Personal Background

As a current PhD student in Soil Science within the Faculty of Land and Food Systems at UBC, I study landscape-scale dynamics of ecosystem services in regions dominated by smallholder agriculture. After earning a BA in International Business and Economics and an MSc in International Agricultural Development and Soil Science, I was interested in developing my technical research skills to effectively evaluate new and existing methods employed by subsistence farmers in less-developed countries. The goal of my PhD is to combine quantitative spatial assessment methods of land quality indicators with my economics background to value ecosystem functions and better evaluate tradeoffs based on the priorities of stakeholders and our knowledge of the services of ecosystem functions.

Project Introduction

The maps and data in this application are preliminary results from a baseline assessment carried out in a mountainous agricultural area in northern El Salvador. This assessment is part of a large five-year USAID-funded project titled *Agroforestry for Biodiversity and Ecosystem Services* (ABES). The overarching goal of the ABES project is to evaluate the impact of a slash-and-mulch agroforestry system on ecosystem services. This system was developed as an alternative to slash-and-burn agriculture and is designed to allow long-term production of maize and beans with reduced degradation of soil, air and water resources and more consistent yields. Field trials are currently being carried out to evaluate the impact of the system at the plot scale. Research presented herein is part of an effort to scale this assessment to the landscape and regional scales to: 1) estimate the potential environmental impacts (positive or negative) of wide scale adoption under several scenarios; 2) quantify and value ecosystem services and explore the potential for support (e.g. direct payments, training) to farmers or communities to protect and/or enhance these services and; 3) inform policy makers of tradeoffs in ecosystem service provision and help them to make decisions based on stakeholder priorities.

The first step in this process was to carry out a baseline assessment of existing ecosystem function indicators, including soil properties related to agricultural production. One such property that is of importance in the subtropics is exchangeable (plant-available) calcium (exch-Ca). Adequate levels of calcium help plants overcome environmental stresses, resist disease (fungal and bacterial) and minimize pest impacts by strengthening plant cell walls. Calcium is also critical to the uptake and absorption of other nutrients and low levels can cause poor nodulation by nitrogen-fixing bacteria on legume (e.g. bean) roots (Havlin et al., 2005). Critical calcium deficiency occurs in soils with exch-Ca levels below 2 $cmol_c\ kg^{-1}$ (the Critical Threshold) while levels greater than 7.5 $cmol_c\ kg^{-1}$ (the Sufficiency Threshold) are generally considered adequate for production in tropical soils (AfSIS, 2011; Yost and Uchida, 2000). Deficiencies are most common in soils with low pH and high precipitation, both common in tropical climates such as that found in El Salvador. Here I present the results for analysis of exch-Ca levels in the project area.

Methods

The project area for ecosystem service mapping encompasses 100 km^2 in northern El Salvador in the department of Chalatenango, near the border of Honduras (Figure 1). It is a mountainous area with elevations ranging from 300 - 1300 m.a.s.l., a mean annual temperature of about 22 – 26º C and mean annual rainfall of about 1985mm (from 1971 to 2012). Maps of topsoil exch-Ca (0 – 20 cm) were produced in January 2014 using analysis results of soil samples collected from 144 sites across the project area. Sites were randomly chosen in ArcGIS around 16 clusters to maximize efficiency and minimize fieldwork costs. Sampling was carried out from November 8 to December 19, 2012 with concurrent QuickBird imagery acquired December 4, 2012 while we were in the field. Soils were analyzed using Fourier transformed mid-infrared spectroscopy, a rapid and cost-effective method which permitted us to analyze a large number of samples for multiple properties.

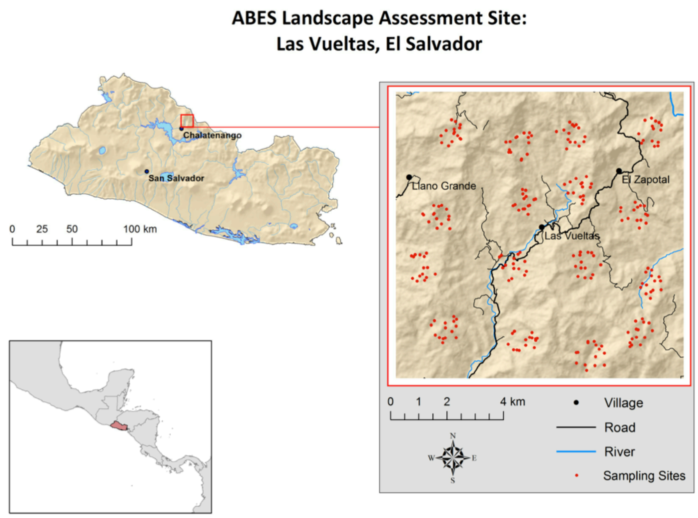


Figure 1. Sampling locations for the baseline landscape assessment within the ABES project area in northern El Salvador

