodged by wind or frequent runoff (Edwards & Burney, 2005)	Quantity and quality of biomass (Edwards & Burney, 2005) Cover type (Ruiz-Colmenero, Bienes, & Marques, 2011) Insecure land tenure, need of short-term outcomes (Erenstein, 2003)	Low tillering ability and low root densities (Rodriguez, 1997; Xiao et al., 2011; Xiao et al., 2012) Steeper slopes and higher rainfall intensities (Xiao, et al., 2011) Tillage technologies (Thapa, Cassel, & Garrity, 1999)	Insecure land tenure, land fragmentation, poor extension service, limited technical know-how, and unavailability of planting materials (Neupane & Thapa, 2001) Mulch with poor nutrients quality and complex decomposition patterns (Heineman et al., 1997)

References

Acharya, C. L., Hati, K. M., & Bandyopadhyay, K. K. (2005). How Mulching Influences the Soil Environment. In D. Hillel, C. Rosenzweig, D. Powlson, K. Scow, M. Singer, & D. Sparks (Eds.), Encyclopedia of soils in the environment (1st ed., pp. 521–532). New York, NY: Academic Press.

Adekalu, K. O., Okunade, D. a., & Osunbitan, J. a. (2006). Compaction and mulching effects on soil loss and runoff from two southwestern Nigeria agricultural soils. Geoderma, 137(1-2), 226–230. doi:10.1016/j.geoderma.2006.08.012

Angima, S. D., Stott, D. E., O'Neill, M. K., Ong, C. K., & Weesies, G. a. (2002). Use of calliandra–Napier grass contour hedges to control erosion in central Kenya. Agriculture, Ecosystems & Environment, 91(1-3), 15–23. doi:10.1016/S0167-8809(01)00268-7

Armecin, R. B., Seco, M. H. P., Caintic, P. S., & Milleza, E. J. M. (2005). Effect of leguminous cover crops on the growth and yield of abaca (Musa textilis Nee). Industrial Crops and Products, 21(3), 317–323. doi:10.1016/j.indcrop.2004.04.028

Blanchart, E., Villenave, C., Viallatoux, a., Barthès, B., Girardin, C., Azontonde, a., & Feller, C. (2006). Long-term effect of a legume cover crop (Mucuna pruriens var. utilis) on the communities of soil macrofauna and nematofauna, under maize cultivation, in southern Benin. European Journal of Soil Biology, 42, S136–S144. doi:10.1016/j.ejsobi.2006.07.018

Bu, C., Cai, Q., Ng, S., Chau, K., & Ding, S. (2009). Effects of hedgerows on sediment erosion in Three Gorges Dam Area , China. International Journal of Sediment Research, 23(2), 119–129.

Chaowen, L., Shihua, T., Jingjing, H., & Yibing, C. (2007). Effects of plant hedgerows on soil erosion and soil fertility on sloping farmland in the purple soil area. Acta Ecologica Sinica, 27(6), 2191–2198. doi:10.1016/S1872-2032(07)60050-X

Dinh, V., Hilger, T., Macdonald, L., Clemens, G., Shiraishi, E., Duc, T., … Cadisch, G. (2014). Field Crops Research Mitigation potential of soil conservation in maize cropping on steep slopes. Field Crops Research, 156, 91–102. doi:http://dx.doi.org/10.1016/j.fcr.2013.11.002

Donjadee, S., & Chinnarasri, C. (2012). Effects of rainfall intensity and slope gradient on the application of vetiver grass mulch in soil and water conservation. International Journal of Sediment Research, 27(2), 168–177. doi:10.1016/S1001-6279(12)60025-0

Döring, T. F., Brandt, M., Heß, J., Finckh, M. R., & Saucke, H. (2005). Effects of straw mulch on soil nitrate dynamics, weeds, yield and soil erosion in organically grown potatoes. Field Crops Research, 94(2-3), 238–249. doi:10.1016/j.fcr.2005.01.006

Edwards, L., & Burney, J. (2005). Cover crops. In D. Hillel, J. Hatfield, D. S. Powlson, C. Rosenzweig, K. M. Scow, M. J. Singer, & D. L. Sparks (Eds.), Encyclopedia of soils in the environment (1st ed., p. 592). New York, USA: Elsevier.

