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Soil erosion in the humid tropics: A systematic quantitative review

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ABSTRACT

Healthy soils provide a wide range of ecosystem services. But soil erosion (one component of land degradation) jeopardizes the sustainable delivery of these services worldwide, and particularly in the humid tropics where erosion potential is high due to heavy rainfall. The Millennium Ecosystem Assessment pointed out the role of poor land-use and management choices in increasing land degradation. We hypothesized that land use has a limited influence on soil erosion provided vegetation cover is developed enough or good management practices are implemented. We systematically reviewed the literature to study how soil and vegetation management influence soil erosion control in the humid tropics. More than 3600 measurements of soil loss from 55 references covering 21 countries were compiled. Quantitative analysis of the collected data revealed that soil erosion in the humid tropics is dramatically concentrated in space (over landscape elements of bare soil) and time (e.g. during crop rotation). No land use is erosion-prone per se, but creation of bare soil elements in the landscape through particular land uses and other human activities (e.g. skid trails and logging roads) should be avoided as much as possible. Implementation of sound practices of soil and vegetation management (e.g. contour planting, no-till farming and use of vegetative buffer strips) can reduce erosion by up to 99%. With limited financial and technical means, natural resource managers and policy makers can therefore help decrease soil loss at a large scale by promoting wise management of highly erosion-prone landscape elements and enhancing the use of low-erosion-inducing practices.

1. Introduction

The ecosystem service of soil erosion control, for the delivery of which vegetation cover plays an important role, has been degrading worldwide (Millennium Ecosystem Assessment, 2005). As this regulating service is lost, soil formation can no longer compensate for soil loss due to an increase in erosion, which depletes soil resources and the ecosystem services they support (Lal, 2003; Morgan, 2005). The Millennium Ecosystem Assessment (2005) identified unwise land-use choices and harmful crop or soil management practices as the major drivers of increasing soil erosion. Soil erosion has multiple on- and off-site consequences such as decreasing crop yields, increasing atmospheric CO_2 concentration, decreasing water quality (turbidity and particle-born pollutants), sedimentation of reservoirs, and disturbed hydrological regimes such as increased flood risk due to riverbed filling and stream plugging (Chomitz and Kumari, 1998; Lal, 2003; Millennium Ecosystem Assessment, 2005; Morgan, 2005; Locatelli et al., 2011).

Research on factors influencing soil loss has resulted in widely used models, such as the RUSLE (revised universal soil loss equation). This model was built from plot data of experiments carried out in the United States and predicts soil loss from climatic (rainfall erosivity), edaphic (soil erodibility) and topographic (slope length and slope steepness) factors, as well as soil and vegetation management practices (Wischmeier and Smith, 1978; Renard et al., 1997). Management of soil and vegetation has long been recognized as the most efficient and effective way to influence the extent of soil loss, and therefore soil erosion control (Goujon, 1968).

The humid tropics are rich in carbon and biodiversity and attract major attention because of the rapid loss of rainforests (Strassburg et al., 2010; Saatchi et al., 2011; Tropek et al., 2014). Because of the large amount and high intensity of

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rainfall in the humid tropics, soil erosion can potentially reach dramatic levels in this region (El-Swaify et al., 1982; Lal, 1990). Tropical ecosystems with healthy soils can support multiple ecosystem services (e.g. water regulation, climate regulation through carbon storage and biodiversity support) and support local livelihoods. A better understanding of soil erosion control in the humid tropics is therefore vital (Locatelli et al., 2014).

Theoretically, empirical models of erosion prediction should only be applied under conditions and for purposes similar to those of their development (e.g. predicting erosion from croplands in the United States for the RUSLE). Adapting an empirical model to out-of-range conditions would require parameter calibration, which can consume both time and resources (Nearing et al., 1994). While some studies have adapted temperate model factors to their own geographical contexts (e.g. Streck and Cogo, 2003 for surface soil consolidation and Diodato et al., 2013 for rainfall erosivity), others have directly applied models developed for a temperate context to predict soil erosion in the humid tropics (e.g. Angima et al., 2003; Hoyos, 2005).

