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Impacts of land-cover change and high rainfall on soil erosion among three farms in Cerro Punta, Chiriquí, Panamá.

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Abstract

Soil erosion is a key source leading to the depletion of Earth's natural resources. Beginning with deforestation, soils are stripped of their rich vegetation cover, leaving them vulnerable to wind, water, and sometimes total exhaustion. One of the major causes of deforestation, if not the primary cause, is for agricultural purposes. Extensive agricultural fields, steep slopes, and heavy rains characterize the highlands of Chiriquí; thus, the land displays potential for severe loss of soil. This paper illustrates and discusses the extent of soil erosion in Cerro Punta, Chiriquí, specifically considering the steep terrains and very wet environment that impact the land. Three farms were investigated with 2 sites per farm, as well as 2 randomly selected forested sites. A field of bare soil and a field of moderate vegetation cover were chosen at each farm, and the 2 forested sites were used as reference. Additionally, water clarity was measured in a stream that cuts through cultivated land and in The Río Chirquí Viejo (RCV), which flows through primary, untouched forest. The Universal Soil Loss Equation (USLE) was used to determine potential annual soil loss for the sites. Measurements were carried out from November 11th to the 22nd. Two large rainfall events as well as small, intermittent showers on most days occurred during the period of study. The bare soil sites displayed overall higher loss of soil when compared to the sites of moderate vegetation cover. Both sites of bare soil and moderate vegetation had higher losses of soil than the forested sites. The stream had lower water clarity during the 2 days of heavy rainfall, and the RCV showed no difference in turbidity on rainy and dry days. The results suggest that cultivated soils face more severe threats to erosion, and contribute to increased surface runoff during large rainfall events. Forested areas offer protection from rainfall impact as the canopy and vegetation cover act as natural barriers. It is essential to understand the current state of lands in the region of Panama that provides a majority of produce to the country. Further investigation should look into the rate of soil erosion and direct consequences. Sustainable practices, as well as farming policies should be implemented in the near future to preserve the fertility and offering of these lands.

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Introduction

The land that we live on provides a basis for all human necessities. It offers us fertile soils to grow food, pastureland to care for livestock, diverse landscapes that house natural resources, abundant water resources, and land to build upon. Equally, Earth's land is comprised of the valuable ecosystems that allow us to live. Terrestrial and marine ecosystems are essential for converting the sun's energy into organic material to further expand life. As plants capture solar energy, they initiate a nutrient cycle. This cycle can be expanded to involve plant, animal, and human life, highlighting the interdependence between man and earth. However, this interdependence does not appear to receive the attention that it should.

Continually increasing populations and consequential demands for food in Central America have caused an expansion of agriculture while sustainable practices remain in the background. In recent times, lands have been exposed to intensive practices and overexploitation with little acknowledgement of their resilience to overuse, resulting in severe human-induced degradation, especially in tropical regions. The expansion of livestock production has also pushed into forested lands, driving land conversion rates higher.

In the case of Panama, roughly 80% of the country's agriculture is produced in the highlands of Cerro Punta, Chiriquí. A relatively small land area makes for a suitable investigation of soil erosion and surface runoff processes due to changes in land cover or land use. Panamá's high annual rainfall, alongside a mountainous landscape and exposed soils, leave the country fairly susceptible to erosion. As lowland arable soils are occupied by current farms or bought up for estate construction or tourist purposes, farmers seek slope side lands that are more readily available. Additionally, the exhaustion of lands by aggressive farming techniques, high precipitation, and loss of nutrient rich soil forces famers to find new lands. A destructive cycle arises from the migration of farmers due to degraded land.

Soil erosion stands as a major consequence of land degradation, especially with widespread agriculture. Farmers implement conventional farming techniques, and fail to assess the depletion of their land over time. It seems essential to move forward in a direction of increased sustainability to maintain not only the lands capable of feeding the country, but also to sustain the ecosystems that support Panama's biodiversity. Policies for land conservation can be observed worldwide, and should be taken into consideration. Europe, for example, requires farmers to set aside certain amounts of land for preservation. Furthermore, Israel has adopted a no-tillage method to reduce loss of soil and maintain organic matter for proceeding crops. Certain practices illuminate the benefits of improved land treatment, and will hopefully spark a transition process from conventional to sustainable practices.

Literature Review

Defining land degradation

Natural systems show elasticity to small, temporary stresses or imbalances, restoring to their original state in time. However, continual pressures placed on lands will surpass their resilience and leave soils unsuitable for further cultivation. Land can be loosely defined as a soil resource, but it also includes the water, vegetation, landscape, and microclimatic components of an ecosystem (Scherr, 1996). Degradation is a process of change over time. These definitions can be combined to explain land degradation as the temporary or permanent decline in productive capacity of the land, or its potential for environmental management (Scherr, 1996). Land degradation can be irreversible, but most cases of soil loss can be prevented or reversed with proper mitigation strategies.

Agriculture in Cerro Punta

Due to volcanic origin, the soil of Cerro Punta has a sandy texture that is high in phosphorus, moderate in potassium, and low in aluminum, making for very fertile land (LaBastille, 1973). In the late Pleistocene, a volcanic eruption created a crater that damned the Río Chiriquí Viejo. Once this crater collapsed, rich alluvial sediments were deposited as the river expanded throughout Cerro Punta, further contributing to great agricultural conditions. Slope sides, ranging in steepness from 10%-70%, characterize the agricultural lands of Cerro Punta. Though rich in fertile soil, the slopes leave land vulnerable to degradation as steep gradients increase erosion rates.

Erosion by land cover change

The agricultural potential for Central America is estimated at 576 million hectares, and about 74 percent of croplands are affected by land degradation as compared to 45 percent in South America (Santibáñez, 2007). Similarly, according to a World Bank report, 60 percent of recent deforestation within developing countries can be attributed to the expansion of the agricultural frontier (Dionne, 2008). Removal of vegetation cover for agriculture purposes, creation of pasture lands, or construction purposes all leave land vulnerable to wind and water erosion, as well as desertification.