Both vegetative management and topography impact soil characteristics. Therefore, one spectral layer and one terrain layer were used as co-variates for ordinary co-kriging to create a prediction surface map for each soil property. A correlation matrix was created to determine which layers were most highly-correlated with each soil property (Figure 2). Available and developed spectral layers from the QuickBird imagery included Bands 1 to 4, NDVI and EVI (all resampled to 30m). Available terrain layers were developed using ASTER 30m DEM and included Elevation, Slope, Curvature, Insolation and Total Wetness Index. In order to explore nutrient deficiencies and possible land degradation, two probability maps were also created for each soil property at the Critical and Sufficiency Threshold values identified in the literature. These maps show the probability that a given predicted raster value falls below the identified threshold value.

Figure 2. Correlation matrices for GIS layers and soil properties with topsoil exchangeable calcium (TS_Ca) outlined in black

Spectral Layers

	Band1	Band2	Band3	Band4	NDVI	EVI
TS_SAND	-0.1	-0.11	-0.13	-0.01	0.1	0.03
TS_CLAY	0.06	0.1	0.12	-0.03	-0.07	-0.05
TS_SILT	0.08	0.03	0.03	0.06	-0.04	0.03
SoilDpthAv	0.08	0.08	0.12	-0.11	-0.15	-0.21
TS_P	0.06	-0.01	-0.04	0.09	0	0.1
TS_pH	0.13	0.08	0.05	0.17	0.03	0.15
TS_K	0.15	0.19	0.12	0.39	0.2	0.41
TS_SOM	-0.19	-0.14	-0.11	-0.06	0.1	-0.01
TS_Ca	0.09	0.02	-0.03	0.1	0.02	0.09
TS_Mg	0.08	0.02	-0.03	0.07	-0.01	0.07
Soil_Infil	0.26	0.17	0.22	0.07	-0.14	-0.01

Terrain Layers

	DEM	Slope	Curve	Insol	nTWI
TS_SAND	-0.1	0.03	-0.11	-0.12	0.18
TS_CLAY	0.3	-0.13	0.2	0.3	-0.16
TS_SILT	-0.35	0.1	-0.14	-0.36	-0.01
SoilDpthAv	0.08	0	0.12	0.05	-0.27
TS_P	-0.55	0.11	-0.03	-0.36	0.07
TS_pH	-0.57	0.11	-0.09	-0.36	0.1
TS_K	0.08	-0.18	-0.03	0.17	0.16
TS_SOM	0.5	0.02	-0.16	0.18	0.15
TS_Ca	-0.62	0.02	-0.02	-0.35	0.1
TS_Mg	-0.57	-0.04	-0.02	-0.32	0.01
Soil_Infil	-0.29	0.25	0.1	-0.3	-0.11

Colour scale: 1, 0.6, 0.2, -0.2, -0.6, -1

Results

For exch-Ca, Elevation (DEM) and QuickBird Band 4 showed the best correlation (see outlined rows in Figure 2) and were used as co-variates to map predicted values across the project area (Figure 3). Predicted exch-Ca values ranged from 1.71 to 22.40 cmol$_c$ kg^{-1} with higher values observed in the northeast region and the lowest values observed in the southwest, near the more densely populated area surrounding the city of Chalatenango (not shown). Probability maps show a clearer picture of where calcium deficiencies are most likely to occur (Figure 4). A sizable zone in the southwest corner of the project is likely to have moderate calcium deficiencies (below the Sufficiency Threshold of 7.5 cmol$_c$ kg^{-1}). Widespread critical deficiencies (below 2 cmol$_c$ kg^{-1}) are unlikely, but isolated occurrences are possible in the extreme western and southwestern zones. Upon seeing the high correlation between calcium and elevation, measured exch-Ca values where plotted against binned elevation data to explore this relationship. The boxplot in Figure 5 shows the relationship is consistent and strong and that calcium deficiencies become increasingly likely above about 1100 m.a.s.l.