Erenstein, O. (2003). Smallholder conservation farming in the tropics and sub-tropics: a guide to the development and dissemination of mulching with crop residues and cover crops. Agriculture, Ecosystems & Environment, 100(1), 17–37. doi:10.1016/S0167-8809(03)00150-6

Heineman, A. ., Otieno, H. J. ., Mengich, E. ., & Amadalo, B. . (1997). Growth and yield of eight agroforestry tree species in line plantings in Western Kenya and their effect on maize yields and soil properties. Forest Ecology and Management, 91(1), 103–135. doi:10.1016/S0378-1127(96)03885-6

Kinama, J. M., Stigter, C. J., Ong, C. K., Ng’ang'a, J. K., & Gichuki, F. N. (2007). Contour Hedgerows and Grass Strips in Erosion and Runoff Control on Sloping Land in Semi-Arid Kenya. Arid Land Research and Management, 21(1), 1–19. doi:10.1080/15324980601074545

Lin, C., Tu, S., Huang, J., & Chen, Y. (2009). The effect of plant hedgerows on the spatial distribution of soil erosion and soil fertility on sloping farmland in the purple-soil area of China. Soil and Tillage Research, 105(2), 307–312. doi:10.1016/j.still.2009.01.001

Neupane, R. P., & Thapa, G. B. (2001). Impact of agroforestry intervention on soil fertility and farm income under the subsistence farming system of the middle hills, Nepal. Agriculture, Ecosystems & Environment, 84(2), 157–167. doi:10.1016/S0167-8809(00)00203-6

Niemeyer, R. J., Fremier, A. K., Heinse, R., Chávez, W., & Declerck, F. A. J. (2013). Woody Vegetation Increases Saturated Hydraulic Conductivity in Dry Tropical Nicaragua. Vadose Zone Journal, 13(1), 11. doi:10.2136/vzj2013.01.0025

Ong, C. K., Black, C. R., Wallace, J. S., Khan, A. A. H., Lott, J. E., Jackson, N. A., … Smith, D. M. (2000). Productivity , microclimate and water use in Grevillea robusta -based agroforestry systems on hillslopes in semi-arid Kenya. Agriculture, Ecosystems and Environment, 80, 121–141.

Oshunsanya, S. O. (2013). Spacing effects of vetiver grass (Vetiveria nigritana Stapf) hedgerows on soil accumulation and yields of maize–cassava intercropping system in Southwest Nigeria. Catena, 104, 120–126. doi:10.1016/j.catena.2012.10.019

Rodriguez, O. S. P. (1997). Hedgerows and mulch as soil conservation measures evaluated under field simulated rainfall. Soil Technology, 11, 79–93.

Ruiz-Colmenero, M., Bienes, R., Eldridge, D. J., & Marques, M. J. (2013). Vegetation cover reduces erosion and enhances soil organic carbon in a vineyard in the central Spain. Catena, 104, 153–160. doi:10.1016/j.catena.2012.11.007

Ruiz-Colmenero, M., Bienes, R., & Marques, M. J. (2011). Soil and water conservation dilemmas associated with the use of green cover in steep vineyards. Soil and Tillage Research, 117, 211–223. doi:10.1016/j.still.2011.10.004

Smets, T., Poesen, J., & Knapen, a. (2008). Spatial scale effects on the effectiveness of organic mulches in reducing soil erosion by water. Earth-Science Reviews, 89(1-2), 1–12. doi:10.1016/j.earscirev.2008.04.001

Thapa, B. B., Cassel, D. K., & Garrity, D. P. (1999). Ridge tillage and contour natural grass barrier strips reduce tillage erosion $. Soil and Tillage Research, 51, 341–356.

