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On the measurement of alpine soil erosion

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ABSTRACT

The knowledge of soil erosion processes and especially soil erosion rates in alpine grassland regions is scarce due to the lack of detailed studies. The non-existence of validated methods which are suitable to quantify alpine soil erosion is one of the key issues for the limited process understanding. The aim of this study is to compare different methods and to conclude on suitability for the determination of alpine soil erosion. Furthermore, the advantages and disadvantages of the single measurement methods with regard to alpine basins are focused. We distinguish between sediment traps and sediment cups to determine erosion rates biweekly in 2007 and 2008, and Cesium-137 based measurements to measure long term erosion rates since 1986. The latter method integrates over a time span of 22 years. We investigate three different land cover types: hayfields, pasture with dwarf shrubs and pasture without dwarf shrubs in the Urseren Valley (Central Switzerland) with a mean slope steepness of 37°. Sediment traps are suitable to quantify erosion rates during summer time. However, measurements are not possible during winter time. Sediment cups are an ideal tool for soil movement observation within the plot size but are limited to quantitative measurements. Cesium-137 investigations enable erosion quantification all-throughout-the-year but without identifying related processes. The combination of all three methods turns out to be useful for erosion quantification and process understanding. Mean monthly erosion rates during the vegetation periods 2007 and 2008 based on the sediment traps are between 0.006 t ha^{-1} mo^{-1} and 0.045 t ha^{-1} mo^{-1}. These generally low erosion rates can be explained by a low overland flow of 0.5–1.8% of the measured precipitation. Cesium-137 based measurements yield mean annual erosion rates for the time span 1986–2008 between 8.3 t ha^{-1} yr^{-1} and 26 t ha^{-1} yr^{-1}. We conclude that erosion rates on alpine grassland are dominated by snow driven processes during winter time.

1. Introduction

Erosion is a formative geomorphologic process in alpine environments closely related to steep slopes and extreme climate. Rock falls, avalanches and landslides are among those formative processes and have been studied intensively to prevent from human or infrastructures damage (e.g. Oppikofer et al., 2008; Wang and Cavers, 2008). Although soil erosion in the Alps is a well recognized problem, identified as a priority for action within the soil protocol of the Alpine Convention (e.g. AlpineConvention, 2005), the investigation of soil erosion on alpine sites is limited to a few studies. A comprehensive assessment of soil erosion in the Alps is still missing (ClimChAlps, 2006) and the knowledge of soil erosion and especially sheet erosion on alpine grasslands remains scarce. This study is a contribution to close the gap.

The term soil erosion is used for sheet, rill, interrill and gully erosion as well as for landslides. Alpine grasslands that are the focus within this study do not have the typical rill and interrill pattern. Here, we focus on sheet erosion that is defined as erosion caused by surface water in unconcentrated flow. Soil erosion and the regeneration of soil have been mainly studied on ski slopes (e.g. Leser and Mosimann, 1982). For agricultural sites in lowlands of low mountain ranges, mapping and quantification of soil erosion under different land cover conditions has been studied comprehensively (e.g. Gabriels et al., 2003; Ledermann et al., 2008; Matisoff et al., 2002a; Nearing et al., 1999; Prasuhn, 2011). Generally, different erosion processes operate at different temporal and spatial scales and measurements as well as modeling predictions have to be adapted to the scale. De Vente and Poesen (2005) illustrated the relation between basin area, dominant erosion processes and sediment yield by a combination of measured sediment yield at different scales. Stroosnijder (2005) defined five relevant spatial scales for water erosion in agricultural systems: (1) the point scale (1 m^2) for interrill (splash) erosion, (2) the plot (<100 m^2) for rill erosion, (3) the hill slope (<500 m) for sediment deposition, (4) the field (<1 ha) for channels and (5) the small watershed (<50 ha) for spatial interaction effects. The measurement methods of soil erosion on point scale are splash cups (e.g. Mati, 1994; Van Dijk et al., 2003). On plot scale sediment

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traps (e.g. Pieri et al., 2007; Robichaud and Brown, 2002), Coshocton wheels (e.g. Bonta, 2002; Rochester et al., 1994) and USLE test plot are used (e.g. Bagarello et al., 2008; Wischmeier and Smith, 1978). Radioactive isotope measurements such as Cesium-137, Beryllium-7 and Lead-210 (e.g. Mabit et al., 2007; Matisoff et al., 2002b; Walling et al., 1999) have been used for point measurements that can be extrapolated to plots and basins, depending on the heterogeneity and the number of measurements on the site. The Cesium-137 based erosion measurement is a common method on arable land that has been used many times e.g. Walling (2004). In alpine regions, however, the Cesium-137 method has been introduced by Konz et al. (2010). Furthermore, in-situ as well as laboratory Cesium-137 measurements based on soil sampling were done to test the feasibility of those methods in alpine regions (Schaub et al., 2010). A detailed discussion of general advantages and disadvantages on field and laboratory applications of gamma detectors can be found in Beck and Gogolak (1972), Miller and Shebell (1993) and He and Walling (2000).

