Catena 166 (2018) 56–67

Contents lists available at ScienceDirect

Catena

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

Estimation of soil erosion rates in dehesas using the inflection point of holm oaks

Judit Rubio-Delgado[a,*], Susanne Schnabel[a], Álvaro Gómez-Gutiérrez[a], Manuel Sánchez-Fernández[b]

[a] INTERRA Research Institute, University of Extremadura, 10071 Cáceres, Spain
[b] Technical College, University of Extremadura, 10071 Cáceres, Spain

ARTICLE INFO

Keywords:
Southwest Spain
Soil erosion
Rangelands
Terrestrial laser scanning
Partially exposed roots
Basal growth

ABSTRACT

The exposure of tree or shrub roots represents a clear indicator of soil loss in the surrounding area. Previous studies have used this type of botanical evidence to estimate soil erosion rates, preferring roots at some distance from the tree stem because the inflection point (or root collar) undergoes a vertical displacement caused by basal growth. The aim of this paper is to develop a method that combines the inflection point of holm oaks and high-resolution digital images obtained by means of a terrestrial laser scanner to estimate soil erosion rates in Mediterranean dehesas. To correct for vertical displacement, the basal growth of each tree was determined in the field, differentiating the part of the roots that had been exposed by erosion from that generated by wood growth. Two datasets obtained through different approaches were used for validating the basal growth measured in the field survey: (i) a growth study analysing stems and cores of holm oaks and (ii) field measurements of basal growth of holm oaks located in an area without soil erosion. The results obtained by each method offered similar mean values (12.7 and 8.4 cm, respectively) as compared to the values estimated in the field survey (10.2 cm). Afterwards, soil erosion rates were corrected, reducing the values on average by 40%, with a mean loss of 26.7 t ha^{-1} y^{-1}. No relationship was found between tree age and basal growth. On the other hand, soil erosion rates showed a slightly negative trend with relation to tree age, indicating an upward tendency of soil losses from the year 1640 to 2014. Finally, it was possible to define three periods with varying erosion rates: 10.4 t ha^{-1} y^{-1} (1640–1830), 19.2 t ha^{-1} y^{-1} (1831–1888) and 27.2 t ha^{-1} y^{-1} (1889–2014).

1. Introduction

In the southwestern part of the Iberian Peninsula vast extensions of land are occupied by dehesas, consisting of rangelands with a disperse tree cover of evergreen oaks. With a surface area of 35,159 km^2 (MAPA, 2008), the largest extensions in Spain correspond to the regions of Extremadura (35%) and Andalucia (27%). In Portugal, dehesas are known as montados and they cover a surface of 7190 km^2 (Pereira et al., 2004). The dominant tree species is the holm oak (*Quercus ilex* L. *subsp. ballota* (*Desf.*) *Samp.*) which dominates in 90% of the territory of this agrosilvopastoral system (Papanastasis, 2004), the cork oak (*Q. suber*) being of lesser importance. The herbaceous layer is mainly composed of therophytic species, with shrubs being of minor importance. The main land uses are sheep, cattle and pig livestock rearing, and the cultivation of cereals and forage crops is of lesser importance. Forestry uses consist of firewood production through tree pruning, cork production and livestock acorn consumption. The dehesas have undergone important land use and management changes during the last 60 years (Moreno and Pulido, 2009; Jariego and Lavado Contador, 2010). The Spanish Civil War provoked an agricultural intensification, transforming vast areas into cultivated land from approximately 1940 to 1960. Afterwards, most of these croplands were abandoned in favour of cattle. Since Spain joined the European Union in 1986, domestic animal numbers have doubled (Gonzalo Langa, 2011). All of this, coupled with poor farm management, has created a significant degradation in this ecosystem: soil degradation, woodland regeneration problems, decreased productivity and quality of pastures and acorns, etc. (Papanastasis, 2004; Moreno and Pulido, 2009; Pulido and Picardo, 2010; Pulido et al., 2016; Herguido et al., 2017).