The main crop grown in Central American is corn; however, it has a low productivity level. Thus, farmers compensate for low production with increased total production per unit area, adding more pressure to the land and extending cultivation areas (Etchevers et al., 2004). According to a recent study, the International Soil References and Information Centre (ISRIC) estimated that 56% of the land in Central America has undergone moderate degradation, which means reduced productivity, and 41% has experienced strong degradation, which means it can no longer be used for agriculture (Etchevers et al., 2004). Furthermore, average runoff efficiencies in mosaic and pasture catchments have been measured at 1.8 to 2.7 times greater than forest catchment rates (Ogden et al., 2013).

Erosion by rainfall

Rainfall is one of the most important natural factors affecting soil erosion in the subtropical region. Erosion issues of subtropical and tropical lands are more severe than temperate climate lands, as heavy rainfall conditions make for fragile and easily degraded soils. The repetitive process of planting and harvesting causes the removal of top-layer vegetation, exposing soils to rainfall. Agricultural land is especially present in the highland slope sides of Panama, increasing the severity of surface runoff and soil erosion. Additionally, when rainfall is high, water quality is usually very low due to increased sedimentation in water systems from erosion.

Effects of soil erosion

A significant on-farm effect of soil erosion is declining potential yields. As farmers experience the degradation of their lands, they must use higher levels of input to maintain yields or they seek new marginal lands where the deforestation and erosion process is repeated. A case study in El Valle de Antón suspects that farmers tend to move onto marginal lands because of increased population due to arrival of international tourists (Dionne, 2008). Furthermore, the construction of large estates on lowland fertile soils drives farmers to seek slope-side lands.

Additional consequences of soil erosion are seen off the farm, or as externalities. Large depositions of eroded soil are seen in streams or behind dams, and chemical runoff from cultivated lands contaminates drinking water (Scherr and Yadav, 1996). Irrigation systems also divert water from drinking sources to compensate for low crop yields and low nutrient soils. Ecosystems recurrently face the effects of further deforestation for agricultural purposes. The exhaustion of land and essential soils is leading to cultivation of new lands and fueling a deadly cycle of degradation and migration.

Mitigation against soil erosion

It is evident that land use practices in Panama have a higher impact on soil erosion because the tropical region receives heavy rains. However, soil loss can be significantly reduced with appropriate conservation practices to protect remaining vegetation cover and slow down or halt current erosion rates. As seen in Europe, the Agriculture Policy of European Union (EU-CAP) introduced in 1992, established regulations for European farmers to preserve sections of their arable land for conservation purposes (Dionne, 2008). Surprisingly, a majority of the European farmers set aside their steeper and more erosive land as part of these regulations. Seeing as a large portion of agriculture is implemented in the highlands of Chiriquí among easily eroded slope sides, it is probable that similar regulations will effectively lower soil erosion rates on agriculture lands in Panama.

Sustainable cultivation practices also serve as effective mitigation strategies to land degradation. A no-tillage technique was introduced into farming in Israel, which saves residue, mulch, and organic matter from the previous season and then plants the next season’s crop into this untouched material. Moreover, a study conducted in Mexico that included over 100 experiments over a 5-year period shows that zero tillage reduced erosion rate by roughly 80% in corn crops and by roughly 95% in wheat crops in comparison to conventional tillage (Etchevers et al., 2004).

Research Question

How do changes in land cover and high levels of rainfall lead to soil erosion and surface runoff in the highlands of Chiriquí, Panamá?

Materials and Methods

Characteristics of the study sites

Image 1. Satellite view of Cerro Punta, Guadalupe, and the 3 farm locations. (DigitalGlobe, 2014)

Cerro Punta is a small town located in the western highlands of Panama in the province of Chiriquí. Cerro Punta sits 6,500 feet above sea level, directly south of the continental divide. A rugged terrain and mountainous topography sets Cerro Punta apart from the rest of Panamá. This study was concentrated in Barrio Guadalupe and the main town of Cerro Punta, both which are occupied by steep slopes of agricultural and pasture land, allowing for a good investigation of erosion and sediment runoff. Three farms were chosen, 2 sites per farm, as well as 2 randomly selected forest sites, which are all located at approximately 7,000 feet on the eastern mountainsides of the Cordillera Central.

Farm one is a conventional farm located on the northeastern slopes of Barrio Guadalupe that practices tillage by hand and machine, and grows a variety of crops ranging from potatoes to lettuce to carrots (Image 1). The farm is a mosaic of land, with different crops in season at different periods throughout the year. Consequently, vegetation never covers the entirety of the land at all times. Several months usually occupy the period between harvest and planting seasons, leaving the soil bare for parts of the year. The first site on farm one is a field of bare soil, from which a potato crop was harvested roughly four months past. The field is estimated to exist on a 40% slope gradient, with a sandy loam soil composition. The field has remained untouched in the last four months, but will be tilled for the next season's crop within the next few weeks. The second site on farm one is located just two fields over. This field has a higher vegetation cover, with a lettuce crop in early growth. The lettuce field has a moderate amount of weed growth, increasing total vegetation cover. The slope gradient is estimated at 30% and the soil is also of a sandy loam composition.

The second farm, also located on the northeastern slopes of Guadalupe, is not considered a conventional farm as it demonstrates more sustainable practices (Image 1). The farmer has implemented a terrace-like structure into some of his land in order to mitigate soil erosion. Minimal pesticides and herbicides are utilized among the lands, and crop rotation helps to maintain soil fertility. The 2 sites were located among land without terrace structures to maintain more consistency for all sites. The first site is a field of bare soil, where a broccoli crop was recently harvested. The slope is at a 50% gradient, and the soil has a sandy clay loam composition. The second site is located just 20 meters above the first site, and it has a moderate vegetation cover of a lettuce crop. The field slopes at a 35% gradient, and the soil has a sandy clay loam composition.

