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Rock fragments and soil hydrological processes: Significance and progress

Yinghu Zhang [a], Mingxiang Zhang [a,*], Jianzhi Niu [b,*], Hongli Li [a], Rong Xiao [a], Haijin Zheng [c], Jaume Bech [d]

[a] School of Nature Conservation, Beijing Forestry University, 100083 Beijing, PR China
[b] Key Laboratory of Soil and Water Conservation and Desertification Combating, Ministry of Education, School of Soil and Water Conservation, Beijing Forestry University, 100083 Beijing, PR China
[c] Jiangxi Provincial Institute of Soil and Water Conservation, 330029 Nanchang, PR China
[d] Laboratory of Soil Science, Plant Biology, Faculty of Biology, University of Barcelona, Avenid Diagonal 643, 08028 Barcelona, Spain

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ABSTRACT

In this review, we explore the significance of rock fragments in studies of soil hydrological processes, because according to research, the effects of rock fragments on soil hydrological processes are inconsistent (positive/negative). Rock fragments play a critical role in the biosphere as the primary filter for water and solutions containing contaminants and heavy metals. Rock fragments have a complex influence on soil hydrological processes (e.g. soil erosion, runoff generation, water infiltration, solute transport and water flow) and are highly relevant in a typical system in the soil–plant–atmosphere continuum. Cracks related to rock fragments provide preferential flow paths through which pollutants are transported into groundwater. In this paper, the published literature is reviewed concentrating on rock fragments and their effects on soil hydrological processes. Systematic studies and examples illustrate the effects of rock fragments architecture (i.e. coverage, content, size, position, spatial heterogeneity, morphology, weathering and topography) on soil hydrological processes. Methods and models applied to evaluate the effects of rock fragments on soil hydrological processes are examined in detail. We conclude that the relationship between rock fragments and soil hydrological processes is complicated and requires more international research efforts. This review concludes with a discussion of perspectives on areas of research that can improve understanding of the effects of rock fragments on soil hydrological processes, with insights and suggestions also being provided regarding potential research trends, requirements and solutions.

Contents

* Corresponding authors.
E-mail addresses: pku2015hold@163.com (M. Zhang), yhzhang2015sd@bjfu.edu.cn (J. Niu).

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1. Introduction

Soil hydrological processes are influenced by several interacting factors, which include soil physical–chemical properties, soil structure development, initial soil water content, rock fragments in soil, precipitation, land and vegetation cover, hillslope gradient and spatial scale. Many soils contain abundant rock fragments as a result of both natural soil forming processes and human activities, and the interest has been growing in these soils (Poesen and Lavee, 1994; Poesen et al., 1999; van Wesemael et al., 1995, 1996, 2000; Cerdà, 1996, 1998, 2001; Cousin et al., 2003; Mandal et al., 2005; Mayor et al., 2009; Smets et al., 2011; Zhou et al., 2011; Jomaa et al., 2012a,b, 2013; Economou-Eliopoulos et al., 2014; Gordillo-Rivero et al., 2014; Sohrt et al., 2014; Gargiulo et al., 2015; Hlaváčiková et al., 2015; Wang et al., 2016). The term "rock fragments" is often used instead of "stones" because the latter refers to a particular rock fragment size class with class limits depending on the classification system used (Poesen and Lavee, 1994). For example, stones are rock fragments 75 to 250 mm in size in the F.A.O. classification and 250 to 600 mm in the U.S. classification. Despite the potential effects that rock fragments (soil particles larger than 2 mm in diameter) (Miller and Guthrie, 1984; Novák et al., 2011; Novák and Kňava, 2012; Tetegan et al., 2015b) in the soil profile or resting on the soil surface have on pedological and geoecological processes, studies on soil hydrological processes are typically both theoretically and experimentally burdensome (Ingelmo et al., 1994). Rock fragments affect soil hydrological processes by modifying soil physical–chemical properties (Poesen et al., 1999; Cousin et al., 2003) and tortuosity of water flow pathways (Zhou et al., 2011). Many studies specifically address the relationship between rock fragments and soil hydrological processes (e.g. soil erosion, water infiltration, runoff generation, solute transport and water flow); however, contrasting results are observed for the association between the two variables that are dependent on soil structure development, hillslope gradient, spatial distribution and amount of rock fragments, study scale, physical–chemical processes and pedoclimatic conditions (Ingelmo et al., 1994; Valentin, 1994; Poesen et al., 1999). In studies by Stuart and Dixon (1973), Constantz et al. (1988), and Ingelmo et al. (1994), rock fragments in the soil profile led to reduced water infiltration and increased runoff generation, whereas Poesen et al. (1999) found a negative relationship between rock fragments and sediment production by rill erosion at different spatial scales. In Poesen et al. (1990), the relationship between rock fragments and water infiltration was positive when rock fragments rested on the soil surface but was negative when rock fragments were embedded in soil. In particular, Dadkhah and Gifford (1980) found that water infiltration increased with increased coverage of rock fragments on soils that were not compacted, whereas water infiltration decreased on those that were compacted. The interaction between rock fragments and soil hydrological processes is strong, and the importance of rock fragments was recognized by Lowdermilk and Sundling (1950), Moustakas et al. (1995), van Wesemael et al. (1995, 1996, 2000), Cousin et al. (2003), Zavala and Jordán (2008), Zavala et al. (2010), Zhou et al. (2009, 2010, 2011), Smets et al. (2011), Gordillo-Rivero et al. (2014), Fang et al. (2015) and Hlaváčiková et al. (2015).