Wang, Y., Zhang, B., Lin, L., & Zepp, H. (2011). Agroforestry system reduces subsurface lateral flow and nitrate loss in Jiangxi Province, China. Agriculture, Ecosystems & Environment, 140(3-4), 441–453. doi:10.1016/j.agee.2011.01.007

Xiao, B., Wang, Q., Wang, H., Dai, Q., & Wu, J. (2011). The effects of narrow grass hedges on soil and water loss on sloping lands with alfalfa (Medicago sativa L.) in Northern China. Geoderma, 167-168, 91–102. doi:10.1016/j.geoderma.2011.09.010

Xiao, B., Wang, Q., Wang, H., Wu, J., & Yu, D. (2012). The effects of grass hedges and micro-basins on reducing soil and water loss in temperate regions: A case study of Northern China. Soil and Tillage Research, 122, 22–35. doi:10.1016/j.still.2012.02.006

APPENDIX F

Establishment and maintenance cost for the selected soil conservation practices. Some cost varies depending the slope steepness (gentle <15%, moderate 15-30%, steep >15%). Cost are established at pixel level (900m2).WD: Working days

	Hedgerow								
	<15%, 60 lineal m			15-30%, 90lineal m			>15%, 180lineal m		
Establishment	Qty	$	Total ($/ha)	Qty	$	Total ($/ha)	Qty	$	Total ($/ha)
WD*	4.4	18.0	79.1	8.0	18.0	143.8	14.0	18.0	251.6
Seeds (kg)	10.0	5.0	50.0	18.2	5.0	90.9	31.8	5.0	159.1
Maintenance (y)									
WD	1.1	18.0	19.8	2.0	18.0	35.9	3.5	18.0	62.9
Total			**148.8**			**270.6**			**473.6**

	Agroforestry high density			Agroforestry low density		
	277 trees**			62 trees***		
Establishment	Qty	$	Total ($/ha)	Qty	$	Total ($/ha)
WD	13.1	18.0	235.7	3.2	18.0	57.7
Seeds (kg)****	0.06	96.0	6.7	0.01	87.0	1.4
Maintenance (y)						
WD	13.1	18.0	235.7	3.2	18.0	57.7
Total			**462.2**			**116.7**

	Mulch			Cover crops		
	<15%			>15%		
Establishment	Qty	$	Total ($/ha)	Qty	$	Total ($/ha)
WD	8.5	18.0	153.1	4.3	18.0	76.5
Seeds (kg)				51.6	5.0	258.1
Animal (day)	1.4	20.0	28.4			
Maintenance (y)						
WD	7.1	18.0	127.6	7.1	18.0	127.6
Total			**309.1**			**462.2**