The third farm, located east of the center town of Cerro Punta, is a conventional farm with cultivated land sitting directly above neighborhood homes (Image 1). Part of the land is tilled by hand because machines are incapable of maneuvering the steep slopes. Moderate levels of pesticides and herbicides are applied to the crops. The first site is a field plot of bare soil with a 50% slope gradient, in which the farmer is waiting for the next planting season of a new crop. The second site, located one field over, is occupied by moderate vegetation cover of a lettuce crop and rests on a 35% slope gradient. The two sites have soil with a sandy loam composition.

Two forested sites were randomly selected to provide a comparison between deforested land and primary forest. The first forest site is located above the second farm at the border of a primary forest. The second forest site is located slightly east of the third farm, occupied by a mixture of shrubs and primary growth trees. The first forest site exists on a slope with a gradient of 40%, the second site with a slope gradient of 30%, and both have a sandy loam soil composition.

Methodology

The 6 farm sites are representative of shifting land cover from forested land to cultivated land for agricultural purposes, and the 2 forest sites are representative of primary, untouched growth. Erosion pins are used to gather a first approximation of the amount of erosion in a given situation. This method is advantageous because the pins are cheap and simple, so many measurements can be made and results can be both representable and believable. There is no instrument standardization in soil erosion research, but plots of 10 m are suggested to represent a sufficient distance for exposing soil erosion (Thomaz, 2008).

Data was collected at 8 sites. Six erosion pins were placed along a 20 m transect at each site. The pins were placed at 3, 6, and 9 meters for each 10 m distance. They were driven into the soil so that the top of the pin gives a reference point from which changes in the soil surface level can be measured (Bartley et al., 2006). The length of the slope was measured and the slope gradient was estimated for each site. A small soil sample was extracted from each field and the composition was recorded on site.

Measurements were recorded from November 11th to November 22nd, 2014. Initially, erosion pins were checked every day, but it was determined that at least two or three days must pass between measurement days to receive more conclusive data. Rainfall was inconsistent, with some full days of rain and some completely dry days. Over the 12-day period, 4 separate measurements were taken. For every day of measurement, the amount of soil loss was recorded in cm and the pins were removed and relocated to the next site.

Secchi Disk

A secchi disk is an alternative method to a turbidity meter, and it is a universally accepted tool for measuring water clarity. It is a disk of varying diameter with alternating black and white quadrants that is lowered into the water until it can no longer be seen. To measure sediment runoff from cultivated lands, the disk is lowered into the water until it disappears from view. The calibrated line measurement along the side of the tube is recorded when the disk is out of view (Green et al., 1996).

At each farm, a small stream was located running through the cultivated land. The streams eventually flow into the Río Chiriquí Viejo at the bottom of the slopes. For the three streams, a high, middle, and low point were determined and a secchi disk reading was recorded at each point. Measurements were recorded from November 14th to November 21st. Due to increased sediment runoff from rainfall, it is valuable to measure water clarity during a rainfall event. However, only two large rainfall events occurred during the 8 days of data collection, so 6 measurements of water clarity were recorded during clear days and 2 measurements were recorded for rainy days. The measurements were compared. Additionally, for every day of stream measurements, the Río Chiriquí Viejo (RCV) was tested at a high, middle and low site. Each site was determined at a location where the river runs through primary forest. Therefore, it was interesting to compare a water system that runs through disturbed, cultivated land and one that runs through untouched land.

USLE

The Universal Soil Loss Equation (USLE) predicts the long-term average annual rate of erosion on a field slope based on levels of rainfall, soil type, topography, crop system, and management practices (Stone, 2012). This equation only predicts the amount of soil loss that results from sheet or rill erosion, and does not concern soil loss that may occur from gully, wind or tillage erosion. Five major factors are used to calculate soil loss, and each factor is an estimate of a specific condition that affects soil erosion at a specific location (Stone, 2012).

$$A = R \times K \times LS \times C$$

A is the potential long-term annual soil loss in tons per hectare (tons per acre) per year.

R is the rainfall factor based on geographic location. The greater the wetness of a location, the higher the numerical value will be for R. No technology was used to determine rainfall amounts during the study period, so the R value was based off a study that used USLE to calculate soil loss in the Panama canal watershed. Since the study was conducted in the wet season for Panama, R was held constant at 245 (Lee et al., 2012).

K is the soil erodibility factor, or the average soil loss in tons per hectare (tons per acre) for a particular soil in the particular area of investigation. It is the measure of susceptibility of soil to detachment due to rainfall and runoff. A K value of 0.20 was used for sandy clay loam and 0.13 was used for sandy loam (Stone and Hilborn, 2012) (Appendix A).

LS is the slope-length gradient factor. This factor is a ratio of soil loss under certain slope steepness conditions. The factor can be calculated if the slope angle and length are known. Since the slope angles were unable to be determined, a topographic factor chart was used to determine LS factors (Wischmeier and Smith, 1978) (Appendix B). The chart assumes slopes that have essentially uniform gradients.

C represents how susceptible the land is to erosion depending on the land cover. Cleared land has a higher value than forest land. Cleared land has a value of 0.45 and forested land has a value of 0.003 (Wischmeier and Smith, 1978) (Appendix C).

The Universal Soil Loss Equation is used to calculate the annual soil loss for all 8 sites. USLE determines how factors, such as slope gradient, soil type, and rainfall, affect the average annual rate of erosion. Once the soil loss is calculated for each site, the results are compared to determine if such factors have a significant impact on soil erosion. Results are important for understanding soil loss rates, which combination of factors produces the most severe loss of soil, and how farmers can alter their practices to reduce or halt erosional processes.

