ARTICLE IN PRESS

Catena xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Catena

journal homepage: www.elsevier.com/locate/catena

Improving the utility of erosion pins: absolute value of pin height change as an indicator of relative erosion

S.P. Kearney[a,*], S.J. Fonte[b], E. García[c], S.M. Smukler[a]

[a] Faculty of Land and Food Systems, University of British Columbia, 2357 Main Mall, Vancouver, BC V6T 1Z4, Canada
[b] Department of Soil and Crop Sciences, Colorado State University, 1170 Campus Delivery, Fort Collins, CO 80523, United States
[c] International Center for Tropical Agriculture, Km 17 Recta Cali-Palmira, Apartado Aéreo 6713, Cali 763537, Colombia

ARTICLE INFO

Keywords:
Erosion pins
Slash and mulch agroforestry
Soil erosion
RUSLE
Land degradation

ABSTRACT

Erosion pins can be an inexpensive and intuitive method to estimate hillslope soil erosion and deposition. It is common practice to calculate annual erosion/deposition rates (also called ground advance/retreat or ground lowering) from pin measurements as the mean net change in pin height over a given area. However, many studies have found this net 'real number' change does not produce strong relationships with erosion rates estimated using other methods, or with variables expected to be highly correlated with erosion, calling into question the efficacy of this approach. Here we evaluate an alternative (or complementary) approach - using the absolute value of pin height change to capture the overall magnitude of soil movement as an indicator of erosion. We used measurements from erosion pins in experimental plots across different maize-bean production systems and forest-fallows in northern El Salvador to compare both the absolute and 'real number' change in erosion pin height against modeled erosion, related factors (e.g., slope and soil cover), and soil loss collected in erosion pits. We found that the absolute value of pin height change was strongly correlated ($r = 0.67$, $p < 0.01$) with erosion rates predicted from the Revised Universal Soil Loss Equations (RUSLE) and moderately correlated ($r = 0.82$, $p < 0.10$) with erosion measured in collection pits, while no relationships were found for the real number value. The absolute value was also strongly correlated with RUSLE factors related to slope and cover, while no correlations existed for the real number value. Statistically significant differences in RUSLE-predicted erosion were found between plots classified as having 'high', 'medium' and 'low' vegetative cover, and these differences were also detected using absolute value of pin height change. Conversely, such differences were not detected using the net real number value. We conclude that, when using erosion pins for comparative analysis between land management practices or monitoring changes in erosion over time, the absolute value of pin height change is likely a better indicator than net real number change. We encourage additional research using new and existing datasets to further evaluate the utility of absolute value of pin height change as an indicator of relative erosion.

1. Introduction

Erosion pins are an inexpensive method to estimate hillslope soil erosion and deposition used by numerous studies with varied success (Benito et al., 1992; Diaz-Fierros et al., 1987; Edeso et al., 1999; Haigh, 1977; Hancock and Lowry, 2015; Shi et al., 2011; Sirvent et al., 1997). Typically, narrow metal pins are inserted into the soil to a known depth in a grid or transect pattern along a hillslope, and the length of the pin protruding from the soil is measured at multiple points in time (Haigh, 1977). Most studies calculate annual erosion/deposition rates (also called ground advance/retreat or ground lowering) as the mean net change in pin height for a given experimental unit, usually given in mm yr^{-1}. This net change value, what we are calling a net 'real number' change, is often then converted to a unit mass per area (e.g., kg ha^{-1} yr^{-1}) using soil bulk density (e.g., Benito et al., 1992).

This approach has the obvious advantage of quantifying erosion/deposition rates at a relatively low cost, and intuitively it makes sense, but many studies have found that results calculated in this way do not have strong relationships with erosion rates estimated using other methods and models, nor with variables that one would expect to be strongly correlated with erosion, such as slope or precipitation. For example, a review by Haigh (1977) reported that several studies found no correlation between erosion pin measurements and topographic variables, including slope. Diaz-Fierros et al. (1987) did not find a

* Corresponding author at: 2357 Main Mall, Room 124, Vancouver, BC V6T 1Z4, Canada.
E-mail address: sean.kearney@alumni.ubc.ca (S.P. Kearney).

https://doi.org/10.1016/j.catena.2017.12.008
Received 30 March 2017; Received in revised form 23 August 2017; Accepted 7 December 2017
0341-8162/

Please cite this article as: Kearney, S.P., Catena (2017), https://doi.org/10.1016/j.catena.2017.12.008

relationship between soil erosion estimated from pins and that estimated by the Universal Soil Loss Equation (USLE) in northern Spain, and also noted a lack of correlation with slope. More recently, Hancock et al. (2010) found no apparent relationships between erosion/deposition patterns and hillslope position using erosion pins. Likewise, they found no correlation between pin data and caesium-137 (^{137}Cs) radioisotope concentrations (an indicator of soil erosion). Another recent study in Australia did not find statistically significant relationships between erosion pin data and topographic variables derived from high-resolution airborne laser scanning (ALS, also called LiDAR) or rainfall data (Hancock and Lowry, 2015).