Previous works have studied soil erosion in dehesas, highlighting the negative effect of excessive livestock density (Schnabel, 1997; Schnabel et al., 2009). Predominant soil erosion processes are sheet erosion on hillslopes (Schnabel, 1997) and gully erosion in valley bottoms (Gómez-Gutiérrez et al., 2009). In dehesas, rill erosion is

* Corresponding author.
E-mail address: juditrd@unex.es (J. Rubio-Delgado).

https://doi.org/10.1016/j.catena.2018.03.017
Received 29 June 2017; Received in revised form 16 March 2018; Accepted 18 March 2018
0341-8162/

incidental and limited to areas where the land has been tilled for cultivation or shrub clearing (Schnabel et al., 2013). Authors such as Coelho et al. (2004), Martínez-Zavala and Jordán (2008) or Shakesby et al. (2002), carried out research in dehesa environments. Shakesby et al. (2002) compared the risk of soil erosion associated with different forestry uses, concluding that excessive stocking rates and/or tillage frequency could favour erosion in dehesas and montados. Using simulated rainfall experiments, Coelho et al. (2004) discovered an increase in soil degradation due to land use changes in marginal montado areas in Portugal and in the Maghreb. In a Spanish dehesa, Martínez-Zavala and Jordán (2008) demonstrated the effect of rock fragment cover on infiltration rates, resulting in a decrease in surface runoff and soil losses.

The soils in dehesas are commonly shallow, being frequently < 30 cm deep (Schnabel et al., 2013). Under the current environmental conditions, with low slope gradients and mean annual rainfall amounts of 500–600 mm, one would expect deeper soils, such as Luvisols which can be found in some areas. Soil erosion studies under natural rainfall using open plots and carried out in a typical dehesa with shallow soils, offered mean sheet erosion rates of only 0.63 $t\,ha^{-1}\,y^{-1}$ (Schnabel et al., 2010). Consequently, the current shallowness of soils cannot be explained by this erosion rate, at least in this case, indicating higher soil losses in the past. Furthermore, dehesas have experienced land use and vegetation cover changes in the last centuries, which may have provoked variations in erosion rates. Hence, in view of the scarce information available and the likely variation in soil losses in the past, a study of historical erosion rates is justified. In addition, Schnabel et al. (2006) reported great variation in the degree of soil degradation between a large number of dehesa farms, suffering approximately 40% heavy or moderate sheet erosion.

Several methods have been developed to quantify medium to long-term soil erosion, such as partially or totally exposed roots (LaMarché Jr, 1961; Eardley and Viavant, 1967; Valmore and LaMarche, 1968; Dunne et al., 1978; Carrara and Carroll, 1979; Schnabel, 1994; Bodoque et al., 2005; Gärtner, 2007; Corona et al., 2011; López Saez et al., 2011; Ballesteros-Cánovas et al., 2013; Bodoque et al., 2015). Other anatomical references could present methodological problems, as in the case of the inflection point (IP), i.e. the boundary between the root and the trunk of the tree (Valmore and LaMarche, 1968). The position of the IP represents the oldest tissues of the plant, and the pith in the tree trunk or the xylem core in the root indicate the date of germination (Telewski, 1993). However, several authors (Valmore and LaMarche, 1968; Carrara and Carroll, 1979; Gärtner, 2007; Stoffel et al., 2013; Bodoque et al., 2015) supported the idea that the use of the IP to estimate soil erosion rates produces an overestimation due to upward migration of the IP within the lifetime of the tree with respect to the surface of the soil. This displacement is the consequence of secondary growth, because roots of woody plants grow in two ways: by longitudinal extension, due to the activity of the apical meristem, or by secondary growth, producing successive layers of secondary xylem around the primary axis (Esau, 1965). No literature references were found which focus on correcting the overestimation caused by secondary growth when using roots closer to the stem or the inflection point. Gärtner (2007) developed a methodology to date the root exposure time, analysing the anatomical changes in the growth rings. In addition, this method allows to differentiate between exposure caused by erosion and that produced as a result of secondary growth. However, Gärtner and other authors (Bodoque et al., 2015; Carrara and Carroll, 1979; Corona et al., 2011; Gärtner, 2007) proposed sampling roots at distances of 0.5 to 1 m of the stem. The reason is that close to the base of the tree, the anatomical structure of roots is strongly altered by the mechanical forces of the stem to compensate effects such as those generated by the topography or the slope. Therefore, to estimate soil erosion rates using the IP it is necessary to correct the secondary growth of the stem base.