Results

Rainfall characteristics and soil loss patterns

Rainfall is one of the most prominent physical factors affecting soil erosion in the tropical region. Therefore, the effects of rainfall are essential in understanding erosion and runoff. During the two-week period, two moderate rainfall events were observed as well as small intermittent showers on a majority of the days. Exact measurements of daily rainfall were not recorded due to restricted equipment. Historical records show an average rainfall of 2,096mm per year (IDP, 2010), while the month of November has the second highest monthly rainfall for the country and the 7^{th} highest monthly rainfall for Cerro Punta. For Panama, the months of May to November have much greater levels of rainfall than the summer months of December to April (Figure 1). The experimental year was dry in comparison to the historical annual rainfall average, so the dry year may have impacted soil erosion and runoff results.

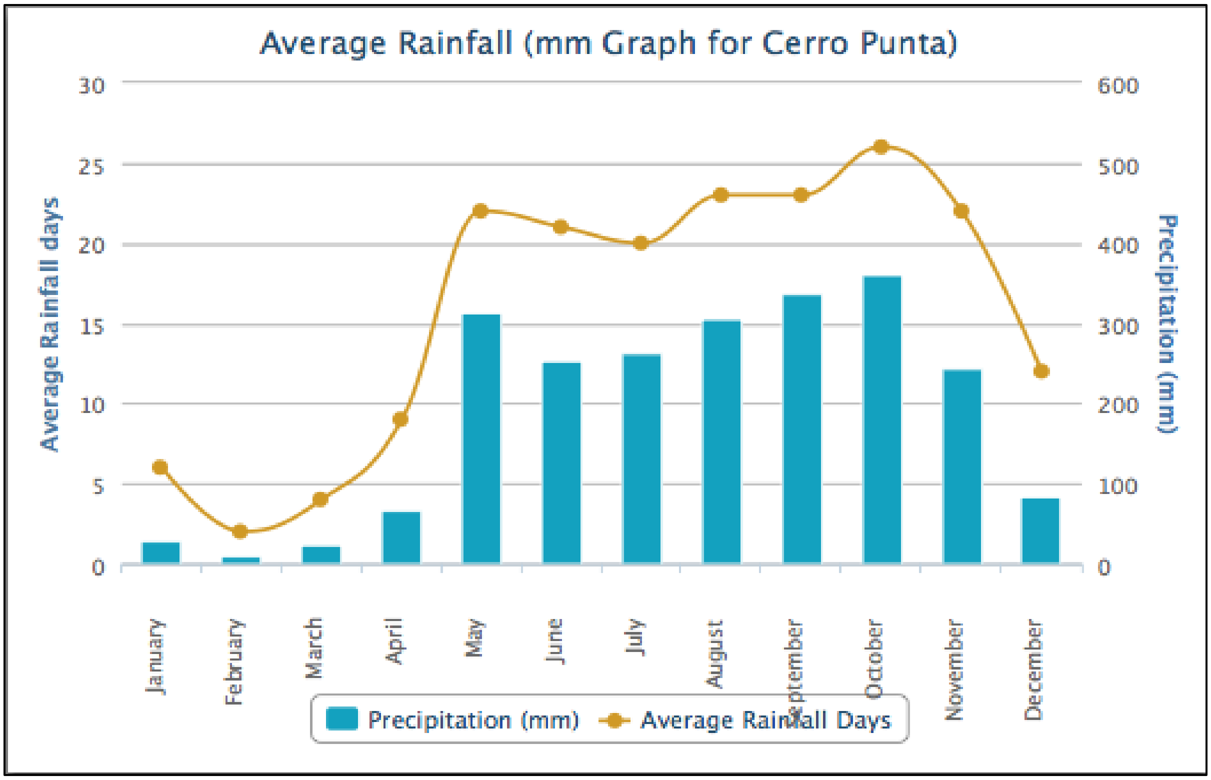

Figure 1. Monthly average precipitation and monthly average rainfall days for Cerro Punta, Panama (World Weather Online, 2014, http://www.worldweatheronline.com/Cerro-Punta-weather-averages/Chiriqui/PA.aspx).

The 8 sites of investigation were all exposed to rainfall throughout the 12-day period. Each rainfall event was considered important for soil loss results, but the 2 largest observed rainfall events were most significant in impacting soil loss. Each site had varying measurements of soil loss, but it is evident that the bare soil sites had the highest levels of soil loss (Figure 2). Sites with moderate vegetation cover had the second highest levels of soil loss, and forested sites showed an average soil loss of zero. Several times, a small amount of soil buildup was found on the backside of the erosion pins, so the measurement was taken from the front side of the pin where soil had been lost. The uneven distribution of soil around the perimeter of the pin may contribute to error in the measurement of soil loss.