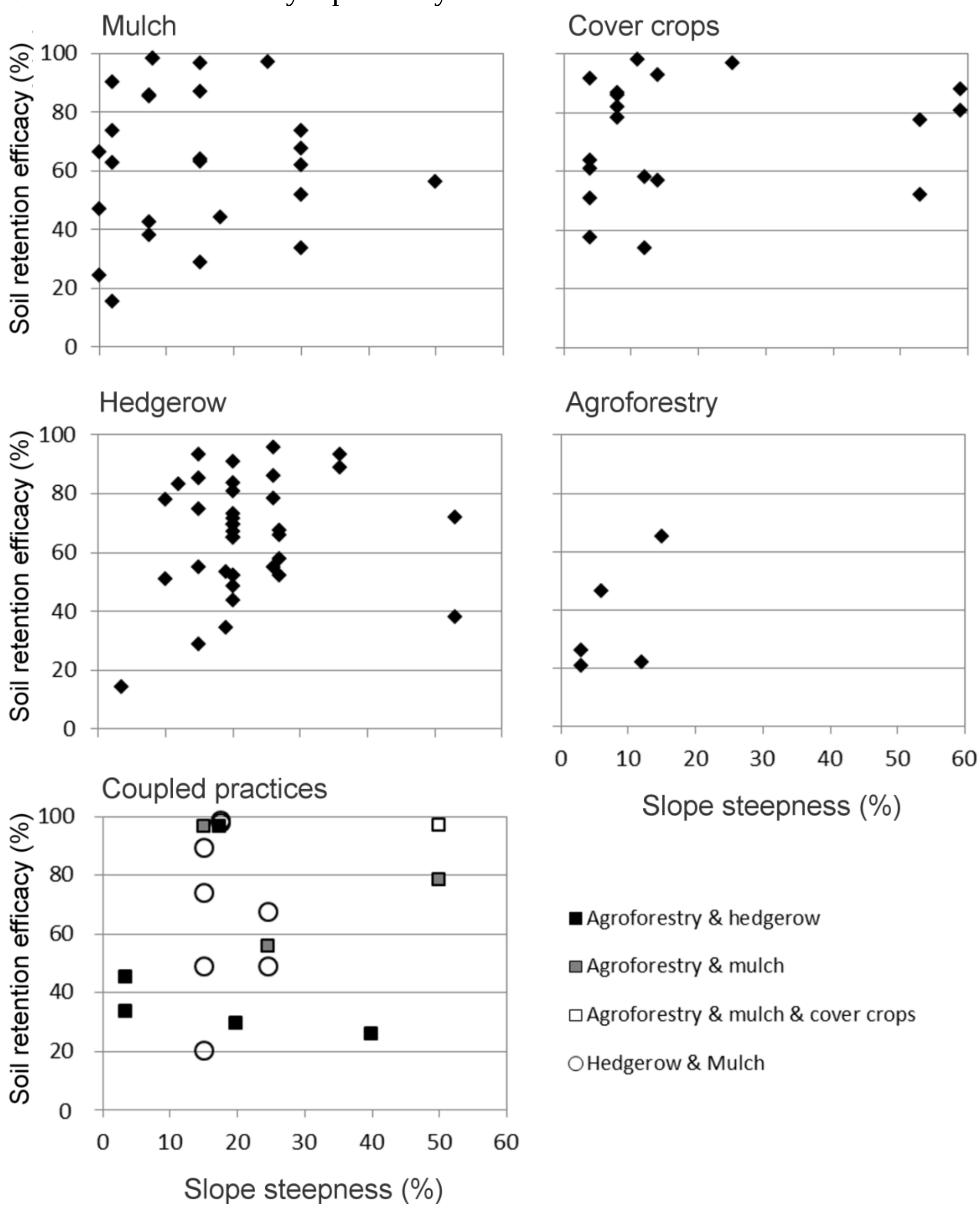
* Minimum wage in Costa Rica for 2014 is ₡8944.51 according to the Ministry of labor and Social Security (http://www.mtss.go.cr/images/stories/Lista_salarios-2014-1semestre.pdf). We used the average value reported in Oanda to convert it from Costa Rica currency to US dollar (₡497.677=$1).
**Highest tree density usually associated to pastures. Density reported in the agroforestry guideline of the Costa Rican national office (http://onfcr.org/media/uploads/documents/guia_saf_onf_para_web.pdf).
*** Rainforest Alliance certified coffee farms number of trees in average (http://www.rainforest-alliance.org/about/documents/tensie-25anniversary-presentation.pdf)
****One kilogram of mixed seeds of endangered trees species contain in average 19,950 viable seeds per kilogram.

APPENDIX G

Results from the literature review to estimate the soil retention efficacy of each soil conservation practice we modeled.

We conducted a literature review to estimate the soil retention efficacy (SRE) of each soil conservation practice. A larger numbers of the assessed experiments were conducted at gentle slopes (Figure 1).

Figure 1. Soil retention efficacy reported by 30 studies and 107 observations



We estimated SRE since the reported combinations of soil conservations practices in the reviewed experiments did not match the combinations of our ideal cropping systems. Also, we consider the high variability of the reported SRE and decided to choose a conservative method. The estimated SRE is the sum of the minimum reported SRE for each soil conservation practice in each ideal cropping system. Ideal cropping systems at slopes higher than 30% should not incorporate mulching practices but cover crops. We used the average estimated SRE for ideal cropping systems using mulching or cover crops (i.e. perennial avg =59%) (Table 1). Reported SRE corresponds to seventeen experiments also with highly variable results. Table 1 also shows the minimum value reported for the combinations reported in the reviewed research.

Table 1. Minimum reported and estimated soil retention efficacy (SRE) for coupled soil conservation practices. Reported soil retention efficacy corresponds to the minimum reported value in seventeen experiments. Estimated SRE is the sum of the minimum SRE reported for each soil conservation practice.

Coupled soil conservation practices	**Mulch**	**Cover crops**	**Hedgerow**	**Agroforestry**	**SRE**
Reported SRE			X	X	26
	X			X	56
	X	X		X	97
	X		X		20
Estimated SRE per ideal cropping system					
Perennial		X	X	X	69
	X		X	X	50
Annual		X	X	X	69
	X		X	X	50
Semi-perennial			X	X	35
Pasture			X	X	35

References

Adekalu, K. O., Okunade, D. a., & Osunbitan, J. a. (2006). Compaction and mulching effects on soil loss and runoff from two southwestern Nigeria agricultural soils. Geoderma, 137(1-2), 226–230. doi:10.1016/j.geoderma.2006.08.012

Alegre, J. C., & Rat, M. R. (1996). Soil and water conservation by contour hedging in the humid tropics of Peru. Agriculture, Ecosystems and Environment, (57), 17–25.

