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Tolerable versus actual soil erosion rates in Europe

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ABSTRACT

Erosion is a major threat to soil resources in Europe, and may impair their ability to deliver a range of ecosystem goods and services. This is reflected by the European Commission's Thematic Strategy for Soil Protection, which recommends an indicator-based approach for monitoring soil erosion. Defined baseline and threshold values are essential for the evaluation of soil monitoring data. Therefore, accurate spatial data on both soil loss and soil genesis are required, especially in the light of predicted changes in climate patterns, notably frequency, seasonal distribution and intensity of precipitation. Rates of soil loss are reported that have been measured, modelled or inferred for most types of soil erosion in a variety of landscapes, by studies across the spectrum of the Earth sciences. Natural rates of soil formation can be used as a basis for setting tolerable soil erosion rates, with soil formation consisting of mineral weathering as well as dust deposition. This paper reviews the concept of tolerable soil erosion and summarises current knowledge on rates of soil formation, which are then compared to rates of soil erosion by known erosion types, for assessment of soil erosion monitoring at the European scale.

A modified definition of tolerable soil erosion is proposed as 'any actual soil erosion rate at which a deterioration or loss of one or more soil functions does not occur,' actual soil erosion being 'the total amount of soil lost by all recognised erosion types.' Even when including dust deposition in soil formation rates, the upper limit of tolerable soil erosion, as equal to soil formation, is ca. 1.4 t ha^{-1} yr^{-1} while the lower limit is ca. 0.3 t ha^{-1} yr^{-1}, for conditions prevalent in Europe. Scope for spatio-temporal differentiation of tolerable soil erosion rates below this upper limit is suggested by considering (components of) relevant soil functions. Reported rates of actual soil erosion vary much more than those for soil formation. Actual soil erosion rates for tilled, arable land in Europe are, on average, 3 to 40 times greater than the upper limit of tolerable soil erosion, accepting substantial spatio-temporal variation. This paper comprehensively reviews tolerable and actual soil erosion in Europe and highlights the scientific areas where more research is needed for successful implementation of an effective European soil monitoring system.

Contents

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1. Introduction

1.1. General

Soil loss occurs mostly through physical pathways but can also occur as a result of biochemical processes, including weathering of mineral particles in soil, which is known as chemical denudation. Removal of particles or even small aggregates from the in situ soil system then takes place in suspension or solution, as bed load or by gaseous export. Organic soil material is lost mainly through decomposition processes, except in the case of peat erosion where organic particles are removed and transported by water or wind. Physical pathways of soil loss predominate and fall within the domain of soil erosion, which is defined as “the wearing away of the land surface by physical forces such as rainfall, flowing water, wind, ice, temperature change, gravity or other natural or anthropogenic agents that abrade, detach and remove soil or geological material from one point on the earth's surface to be deposited elsewhere” (Soil Science Society of America, 2001; Jones et al., 2006, pp. 24–25). With respect to soil degradation, most concerns about erosion are related to ‘accelerated soil erosion,’ where the natural (or ‘normal,’ or ‘geological’) rate has been increased significantly by human activity.

The cause and extent of accelerated soil erosion are influenced by a number of factors (Morgan, 2005) and the most significant are:

Soil erodibility or susceptibility to erosive forces, as determined by soil physical, chemical and biological properties (Chepil, 1950; Bryan, 1968; Wischmeier and Mannering, 1969; Aspiras et al., 1971; Wischmeier et al., 1971; Tisdall and Oades, 1982; Rauws and Govers, 1988; Forster, 1989; Chenu, 1993; Oades, 1993; Marinissen, 1994; Edgerton et al., 1995; LeBissonnais, 1996; Degens, 1997; Ketterings et al., 1997; Kiem and Kandeler, 1997; Hallett and Young, 1999; Czarnes et al., 2000; Doerr et al., 2000; Scullion and Malik, 2000; Boix-Fayos et al., 2001; Ritz and Young, 2004; Allton, 2006; Shakesby and Doerr, 2006).

Erosivity or energy of the eroding agent, e.g. rainfall, overland flow or wind (Wischmeier and Smith, 1958; Skidmore and Woodruff, 1968; Fournier, 1972; Zachar, 1982; Morgan et al., 1986; Knighton, 1998).

Slope characteristics, gradient, length and form (Zingg, 1940; Musgrave, 1947; Kirkby, 1969; Horváth and Erödi, 1962; Chepil et al., 1964; Meyer et al., 1975; D'Souza and Morgan, 1976; Wischmeier and Smith, 1978).

Land cover use and management (Wischmeier and Smith, 1978; Wiersum, 1979; De Ploey, 1981; Dissmeyer and Foster, 1981; Laflen and Colvin, 1981; Foster, 1982; Temple, 1982; Lang and McCaffrey, 1984; Armstrong and Mitchell, 1987; Quinton et al., 1997; Lal, 2001; Gyssels et al., 2005; Zhang et al., 2007).

This paper reviews the dominant causes and rates of soil loss that occur in Europe via the process of detachment (e.g. water, wind, tillage, crop harvesting and land levelling), and subsequent transport and deposition of the detached soil material. Whilst all pathways of soil loss need to be considered and monitored carefully, once detachment of soil particles occurs, the functionality of the remaining soil is impaired to a greater or lesser extent depending on the amount of soil lost. Thus prevention of the detachment phase of the erosion process (Meyer and Wischmeier, 1969) is crucial if the functionality of the soil system is to be safeguarded for future generations.

This review focuses on erosion of mineral soils in Europe, because this is the dominant type of soil loss on the continent (Boardman and Poesen, 2006). Mineral soils are here defined as those that consist predominantly of, and have properties mainly determined by, mineral matter, and usually contain less than 20% organic carbon (SSSA, 2001). Relatively recent research (Holden and Burt, 2002; McHugh et al., 2002; Holden, 2005) has shown that erosion processes also account for substantial losses from organic soils, for example by piping and gullying in peatlands. However, organic soils are far less extensive than mineral soils in Europe (Montanarella et al., 2006) and constitute a different ecosystem; thus consideration of their erosion is not included in this paper.

1.2. Scale

Soil erosion research has considered various spatial and temporal scales at which the different erosion processes operate. The experience and knowledge gained from these studies is generated by, and serves, a very wide audience, ranging from developers of sub-process, physically based erosion models, such as EUROSEM (Morgan et al., 1998) and WEPP (Nearing et al., 1989), through to regional planners and policy makers. Ciesiolka and Rose (1998) observe that smaller scale studies tend to focus on ‘on-site’ impacts of soil erosion, whilst larger spatial scale studies concentrate on the ‘off-site’ impacts.

The temporal scale variation in erosion processes is implicit in Table 1, with small spatial scale processes such as raindrop impact occurring in fractions of seconds, and catchment scale processes usually being monitored over much longer time scales (i.e. seasons, years, decades or even geological timescales). Sediment delivery ratios are also time-dependent, ranging from effectively no sediment delivered at the exact moment of detachment to sediment delivery