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A comparison of methods for evaluating soil redistribution in the severely eroded Stavropol region, southern European Russia

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Abstract

In this paper, we combined several erosion assessment methods to construct a sediment budget describing soil redistribution and sediment delivery within a study area containing grassed upper slopes, a large arable field of 1.3 km^2 with a semipermanent rill and ephemeral gully network and a downslope buffer zone of a grassed dry valley (balka) bank with depositional fans. The study site is in the Stavropol Upland—one of the most severely eroded, intensively cultivated areas of European Russia. The methods include two variations of the soil survey approach; a proportional ^{137}Cs conversion model; a mass balance ^{137}Cs conversion model; a ^{137}Cs-based tracer budget; direct measurement of gully volume by theodolite; examination of ^{137}Cs depth profiles; and a version of the USLE model modified and calibrated for Russian conditions. Our results highlight the importance of (i) comparing such techniques, (ii) validating the results from them, and (iii) the value of combining the outputs of different measurement methods. In particular, the soil survey approach was able to separate the influence of sheet and linear erosion; the proportional ^{137}Cs and mass balance ^{137}Cs models estimated similar soil redistribution rates (5.5±0.8 and 5.3±0.8 kg m^{-2} $year^{-1}$, respectively) and were improved when combined with direct measurements of gully volumes. Rates and locations of sediment redeposition within sinks, such as grassed valley banks, were best evaluated by combining ^{137}Cs depth profile analysis and conversion models with soil profile descriptions. There was good agreement between the soil survey and the ^{137}Cs tracing (combined with gully volume measurement) approaches. Average erosion rates estimated using the Russian version of the USLE model were lower by a factor of six compared to the physically based approaches. It may have been successful in assessing water erosion rates within inter-rill areas, and the discrepancy may provide insight into the contribution of tillage erosion. We conclude that the USLE model should be used only in combination with other techniques on arable fields where intensive rill erosion, ephemeral gullying, and mechanical translocation of soil take place.

Keywords: Soil redistribution; Caesium-137; USLE; Soil survey; Rill measurement; Sediment delivery

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1. Introduction

Human-accelerated soil erosion is estimated to affect ~10^9 ha of continental landmasses (Lal, 1994). In many areas, however, reliable erosion measurements are limited, and assessing its extent and seriousness remains difficult (Higgitt, 1991). Catchment managers and land use agencies are increasingly required to make decisions regarding the impact of land use or land management changes on sediment delivery downstream. The advent of GIS-based tools combined with erosion models such as USLE (and its derivatives) promise much in terms of documenting slope erosion at catchment scales, especially where labor and funding is limited or where data are absent or of poor quality (Prosser et al., 2001). However, care must be taken to assess the appropriateness of such erosion models and the circumstances under which they can be applied. One way to achieve this is to compare model-based estimates of erosion losses with those obtained by independent methods.

Methods for measuring soil erosion and redistribution at the hill slope scale include theodolite surveys, rill volume measurements (Govers and Poesen, 1988; Poesen et al., 1996), suspended sediment runoff monitoring (Kronvang et al., 1997), soil surveys (Larionov et al., 1973), and various tracing techniques, of which ^{137}Cs is the most widely adopted (Ritchie et al., 1974; Kachanoski, 1987; Walling and Quine, 1990; Walling and He, 1999). The outcomes of these measurements may then be incorporated into a sediment budget (Dietrich and Dunne, 1978; Loughran et al., 1992; Golosov et al., 1992; Walling, 1999). Any comparison of methods needs to be undertaken at the same spatial and temporal scales, and the suitability of a method to a particular spatial and temporal resolution must be accounted for. The upscaling of results from a single technique can also result in poor understanding of erosion processes. An example of this would be the extrapolation of soil loss rates from erosion plots to whole slope or catchment scales without allowing for deposition and storage and the resulting reduced sediment delivery to streamlines (Walling, 1983).

The opportunities for comparison and integration of results from different erosion estimation methods are limited, and examples in the literature are rare (Montgomery et al., 1997; Turnage et al., 1997). The scarcity of such comparisons is unfortunate because important information on the role of different erosion processes and their influence at different scales are not revealed (Boardman et al., 1990). Furthermore, because some methods are suited to quantify particular processes (e.g., plots for sheet or rill erosion) and others to quantify overall net losses (e.g., inventories of ^{137}Cs), it is likely that a combination of approaches will yield the most informative estimates of soil redistribution and losses occurring from large fields and small catchments. These are the scales that management is most frequently undertaken and for which information is required.

In this study, we applied a suite of methods to evaluate soil redistribution in a study area comprising grassed slopes, a large arable field, and downslope depositional areas (total area ~2 km^2) located within the Stavropol Upland, southern European Russia. Erosion in the arable field (1.3 km^2) arises from concentrated and unconcentrated flow and mechanical translocation. This is an ideal environment for comparing methods because it allows for detachment, entrainment, transport, deposition, and storage at a scale that is realistic for assessment of whole slope losses and their integration into any catchment scale model. Where appropriate, we combine approaches to quantify the importance of particular processes and their contribution to soil redistribution within, and sediment losses from, the field. Data from these methods are incorporated into a provisional sediment budget, which estimated sediment delivery into the adjoining drainage network. We believe this is the first time that such a comparison and combination of approaches has been carried out at this scale.

There are three different methodological approaches used in this study: (i) direct observations (soil survey and ephemeral gully volume measurements), (ii) soil redistribution tracing using caesium-137 (^{137}Cs) methods, and (iii) application of a version of the USLE model modified for Russian conditions. The advantages and disadvantages of the different methods and approaches are discussed.