In dehesas, partially exposed roots of holm oaks are frequently observed. The main aim of this study is to estimate soil erosion rates using the IP. To do this, a Terrestrial Laser Scanner (TLS) device was used to produce high-resolution 3D models of the partially exposed root systems, the surrounding microtopography and the hillslope topography. Telling et al. (2017) published a review about the advantages and limitations of TLS in the different fields of Earth Sciences, including geomorphology. In addition, it was necessary to develop a methodology to avoid overestimation of erosion rates due to vertical displacement, which is presented in this paper. This approach offers some advantages over more traditional methods used because it is not invasive and allows a more intensive spatial analysis (even when comparing areas covered or uncovered by trees).

The results obtained using the IP will be contrasted with soil erosion rates estimated with the ^{137}Cs method described in a previous work (Rubio-Delgado et al., 2017).

Concluding, the objectives of this work were: 1) Develop a methodology to estimate historical soil erosion rates using the inflection point of holm oaks in dehesas. 2) Correct the vertical displacement of the inflection point to avoid overestimating rates. 3) Check the utility of the method contrasting the results with soil erosion rates estimated using ^{137}Cs in a previous work (Rubio-Delgado et al., 2017) and with other studies carried out in similar environments. 4) Analyse the magnitude of erosion rates and its variation over time.

2. Study areas

Three hillsides located within two farms, were selected as study areas: hillsides B1 and B2 in Buitrera (39°35′ N–5°36′ W) and hillside P in Parapuños (39°37′ N–6°8′ W) (Fig. 1). Both farms are representative of the dehesa land use system and show evident signs of soil erosion such as partially exposed roots. In addition, according to Schnabel et al. (2006), both farms were reported to suffer heavy sheet erosion. The main activities are livestock grazing and forestry.

B1 is the largest hillside (32,917 m^2), with an average slope of 5.4° and predominantly faces the East. B2 has an extension of 19,811 m^2, with the highest average slope (6.1°) and a predominantly easterly orientation. P, with a surface of 16,040 m^2, has the lowest slope (4.3°) and a predominantly southerly orientation. The tree density is higher in B2 than in B1 and P (Table 1).

The study areas belong to an extensive erosion surface characterized by Ediacaran shales and greywackes. Both present similar climatic and topographic characteristics. The topography is undulated while the climate is dry sub-humid, with mean annual rainfall amounts of 500 mm and an average annual temperature of 16 °C in the three study sites (Ninyerola et al., 2005). The soils of Buitrera and Parapuños are very shallow: 15.1 cm in B1, 19.2 cm in B2 and 18.0 cm in P. The soil profiles of the hillsides are similar and composed by a shallow Ah horizon of approximately 3 cm and a subsoil (Bw) of about 15 cm, covering hard bedrock or in some cases weathered rock (C). Soil texture is silty loam and bulk density and pH are similar in all sites (Table 2). Organic matter content is low, especially in B1.

3. Methodology

Historical soil erosion rates were estimated using the IP of holm oaks. The workflow used can be summarized as follows: (i) surveying the topographic surface to produce high-resolution 3D models; (ii) estimating soil erosion rates; (iii) determining the vertical displacement (VD) of the IP to avoid the overestimation of soil erosion rates; (iv) recalculating soil erosion rates using the correction.

3.1. Topographic survey of the study sites

The study sites were scanned at the beginning of autumn when herbaceous vegetation cover was at a minimum. A long-range TLS device (Leica ScanStation C10) was used to obtain a point cloud with coordinates X, Y, Z, colour values (RGB) and intensity. Technical