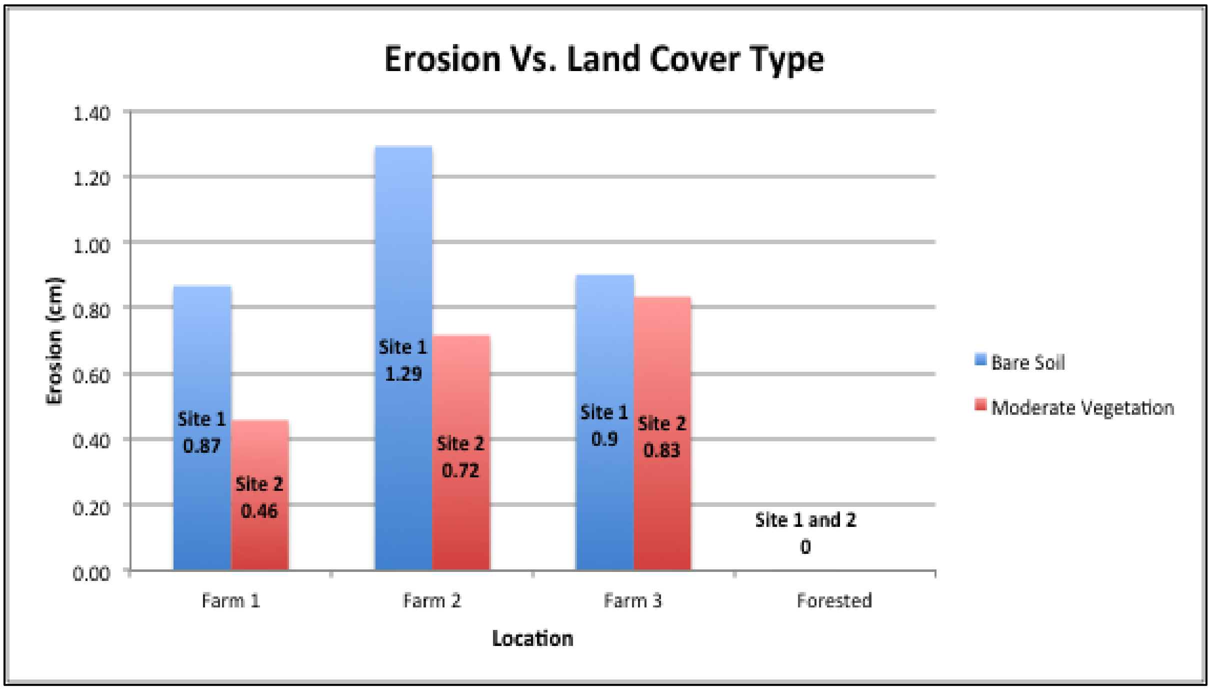

Figure 2. Average soil loss for farm and forested sites.

Rainfall characteristics and sediment runoff into streams

Rainfall events that lasted more than 2 hours with heavy downpours occurred the least, but these events are needed to see any amount of sediment in the water stream with the given equipment. Days with heavy rains showed more suspended sediment in the water, thus decreasing water clarity. Secchi disk measurements during small rainfall events did not provide any results that differed from measurements during dry conditions. Measurements taken during two large rainfall events did show clear differences from those of dry conditions. Water clarity appeared to decrease with lower locations along the slope side. Water was always clearest for the 7 measurements at the highest point on the slope. The middle location showed lower water clarity than the first location, and the lowest site on the slope was determined to have the lowest water clarity (refer to Fig. 3).

Each site for the Río Chiriquí Viejo (RCV) showed constant measurements. There was no difference in water clarity for rainy and dry days. For every high, middle, and low site for the 8 days of measurement, the water clarity remained at 60 cm, which was the highest possible measurement for the secchi disk. The 60 cm limitation for the secchi disk may have rendered conclusions for the water clarity of RCV, but it is evident that the river displayed overall higher clarity than the stream.

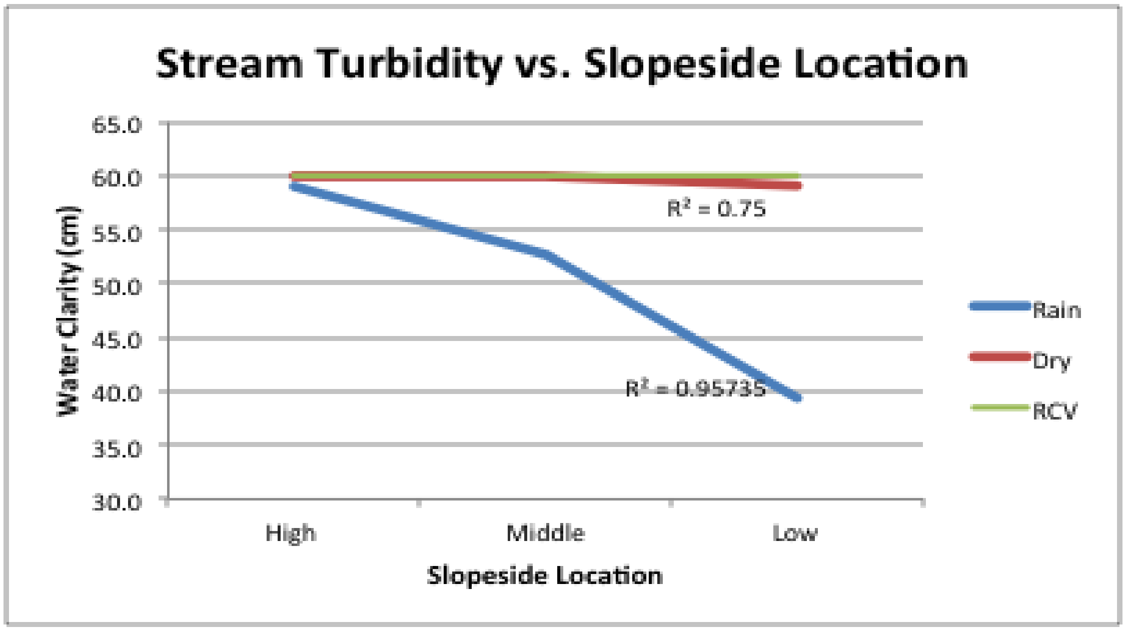

Figure 3. Water clarity for rainy and dry days at a high, middle, and low slope side locations.

USLE

The four main inputs required to fulfill the equation include the rainfall factor (R), soil loss factor (K), slope-length ratio (LS), and the land cover factor (C). The rainfall factor is determined based on the amount of rain that the study area receives. The very wet climate of Cerro Punta, and Panama in general, indicates an R value of 90. The slope length and the degree of the slope determine the soil loss factor. Each site differed in slope length and degree of slope, so the LS factor varied among locations. The LS factor was greater for more severe slope gradients and lengths. As seen in Table 1, USLE results predict severe soil loss for the 8 sites. The steep slopes, cultivated land, and high level of rainfall contribute to heavily eroded soils. The 2 sites with a 50% slope gradient predict the highest levels of soil loss, and the 2 forested sites predict the lowest levels of soils loss.