The incongruence between erosion estimated from pins and other methods, and the apparent lack of correlation with erosion-related variables, calls into question the efficacy of the net 'real number' change in pin height as an erosion indicator, especially for comparative studies evaluating the treatment effects of different land-management practices. For example, in a location experiencing large amounts of soil movement, some pins will experience high rates of erosion while others will experience high rates of deposition between measurements. When the mean net change value is taken for a given experimental unit and measurement period, pins experiencing erosion and pins experiencing deposition will offset each other, and the final 'real number' change value is often near zero (Luffman et al., 2015). This can mask the magnitude of overall soil movement, and may explain the lack of correlations observed in the aforementioned studies. Other studies have noted that the spatial pattern of erosion pin data is more randomly distributed than that of erosion predicted by other methods (e.g., Shi et al., 2011), suggesting that in an erosive environment individual pins will experience both erosion and deposition at varying and random rates between measurements. In many cases, soil may move downslope in waves, and soil deposited at a pin in a given measurement period may be more available for transport during subsequent rain events (Hancock and Lowry, 2015).

An alternative (or complementary) approach to using the net 'real number' change in pin height is to use the absolute value of pin height change to capture the overall magnitude of soil movement, as proposed by (Couper et al., 2002). The absolute value treats positive and negative changes in pin height equally as a general indicator of soil movement, erosion activity and soil instability (Couper et al., 2002), thereby avoiding the challenges mentioned above.

We propose that the absolute value of pin height change offers a valid and underutilized indicator of soil erosion, and may be especially useful in comparative studies assessing the soil conservation potential of differing land management practices. Couper et al. (2002) explored how different methods of handling negative changes in erosion pin height (including an index of 'activity', or absolute value) affected erosion comparisons, but only for river banks. They concluded that the manner in which negative pin readings are treated greatly influences deductions about erosion, and that absolute value better captured relationships between erosion and environmental drivers such as temperature and precipitation (Couper, 2003). Luffman et al. (2015) used both mean pin height change (i.e., real number change) and the absolute value of change to study gully erosion and found that of the two, only absolute value was correlated with precipitation variables and showed significant differences between morphological settings.

Although the utility of the absolute value has been demonstrated in some systems, it has not been studied for comparing erosion activity as it relates to land management, especially for hillslope, sheet and rill erosion. We propose that the absolute value of pin height change offers a valid and underutilized indicator of soil erosion that may be especially useful in comparative studies addressing the soil conservation potential of land management practices.

In order to test this hypothesis, we compared the correlations of absolute and 'real number' change in erosion pin height with modeled erosion, related factors (e.g., slope and soil cover), and soil loss collected in erosion pits within experimental plots under five hillslope agricultural management systems of varying soil conservation potential. We also assessed differences in erosion between management treatments as predicted by the RUSLE and measured using each of the pin height methods.

2. Material and methods

2.1. Study area and experimental design

This study was conducted in northern El Salvador, in a region characterized as a steep mountainous mosaic of forest, forest-fallow patches, agriculture (primarily subsistence cultivation of maize, beans and sorghum) and pastures (Kearney et al., 2017a). Mean annual temperatures for the region are 22–26 °C and annual rainfall averages about 1985 mm, mostly falling between the months of May and October, with a pronounced dry season.

Erosion pins were installed on 25 experimental plots (12 × 20 m), separated into five treatments replicated across five farms. These plots were part of a larger study comparing ecosystem service provision under four maize-bean production systems – conventional (CONV), organic (ORG) and two 'slash-and-mulch' agroforestry systems (SMAS-1 and SMAS-2) – and a forest-fallow (FOR) reference site. Elevation of the experimental plots ranged from 624 to 866 m and slopes ranged from 19 to 40°, typical of the area. The 240-m^2 experimental plots were managed for three growing seasons beginning in April 2013. All plots were planted by hand (i.e., 'dibbling'), following common farmer practice in the region, which allowed pins to remain in place for all three years. A complete description of the experiment and its objectives can be found in Kearney et al. (2017b).

2.2. Erosion pins

Steel erosion pins (0.6 cm diameter, 40 cm length) were installed in the experimental plots in May 2013, prior to maize planting. Pins were placed in a grid pattern of 3 × 6 pins at 3 m spacing for a total of 18 pins per plot (Fig. 1). Pins were hammered into the soil perpendicular to the slope, leaving approximately 10 cm protruding from the soil surface, following recommended practices (Haigh, 1977).

Eight additional pins were installed in 2 × 5 m erosion collection subplots established within the larger experimental plots (Fig. 1). These subplots were installed on 6 of the cultivated treatment plots, 3 under conventional management (CONV) and 3 under a 'slash-and-mulch' agroforestry system (SMAS-1). Each collection subplot was bordered with metal sheeting protruding at least 10 cm vertically from the soil surface to prevent soil and other debris from entering the plot from above. Sediment was collected approximately biweekly from plastic-lined collection pits (approximately 1.8 × 0.5 × 0.5 m) located on the downhill edge of each subplot. Collected sediment was oven-dried for 24 h at 105 °C, sieved to 2 mm, and both the coarse and fine fractions were weighed and converted to Mg ha^{-1}. Data from one collection subplot was removed due to a failure of the metal border and substantial run-on into the collection pit from outside the subplot.

For this study, pin protrusion was measured in April 2015 (two years after installation) and again in February 2016, covering the entire 2015/16 rainy season. Pins were measured using a digital depth gauge (0.02 mm precision), and the mean overall change in pin height for each plot ($n = 25$) and subplot ($n = 5$) was calculated as both the real number value and absolute value of pin height change in mm over the entire 10-month period (i.e., the difference between the first and last pin measurement). Pins were inspected for damage or disturbance seven times throughout the season, and only pins that remained undisturbed for the entire study period were used in the final calculation. Pin data was further cleaned prior to analysis by removing extreme values, identified as measurements exceeding three standard deviations of the sample distribution of all undisturbed erosion pins.

The real number value was calculated as the change in pin height