Figure 3. Predicted topsoil exch-Ca values for the ABES project area

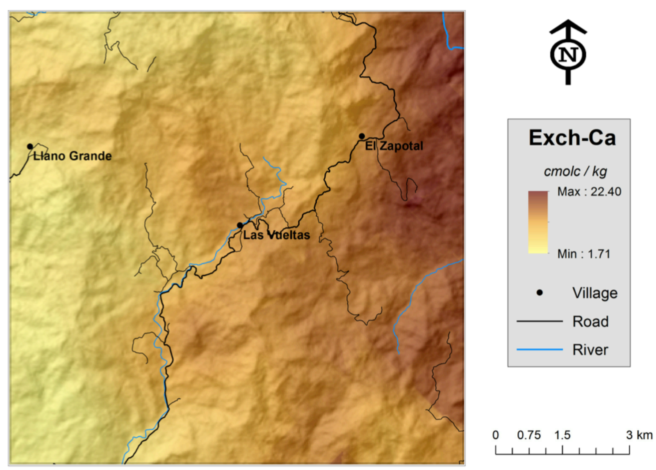
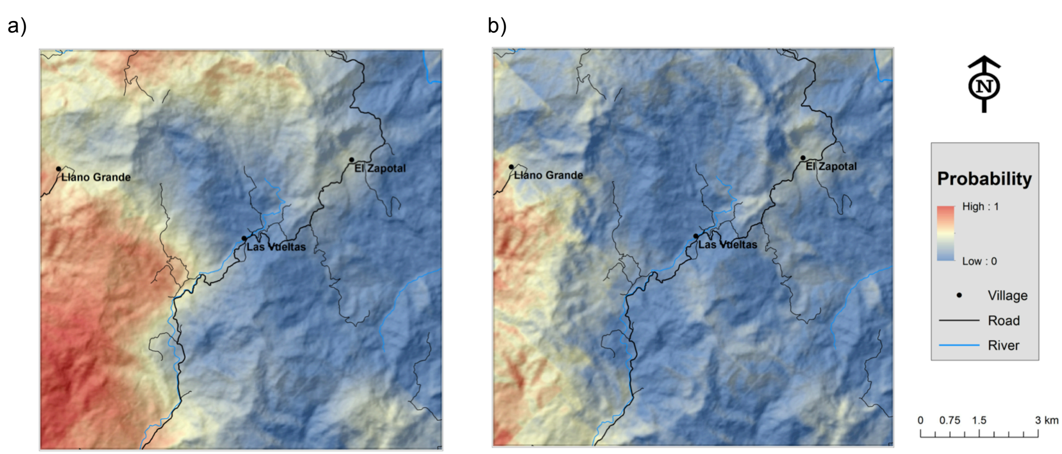


Figure 4. Probability maps for the likelyhood of topsoil exch-Ca values below a) the Sufficiency Threshold (7.5 cmol$_c$ kg^{-1} and b) the Critical Threshold (2 cmol$_c$ kg^{-1})

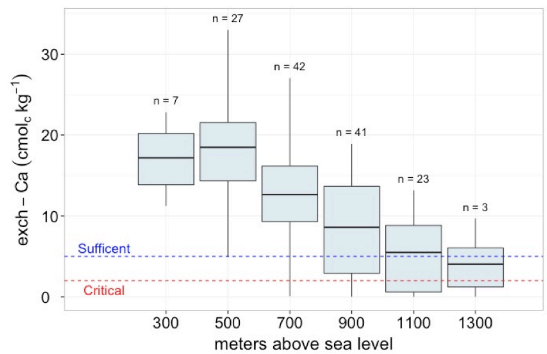


Discussion and Recommendations

Based on measured and predicted levels in the project area, calcium may be deficient in some areas west of the road to Las Vueltas and south of Llano Grande and deficiencies will become increasingly likely with rising elevation. Farmers and technicians in this area should monitor soil exch-Ca when possible and, at a minimum, look for symptoms of calcium deficiency in crops, especially at higher elevations (above 900 - 1100 m). Symptoms may include curling of young leaves, deformities in fruits (e.g. blossom end rot), yellowing/burning of young leaf tips and margins or secretion of a gelatinous material causing leaf tips to stick together (Havlin et al., 2005).

The maps and results presented in this application will be combined with similar analyses of other soil properties to evaluate overall soil quality and land degradation and eventually map total ecosystem service provision. However, these individual maps of soil properties are valuable as stand-alone products, especially in less-developed regions such as rural El Salvador where existing soil data and resources are quite limited.

Figure 5. Boxplot of measured topsoil exch-Ca values by elevation (m.a.s.l.)



The growing availability of high spatial resolution imagery and soil analysis using infrared spectroscopy are for the first time allowing us to map soil properties at the landscape scale. Advances in GIS software and geostatistical analysis afford us further visualization of probabilities and uncertainties associated with predicted values. Putting these pieces together can quickly and effectively communicate key evidence needed by policy makers to make informed decisions.

References

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