The degree of slope for each site was estimated from observations, which may contribute to a source of error. A more precise method of calculating slope degree is necessary for further and more accurate results. The R value was based off cumulative rainfall in the Panama Canal watershed, so this value is not precise for the study location and thus may contribute to a level of error.

Location	Slope %	Slope length	R	K	LS	C	A (tons/acre/year)
Farm 1, site 1	30%	10m	245	0.13	4.5	0.45	64.50
Farm 1, site 2	40%	25m	245	0.13	10.8	0.45	154.8
Farm 2, site 1	35%	15m	245	0.2	7	0.45	154.4
Farm 2, site 2	50%	25m	245	0.2	15.6	0.45	344.0
Farm 3, site 1	50%	20m	245	0.2	14.6	0.45	321.9
Farm 3, site 2	35%	10m	245	0.2	6	0.45	112.3
Forest site 1	40%	20m	245	0.2	10	0.003	1.470
Forest site 2	30%	15m	245	0.2	5.3	0.003	0.780

Table 1. USLE results for the 8 study sites. Total soil loss varies among forested and cultivated lands.

Discussion

Measurement of slope-side soil loss

Despite limitations to using erosion pins for a 12-day period, several themes arise in the results. It is evident that the 3 bare soil sites had significantly higher levels of soil loss than the moderate vegetation and forested sites. The highest loss of soil for moderate vegetation was 0.83 cm compared to 1.29 for bare soil. With lower or no vegetation cover soil is vulnerable to direct rainfall impact, which is assumed to be a major factor contributing to the erosion process. Rainfall loosens soil particles by impact and transports the soil downslope. Though different slope gradients characterize each site, the relatively severe slopes contribute to an increased rate of soil erosion. The USLE indicates that the higher the slope percent, the larger the total soil loss. As slopes become steeper, the effect of gravity increases, which pulls sediment off the slopes more quickly. Site 1 at farm 2 shows a soil loss of 344.0 tons per acre per year at a slope percent of 50. Site 1 at farm 2, however, shows a soil loss of 64.50 tons per acre per year at a slope percent of 30. It is evident that increasing slope percent strongly affects the rate of erosion. These 2 sites differ by almost 300 tons, with only a 20% difference in slope gradient. This large difference indicates that a larger sample size is needed to determine the accuracy of this equation. Moreover, it can be concluded that land cover type has a large impact on soil loss. Both forested sites have a very low total annual loss of 1.470 cm and 0.780 cm. Forest site 1 is estimated to lose about 0.5% of the soil lost at site 2 on farm 2 and forest site 2 is estimated to lose about 0.25% of the soil lost at site 1 on farm 3. These differences indicate that the C value, or land cover factor, largely impacts the rate of soil erosion. It would be beneficial to accompany the erosion pins with a soil catchment system to more accurately measure a quantity of soil loss and then link these results to slope gradient and length characteristics.

Soil erosion is a process that occurs all the time, but it is difficult to measure loss of soil in a 12-day period, especially in an unusually dry year. Further equipment is needed to measure exact levels of rainfall for each event, and erosion pins should remain in the soil for at least 3 to 4 weeks to determine how more rainfall events affect the loss of soil. Further studies should be conducted over a monthly or yearly basis to generate a larger sample size. A larger sample size will allow for the performance of statistical analysis.

The USLE is an effective tool for predicting annual soil losses, especially when all inputs are calculated with the highest precision. In certain cases, some values are more precise than others depending on accessibility to equipment and resources. In this case, it is assumed that the K value is the most precise, because soil composition charts offer exact values. However, the R value were based off another study in Panama, while the C and LS values were determined from Wischmeier and Smith's *Predicting Soil Erosion Losses* (Wischmeier and Smith, 1978). More precise R values can be acquired from local weather stations. Weather stations can track storms for a certain period of time, measuring both total storm energy and maximum 30-minute intensity of a storm (Wischmeier and Smith, 1978). The R value is a direct sum of these storm values. A local Cerro Punta weather station was not located, so the precision of the R value may have affected results. Furthermore, the value of C can be determined looking at variables such as crop canopy, residue mulch, and tillage. None of these factors were measured so additional precision could have altered results.

Mass erosion

The slope sides of Cerro Punta face potential risks of mass wasting, or the process by which sand, soil, and rock move downslope in a mass. Steep slopes and high rainfall make the area very prone to large displacements of soil. According to a review of mass erosion, mass movement processes feature catastrophic removal or displacement by gravity of a large soil body from a slope (Blaschke et al., 2000). Though the threshold of slope steepness varies greatly, the same review discusses the greater probability for mass movements on slopes greater than 30 degrees (Blaschke et al., 2000). Furthermore, it is clear that rainfall is a dominant factor in triggering loss of soil. A study of land cover changes and landslide activity in the Spanish Pyrenees finds the development of pore pressures in soil due to infiltration of water during intense or extended periods of rainfall to be the main trigger for mass movements (Beguería, 2006). The 8 sites of investigation located in a very wet tropical environment and having slope degrees of 30% or higher may therefore have a higher susceptibility to large erosional processes.

The shift of land from forest to agriculture or pasture cover also raises a question of whether land cover type influences vulnerability to erosion. A clear border exists between the primary and secondary forests of Parque Internacional La Amistad (PILA) and cultivated land among the slopes of Cerro Punta. When land is stripped of vegetation cover, it can be assumed that its vulnerability to wind and water erosion increases significantly. Specifically, vegetation notably modifies soil hydrology by increasing rainfall interception, infiltration and evapotranspiration (Begurían, 2006). Interception and evapotranspiration reduce the amount of water that reaches the soil and that is stored in it, which is important for initial moisture conditions in soil when a large rainfall event occurs. Also, soil strength increases with reinforcement of root structures and thus reduces the rate of erosional processes. Additional investigation is needed to determine the extent of past or current mass erosion in the highlands of Cerro Punta.