Angima, S. D., Stott, D. E., O'Neill, M. K., Ong, C. K., & Weesies, G. a. (2002). Use of calliandra–Napier grass contour hedges to control erosion in central Kenya. Agriculture, Ecosystems & Environment, 91(1-3), 15–23. doi:10.1016/S0167-8809(01)00268-7

Bhatt, R., & Khera, K. L. (2006). Effect of tillage and mode of straw mulch application on soil erosion in the submontaneous tract of Punjab, India. Soil and Tillage Research, 88(1-2), 107–115. doi:10.1016/j.still.2005.05.004

Blanchart, E., Villenave, C., Viallatoux, a., Barthès, B., Girardin, C., Azontonde, a., & Feller, C. (2006). Long-term effect of a legume cover crop (Mucuna pruriens var. utilis) on the communities of soil macrofauna and nematofauna, under maize cultivation, in southern Benin. European Journal of Soil Biology, 42, S136–S144. doi:10.1016/j.ejsobi.2006.07.018

Bu, C., Cai, Q., Ng, S., Chau, K., & Ding, S. (2009). Effects of hedgerows on sediment erosion in Three Gorges Dam Area , China. International Journal of Sediment Research, 23(2), 119–129.

Dinh, V., Hilger, T., Macdonald, L., Clemens, G., Shiraishi, E., Duc, T., … Cadisch, G. (2014). Field Crops Research Mitigation potential of soil conservation in maize cropping on steep slopes. Field Crops Research, 156, 91–102. doi:http://dx.doi.org/10.1016/j.fcr.2013.11.002

Donjadee, S., & Chinnarasri, C. (2012). Effects of rainfall intensity and slope gradient on the application of vetiver grass mulch in soil and water conservation. International Journal of Sediment Research, 27(2), 168–177. doi:10.1016/S1001-6279(12)60025-0

Döring, T. F., Brandt, M., Heß, J., Finckh, M. R., & Saucke, H. (2005). Effects of straw mulch on soil nitrate dynamics, weeds, yield and soil erosion in organically grown potatoes. Field Crops Research, 94(2-3), 238–249. doi:10.1016/j.fcr.2005.01.006

FAO. (2000). Manual on integrated soil management and conservation practices (1st ed., p. 228). Rome, Italy: Food and Agriculture Organization of the United Nationas. Retrieved from ftp://ftp.fao.org/agl/agll/docs/lw8e.pdf

Gómez, J. a., Guzmán, M. G., Giráldez, J. V., & Fereres, E. (2009). The influence of cover crops and tillage on water and sediment yield, and on nutrient, and organic matter losses in an olive orchard on a sandy loam soil. Soil and Tillage Research, 106(1), 137–144. doi:10.1016/j.still.2009.04.008

Guto, S. N., de Ridder, N., Giller, K. E., Pypers, P., & Vanlauwe, B. (2012). Minimum tillage and vegetative barrier effects on crop yields in relation to soil water content in the Central Kenya highlands. Field Crops Research, 132, 129–138. doi:10.1016/j.fcr.2011.10.014

Huang, D., Han, J. G., Wu, J. Y., Wang, K., Wu, W. L., Teng, W. J., & Sardo, V. (2010). Grass hedges for the protection of sloping lands from runoff and soil loss: An example from Northern China. Soil and Tillage Research, 110(2), 251–256. doi:10.1016/j.still.2010.08.013

INIA. (2002). Tecnologías apropiadas para el manejo sustentable de los suelos de la región del Maule. (E. Varas & J. Riquelme, Eds.) (Serie Acta., p. 146). Villa Alegre, Chile: Instituto de Investigaciones Agropecuarias, INIA.