Regarding measurements during the vegetation period, some of the plot measurement methods have been also sporadically used in alpine environments (e.g. Felix and Johannes, 1995). But since snow dynamics make it impossible to measure soil erosion in alpine regions throughout the entire year, erosion measurements in alpine regions have been conducted during the vegetation period only without the influence of snow (Descroix and Mathys, 2003; Felix and Johannes, 1995; Isselin-Nondedeu and Bedecarrats, 2007). Felix and Johannes (1995) measured erosion rates between 0.0001 and 0.2 t ha^{-1} during the vegetation period with sediment traps. Isselin-Nondedeu and Bedecarrats (2007) determined the influence of several plants on soil erosion. They found considerable differences between plant species with Festuca Alpina having the highest amount of sediment deposition. Frankenberg et al. (1995) measured erosion rates up to 20 t ha^{-1} yr^{-1} on arable alpine sites during the vegetation period.

The aim of our work is to identify appropriate measurement systems for alpine soil erosion processes and to quantify soil erosion rates of different land cover types. Since slope steepness, land cover conditions as well as vegetation cover have to be constant, the measurement plots were planned to be 2 m in width and 20 m in length. The applicability of the three applied measurement methods in respect to their suitability for alpine regions is discussed. Measurements were conceived to give separate information on erosion rates during the vegetation period (sediment traps) and whole year rates (Cesium-137 measurements) to separate winter processes from erosion processes during the vegetation period. The information of soil erosion results from sediment traps were supplemented by point measurements with sediment cups.

2. Materials and methods

2.1. Investigation area

The study area is located in Central Switzerland (Canton Uri) in the Urseren Valley (Fig. 1). The elevation of the W–E extended mountain valley ranges from about 1400 m a.s.l. up to about 2500 m a.s.l.

The mean annual rainfall from 1986 to 2008 is 1516 mm, mean air temperature is 3.1 °C (MeteoSwiss, 2007) measured at an altitude of about 1480 m a.s.l. The valley is snow covered from November to April with a mean annual snowfall from 1986 to 2008 of 448 mm. Surface flow is usually controlled by snowmelt from May to June. Important contributions to the flow regime are early autumn floods. The prevailing land cover types in the valley are hayfields near the valley bottom (from 1400 to approximately 1600 m a.s.l.) and pasture further upslope. Siliceous material is dominant, and forms Cambic Podzols (Anthric) and Podzols (Anthric) at our sites classified after IUSS Working Group (2006). The characteristic of these soils is a migration (M-horizon) horizon within the upper 100 cm that has been caused by sedimentation in the past. The thickness of the M-horizon is between 5 and 45 cm. For a detailed description of the Urseren Valley see Meusburger and Alewell (2008).

2.2. Experimental plots

The nine experimental plots are situated at the south-facing slope at altitudes between 1550 m a.s.l. and 1800 m a.s.l. Three different land cover types with three replicates each were investigated: hayfields, (hf1–3), pasture with dwarf shrubs (paw1–3) and pasture without dwarf shrubs (pawo1–3). The slopes of all plots were in the range of 35°–39°. Soil type of hayfield hf2, paw2 and pawo1 is sandy loamy silt, paw1 is loamy sand and hf1, hf3, pawo2, pawo3 and paw3 is silty loamy sand. Vegetation of hayfields is dominated by *Trifolium pratense, Festuca, Thymus serpyllum* and *Agrostis capillaries*. Pasture with dwarf shrubs are dominated by *Calluna vullgaris*, *Vaccinium myrtillus*, *Festuca*

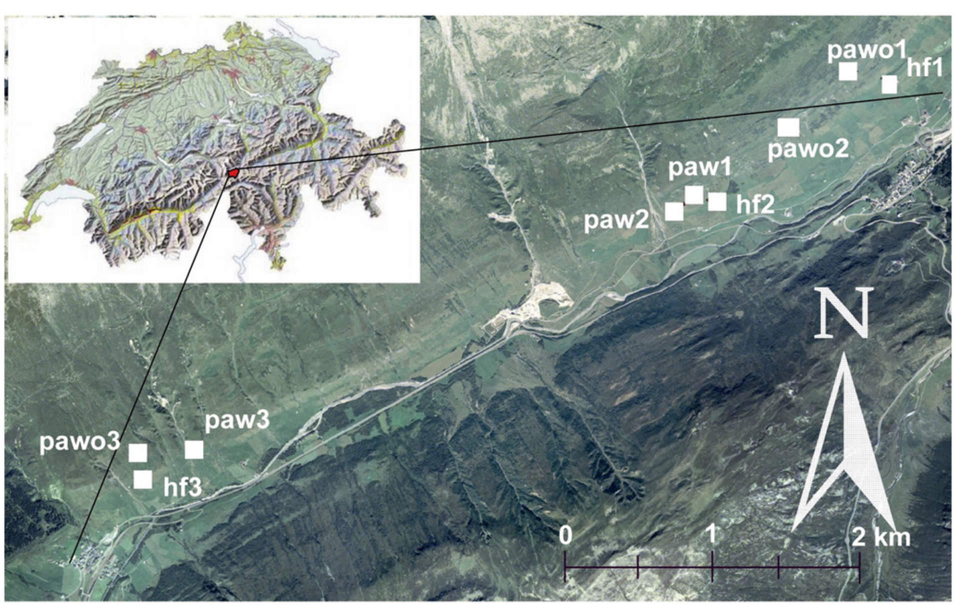

Fig. 1. The Urseren Valley in Southern Switzerland and the location of the investigated sites with three grassland types: hayfield (hf), pasture without dwarf shrubs (pawo) and pasture with dwarf shrubs (paw).