Sediment Runoff

Days with heavy rains were not frequent during the period of study, making for the measurement of sediment runoff from rainfall difficult. The water source that flows through cultivated land showed similar results to the RCV for dry days, but significantly different results for rainy days. When comparing the two water sources, it is evident that the small stream receives greater levels of sediment due to the surrounding cultivated land. When the land is cultivated, the soil is exposed to increased rates of detachment because it is altered from its natural state. Especially with little or no vegetation cover, the soil suffers the direct impact of raindrops, increasing the movement of soil down a slope. However, in a primary forest, the RCV flows through dense canopy cover and is surrounded by soil with heavy vegetation cover. During periods of intense rainfall, the lands near the RCV are protected from raindrop impact by a thick ceiling of leaves. The RCV was, however, only measured upstream where fewer tributaries discharge sediment into the major water stream, so measurements further downstream could show higher levels of runoff.

Loss of land productivity

Erosion can be seen over an extended period of time, with slow removal of layers of soil, or within a second as large masses of soil disconnect from a slope. The loss of soil through erosion causes declines in land productivity, including decreases in plant rooting depth, alterations in plant-available water reserves, degradation of soil structure, loss of organic matter, and loss of plant nutrients and soil fertility (Beguría, 2006). The removal of organic and nutrient-rich topsoil is unfavorable for plant growth, which may result in poor crop production for farmers and necessary migration to new land. Additionally, removal of soil from steep slopes can reduce productivity downstream. The transport of sediment from cultivated lands to river networks can damage irrigation systems and hinder water quality.

Soil Conservation

Surface erosion and mass movements are surely influenced by the basic characteristics of the land, such as steep slopes and a very wet environment. Poor land management, however, can further aid to the degradation of land. Excessive cultivation, overgrazing of vegetation cover, or repeated use of large machines contributes to increased rates of erosion (Beguría, 2006). It is important to consider conservation practices or policies to reduce rates of soil loss. High cost technologies, such as terraces have been implemented in some Central American farmlands, but these technologies have not been found to solve the problem. Some technologies require large movement of soil volume or produce heavy soil losses at the beginning of implementation (Etchevers et al., 2004). To determine more effective approaches, assessments of the lands, especially those involved in agricultural practices, should be carried out to determine the state of the soils. The assessment should categorize the area into critical lands and super critical lands, with very high soil conservation requirements (Gabriels, 2005). The categorized area should limit the use of land for agriculture on slightly eroded soils and only particular crops or agroforestry on severely eroded soils.

Conclusion

In the highlands of Chiriquí, and all throughout Panama, important land cover and land use changes continue to occur every day. Transforming forested land for the purpose of agriculture can be seen as necessary to generate food for the population. Yet, it is seen that soil loss in Cerro Punta threatens the nation's production of agriculture. The rate of soil erosion is particularly high in this area, as steep slope sides and heavy rains make lands more vulnerable to surface runoff. The loss of soil is evidently higher for lands with bare, exposed soil when compared to land with moderate cover of crops.

The time period of study limited the amount of data, for soil erosion is more accurately measured over several months or years. Though measurements are little, they still reveal the occurrence of soil loss even over the course of two weeks. The sites investigated on farmland demonstrate a higher loss of soil because raindrop impact hits the soil surface with a strong force. Whereas, forested sites are protected by natural vegetation barriers that interfere with direct rainfall. The strength of gravity among steep slopes with gradients ranging from 20% to 50% pulls soil down the slope sides more rapidly than lower gradient or flat fields. Moreover, water systems receive higher runoff from agriculture fields during periods of heavy rain. However, forested sites showed zero loss of soil and very high water clarity during the period of measurement, illuminating the risks of land cover change. Vegetation cover means higher soil strength due to support from root networks. Hence, bare soils or fields of little vegetation cover lose important stability and are more prone to detachment from the ground.

Surely, ever-increasing human populations depend on expanding agricultural lands, but a vital factor for sustaining growing populations and maintaining the country's rich ecosystems is conservation. The cultivated land of Cerro Punta may be an extreme case due to the steep topography, but it evidently exemplifies the occurrence of soil erosion. It is essential to identify the costs of land degradation, and implement sustainable practices and introduce farming policies not only in Cerro Punta, but also across the country. The preservation of vital land will impact the wellbeing of future generations, as well as Panama's exceptional biodiversity.