Kinama, J. M., Stigter, C. J., Ong, C. K., Ng'ang'a, J. K., & Gichuki, F. N. (2007). Contour Hedgerows and Grass Strips in Erosion and Runoff Control on Sloping Land in Semi-Arid Kenya. Arid Land Research and Management, 21(1), 1–19. doi:10.1080/15324980601074545

Lenka, N. K., Dass, A., Sudhishri, S., & Patnaik, U. S. (2012). Soil carbon sequestration and erosion control potential of hedgerows and grass filter strips in sloping agricultural lands of eastern India. Agriculture, Ecosystems & Environment, 158, 31–40. doi:10.1016/j.agee.2012.05.017

Li, X.-H., Zhang, Z.-Y., Yang, J., Zhang, G.-H., & Wang, B. (2011). Effects of Bahia Grass Cover and Mulch on Runoff and Sediment Yield of Sloping Red Soil in Southern China. Pedosphere, 21(2), 238–243. doi:10.1016/S1002-0160(11)60123-9

Lin, C., Tu, S., Huang, J., & Chen, Y. (2009). The effect of plant hedgerows on the spatial distribution of soil erosion and soil fertility on sloping farmland in the purple-soil area of China. Soil and Tillage Research, 105(2), 307–312. doi:10.1016/j.still.2009.01.001

Malik, R. K., Green, T. H., Brown, G. F., & Mays, D. (2000). Use of cover crops in short rotation hardwood plantations to control erosion. Biomass and Bioenergy, 18(6), 479–487. doi:10.1016/S0961-9534(00)00016-7

Paningbatan, E. P., Ciesiolka, C. a., Coughlan, K. J., & Rose, C. W. (1995). Alley cropping for managing soil erosion of hilly lands in the Philippines. Soil Technology, 8(3), 193–204. doi:10.1016/0933-3630(95)00019-4

Pansak, W., Hilger, T., Dercon, G., Kongkaew, T., & Cadisch, G. (2008). Changes in the relationship between soil erosion and N loss pathways after establishing soil conservation systems in uplands of Northeast Thailand. Agriculture, Ecosystems & Environment, 128(3), 167–176. doi:10.1016/j.agee.2008.06.002

Presbitero, A. L., Escalante, M. C., Rose, C. W., Coughlan, K. J., & Ciesiolka, C. A. (1995). Erodibility evaluation and the effect of land management practices on soil erosion from steep slopes in Leyte , the Philippines. Soil Technology, 8, 205–213.

Rodriguez, O. S. P. (1997). Hedgerows and mulch as soil conservation measures evaluated under field simulated rainfall. Soil Technology, 11, 79–93.

Ruiz-Colmenero, M., Bienes, R., & Marques, M. J. (2011). Soil and water conservation dilemmas associated with the use of green cover in steep vineyards. Soil and Tillage Research, 117, 211–223. doi:10.1016/j.still.2011.10.004

Ruiz-Colmenero, M., Bienes, R., Eldridge, D. J., & Marques, M. J. (2013). Vegetation cover reduces erosion and enhances soil organic carbon in a vineyard in the central Spain. Catena, 104, 153–160. doi:10.1016/j.catena.2012.11.007

Thapa, B. B., Cassel, D. K., & Garrity, D. P. (1999). Ridge tillage and contour natural grass barrier strips reduce tillage erosion $. Soil and Tillage Research, 51, 341–356.

Wang, Y., Zhang, B., Lin, L., & Zepp, H. (2011). Agroforestry system reduces subsurface lateral flow and nitrate loss in Jiangxi Province, China. Agriculture, Ecosystems & Environment, 140(3-4), 441–453. doi:10.1016/j.agee.2011.01.007

Xiao, B., Wang, Q., Wang, H., Dai, Q., & Wu, J. (2011). The effects of narrow grass hedges on soil and water loss on sloping lands with alfalfa (Medicago sativa L.) in Northern China. Geoderma, 167-168, 91–102. doi:10.1016/j.geoderma.2011.09.010

Xiao, B., Wang, Q., Wang, H., Wu, J., & Yu, D. (2012). The effects of grass hedges and micro-basins on reducing soil and water loss in temperate regions: A case study of Northern China. Soil and Tillage Research, 122, 22–35. doi:10.1016/j.still.2012.02.006

Xiao, B., Wang, Q., Wu, J., Huang, C., & Yu, D. (2010). Protective function of narrow grass hedges on soil and water loss on sloping croplands in Northern China. Agriculture, Ecosystems & Environment, 139(4), 653–664. doi:10.1016/j.agee.2010.10.011