A quantitatively accurate description of the relationship between rock fragments and soil hydrological processes is the goal, but this is difficult to achieve because of the strong heterogeneity of rock fragments resting on the surface or within soils (Tetegan et al., 2012). Compared with the fine phase or fine soil fraction, particles <2 mm in diameter, the stony phase is composed of rock fragments larger than 2 mm in diameter that remains inert in heterogeneous soils (Novák et al., 2011; Tetegan et al., 2011, 2015b). Although rock fragments are of vital importance in water conservation, previous scientific studies often ignored the effects of the stony phase (Poesen and Lavee, 1994; Cousin et al., 2003), and when only the fine phase is considered, as a consequence, soil hydrological properties are not estimated accurately. Currently, however, accurate estimates of soil hydrological processes in stony soils remain difficult to characterize (Tetegan et al., 2011, 2012). Moreover, rock fragments in stony soils increase the complexity of soil hydrological processes (Zhou et al., 2011). Based on the characteristics of rock fragments, water redistribution and some soil hydrological processes during rainfall events are affected (Cousin et al., 2003; Katra et al., 2008). With moderated temperatures, soils under rock fragments often have microclimatic conditions that favor increases in the activity of soil biota, which affect soil hydrological processes (Danalatos et al., 1995; Katra et al., 2008). Rock fragments, in particular those resting on the soil surface, are important in affecting soil hydrological processes by (i) protecting topsoil from detachment and the impact of raindrops; (ii) reducing physical degradation of the soil surface; and (iii) slowing the rate of runoff generation (Poesen et al., 1994; Nyssen et al., 2001; Rieke-Zapp et al., 2007; Guo et al., 2010). Soil hydrological processes (e.g. soil erosion, runoff generation, water infiltration, solute transport and water flow) are a major environmental concern when correlated with the transport of pollutants from soil surfaces to depth, including to groundwater level, by preferential flow paths. The measurement of soil heavy metals in groundwater resources, nitrogen and phosphorus loss with runoff and sediment, landslide and debris flow from soil and water erosion, and crop production and the health of people are all environmental concerns affected by soil hydrological processes. Among environmental problems, the demands are dramatic for increased domestic and industrial water use; therefore, the conservation and storage of water resources are more significant, and hydrologists are focusing on the great potential of rock fragments as a mulch for water conservation (Danalatos et al., 1995).

With potential benefits to develop crop production and for the health of people worldwide, research of the effects of rock fragments is essential. Kosmas et al. (1994) and Danalatos et al. (1995) found higher wheat biomass production in soils containing rock fragments