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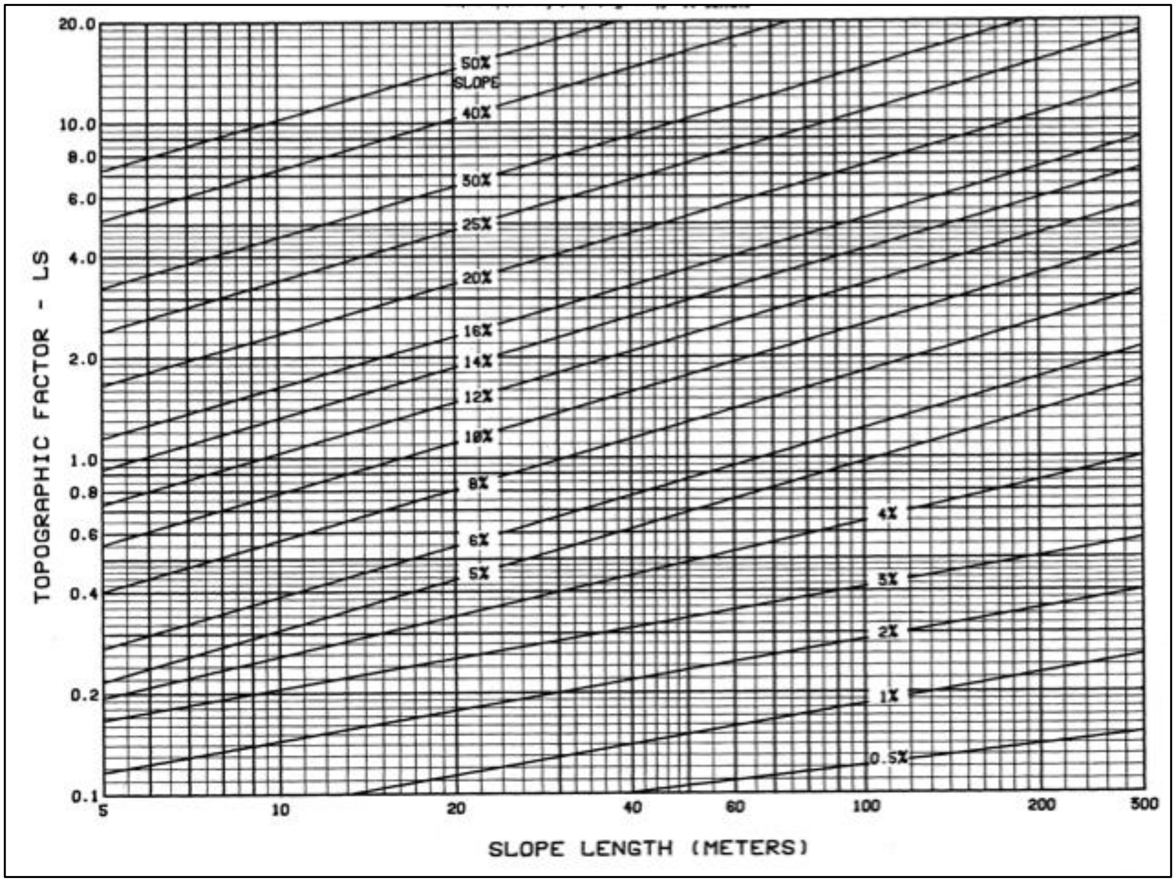
Appendix A. Soil erodibility factor (K)

Textural Class	K Factor tonnes/hectare (tons/acre)		
	Average OMC*	Less than 2% OMC	More than 2% OMC
Clay	0.49 (0.22)	0.54 (0.24)	0.47 (0.21)
Clay loam	0.67 (0.30)	0.74 (0.33)	0.63 (0.28)
Coarse sandy loam	0.16 (0.07)	–	0.16 (0.07)
Fine sand	0.18 (0.08)	0.20 (0.09)	0.13 (0.06)
Fine sandy loam	0.40 (0.18)	0.49 (0.22)	0.38 (0.17)
Heavy clay	0.38 (0.17)	0.43 (0.19)	0.34 (0.15)
Loam	0.67 (0.30)	0.76 (0.34)	0.58 (0.26)
Loamy fine sand	0.25 (0.11)	0.34 (0.15)	0.20 (0.09)
Loamy sand	0.09 (0.04)	0.11 (0.05)	0.09 (0.04)
Loamy very fine sand	0.87 (0.39)	0.99 (0.44)	0.56 (0.25)
Sand	0.04 (0.02)	0.07 (0.03)	0.02 (0.01)
Sandy clay loam	0.45 (0.20)	–	0.45 (0.20)
Sandy loam	0.29 (0.13)	0.31 (0.14)	0.27 (0.12)
Silt loam	0.85 (0.38)	0.92 (0.41)	0.83 (0.37)
Silty clay	0.58 (0.26)	0.61 (0.27)	0.58 (0.26)
Silty clay loam	0.72 (0.32)	0.79 (0.35)	0.67 (0.30)
Very fine sand	0.96 (0.43)	1.03 (0.46)	0.83 (0.37)
Very fine sandy loam	0.79 (0.35)	0.92 (0.41)	0.74 (0.33)
* Organic matter content			

(Stone and Hilborn, 2012)

Appendix B. Slope-length gradient factor (LS)



(Wischmeier and Smith, 1978)

Appendix C. Cover and management factor (C)

Vegetative canopy		Cover that contacts the soil surface						
			Percent ground cover					
Type and height[2]	Percent cover[3]	Type[4]	0	20	40	60	80	95+
No appreciable canopy		G	0.45	0.20	0.10	0.042	0.013	0.003
		W	.45	.24	.15	.091	.043	.011
Tall weeds or short brush with average drop fall height of 20 in	25	G	.36	.17	.09	.038	.013	.003
		W	.36	.20	.13	.083	.041	.011
	50	G	.26	.13	.07	.035	.012	.003
		W	.26	.16	.11	.076	.039	.011
	75	G	.17	.10	.06	.032	.011	.003
		W	.17	.12	.09	.068	.038	.011
Appreciable brush or bushes, with average drop fall height of 6½ ft	25	G	.40	.18	.09	.040	.013	.003
		W	.40	.22	.14	.087	.042	.011
	50	G	.34	.16	.08	.038	.012	.003
		W	.34	.19	.13	.082	.041	.011
	75	G	.28	.14	.08	.036	.012	.003
		W	.28	.17	.12	.078	.040	.011
Trees, but no appreciable low brush. Average drop fall height of 13 ft	25	G	.42	.19	.10	.041	.013	.003
		W	.42	.23	.14	.089	.042	.011
	50	G	.39	.18	.09	.040	.013	.003
		W	.39	.21	.14	.087	.042	.011
	75	G	.36	.17	.09	.039	.012	.003
		W	.36	.20	.13	.084	.041	.011

(Wischmeier and Smith, 1978)