Yet there is little consensus about the direct applicability of models such as RUSLE (and its predecessors) to a tropical context. Despite over- and under-estimation of soil loss depending on the cropping phase, Almas and Jamal (2000) found the RUSLE model to correctly predict the overall soil loss from a banana–pineapple intercropping system in Malaysia. On the other hand, Cohen et al. (2005) showed that erosion risk prediction was poorly achieved by the USLE (universal soil loss equation) in a watershed of western Kenya, and called for ground surveys to properly calibrate the USLE and similar empirical models.

In the face of this lack of agreement, studies that directly measure soil loss are of great interest as they can help shed light on the influence of vegetation and soil management on soil erosion control. Synthesizing and analyzing available data from multiple sources is necessary given the diversity of study contexts and the impossibility of drawing general conclusions from a single study.

Such syntheses are available for some regions of the world. Focussing on Europe and the Mediterranean, Maetens et al. (2012) reviewed data from 227 stations and 1056 soil erosion plots to analyze the effect of land use on erosion and runoff. They found that (semi-) natural vegetation produced lower erosion (<1 Mg/ha/yr) than vegetation directly influenced by human activities (e.g. croplands and vineyards; 6–20 Mg/ha/yr). Montgomery (2007) also compiled erosion data from globally distributed studies (some in the humid tropics) and showed that conventional agriculture, i.e. with tillage, produced 10–100 times more soil loss than conservation agriculture, i.e. with no-tillage, but conditions were highly variable. For example, plots under conventional agriculture were more erosion-prone (with maximum slope of 37° and maximum annual precipitation of 5600 mm/yr) than those of plots under conservation agriculture (17° and 2000 mm/yr).

Table 1
Land-use types and subtypes.

Land-use type	Land-use subtype	Definitions
Bare		Land has been opened and kept bare for various reasons (includes pre-sowing and post-harvesting cropland and skid trails).
	Tilled	High-disturbance soil management techniques (e.g. ploughing and raking) are used.
	Untilled	Low-disturbance soil management techniques (e.g. slash and burn and weeding with a knife) are used.
Cropland		Crops are sown and harvested within a single agricultural year, sometimes more than once (excludes perennial crops).
	Crop, non-established, without conservation practices	Crop was recently planted and crop cover is not developed; no conservation techniques are practiced.
	Crop, established, without conservation practices	Crop cover is developed; no conservation techniques are practiced.
	Crop with vegetation-related conservation practices	Crop cover may or may not be fully developed. Vegetation-related conservation techniques (e.g. hedgerows, intercropping and mulching) are practiced.
	Crop with vegetation- and soil-related conservation practices	Crop cover may or may not be fully developed. Both vegetation-related (e.g. hedgerows, intercropping and mulching) and soil-related (e.g. no-till farming and contour planting) conservation techniques are practiced.
Grassland		Vegetation is dominated by grasses (includes open grasslands and pastures).
	Pasture	Land is used for grazing and managed through agricultural practices such as seeding, irrigation and use of fertilizer.
	Open grassland	Land is unmanaged and has no trees or shrubs.
Shrubland		Vegetation is dominated by shrubs but can also include grasses, herbs and geophytes.
	Open shrubland	A transitional plant community occurs temporarily as the result of a disturbance such as logging or fire.
Tree-dominated agrosystem		Planted vegetation is dominated by trees, including perennial tree crops such as rubber, fruit and nut trees.
	Tree plantation	A group of planted trees is grown in the form of an agricultural crop, usually with the aim of harvesting wood.
	Tree crop without contact cover	A permanent crop has been planted; it has no contact cover (such as grass or cover crops) underneath.
	Tree crop with contact cover	A permanent crop has been planted and has contact cover (such as grass or cover crops) underneath.
	Simple agroforest	One woody perennial species is planted with one annual crop.
	Complex agroforest	Multiple species of woody perennials, often with natural vegetation regrowth, are planted (usually intercropped) with annual crops.
Forest		Ground is covered with natural vegetation dominated by trees (excludes tree plantations).
	Secondary forest	Forest has regenerated naturally after clear-cutting, burning or other land-clearing activities and contains vegetation in early successional stages.
	Old-growth forest	Forest is ecologically mature, containing trees of various sizes and species (the last stage in forest succession).
	Logged-over forest	Forest has been logged-over.
	Degraded forest	Forest has been degraded by human activities other than logging or by a naturally occurring event such as a fire or severe storm.