Catena 127 (2015) 1–8

Contents lists available at ScienceDirect

Catena

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

Rain simulation in patchy landscapes: Insights from a case study in the Central Alps

Ch. Newesely [a,*], G. Leitinger [a,b], W. Zimmerhofer [a], B. Kohl [c], G. Markart [c], E. Tasser [b], U. Tappeiner [a,b]

[a] Institute of Ecology, University of Innsbruck, Sternwartestrasse 15, 6020 Innsbruck, Austria
[b] Institute for Alpine Environment, European Academy Bozen (EURAC), Drusussallee 1, 39100 Bozen, Italy
[c] Federal Forest Research Center (BFW), Department of Natural Hazards, Hofburg, Rennweg 1, A-6020 Innsbruck, Austria

ARTICLE INFO

Article history:
Received 7 August 2014
Received in revised form 18 November 2014
Accepted 19 November 2014
Available online 23 December 2014

Keywords:
Alpine grasslands
Heavy precipitation event
Runoff coefficient
Runoff formation
Sprinkling
Water provision

ABSTRACT

Simulating heavy rain events to analyze potential surface runoff and related soil erosion is a well-established approach in alpine ecology and hydrology. In steep and inaccessible terrain with highly variable relief and vegetation, as occurs in mountainous regions, the rain simulators used to date are often not adapted to the abovementioned characteristics. This study reviews heavy rainfall simulators and presents a consequentially developed rain simulator that covers an area of 10 m^2. The results of simulated heavy rainfall events (100 mm h^{-1}) demonstrated the sprinkling equipment used here to be a useful tool, delivering robust results when studying surface runoff at small scales in a heterogeneous terrain. A comparison to rainfall simulation on a 50 m^2 plot revealed no significant differences, which demonstrates the equipment used at the scale of 10 m^2 to be above a "minimum area" for rainfall simulation. Finally, the impacts of plot size on runoff behavior are discussed to provide useful information using a rainfall simulator in the field. The presented rainfall simulator turned out to be a valuable tool for obtaining more detailed information on the surface runoff of small patterned landscapes (i.e., in both natural and managed grass and dwarf-shrublands) by delivering results comparable to those of larger-scale rain simulators (covering 50 or 100 m^2).

1. Introduction

Climatic models predict an increase in heavy rainfall events (partially also after a drought) as well as an increase in situations with a high risk of surface runoff for parts of the alpine regions (Beniston et al., 2007; Bronstert et al., 2002; Christensen and Christensen, 2003, 2004; Kirtman et al., 2013; Peter et al., 2014; Reichstein et al., 2013). In the Central Alps, for example, an increase of rain events with intensities of 100 mm h^{-1} is projected. During such high-precipitation events, the risk of surface runoff is high, with important implications for flood formation, landslides, debris flows, and shallow soil erosion around rivers (Auerswald, 2002; Beniston et al., 2007; Bronstert et al., 2002; Cerdà, 2007; Li et al., 2014; Liu et al., 2014; Zema et al., 2012). Surface runoff and the resulting soil erosion are directly connected to the structure of the soil, the composition of the vegetation, the usage of the land and the intensity of the rain event. Vegetation and soil are directly connected to land use practices (Biro et al., 2013; Cerda and Doerr, 2007; Faeh et al., 1997; García-Orenes et al., 2009; Leh et al., 2013; Ziadat and Taimeh, 2013). During recent decades, a significant shift in land use practices, occurred in the alpine region. Areas formerly used as meadows are now used as pastures, and areas that are difficult to access have tended to be abandoned (Schirpke et al., 2013; Tasser and Tappeiner, 2002). Both changes have a significant influence on the water budget, especially on surface runoff during heavy rain events (Newesely et al., 2004; Tasser et al., 2005). The effect of trampling by grazing cows is often associated with a high soil density in the upper soil layers and consequently a decreased infiltration capacity of the soil (Merz et al., 2009; Pietola et al., 2005). This leads to an increased risk of surface runoff. Several investigations have shown that high biodiversity and the resulting good root penetration are very important for soil stability (Martin et al., 2010; Tasser et al., 2003). As a result, high biodiversity lowers the vulnerability to landslides caused by high surface runoff. Modeling of the local effects induced by different climate change scenarios allows a better interpretation of the consequences to be expected. To keep the models as realistic as possible, detailed information on the individual factors influencing the model are required. Thus, facts on the impacts of land use changes on surface runoff and related consequences are necessary. To obtain this information, the simulation of rain events has proven to be a good tool (Beier et al., 2012; Cerdà, 1998; Iserloh et al., 2013; Ries et al., 2013). Using this method, it is possible to analyze the effect of the natural rain situation as well as that of catastrophic heavy rain events on surface runoff.

The first experiments simulating rain events were begun during the first half of the twentieth century. Compilations of the different tools, including their essential parameters and problems related to

* Corresponding author. Tel.: +43 512 507 51618; fax: +43 512 507 51699.
E-mail address: christian.newesely@uibk.ac.at (C. Newesely).

http://dx.doi.org/10.1016/j.catena.2014.11.013
0341-8162/

their construction, are published by Blanquies et al. (2003) and Ries et al. (2013). In the 1970s, a number of different systems for rain simulation were also developed in Europe, with irrigated areas ranging between 4 and 400 m^2 (Auerswald and Eicher, 1992; Auerswald et al., 1991, 1992; Cerdà, 1996; Humphry et al., 2002; Kainz et al., 1992; Karl and Toldrian, 1973). In alpine ecosystems, it is often difficult to investigate surface runoff due to the mosaic of small areas with different soil and vegetation types. This, together with steep meadows or pastures and the availability of sufficient amounts of water makes it often difficult to install a large simulator.

In this study, we present a rain simulator with an irrigation area of only 10 m^2 that is ideally suited to investigate surface runoff on small hydrological response units (HRU) in finely structured landscapes with fine-scale patterns of vegetation and soil. To ensure comparability with other studies we further compared the here presented simulator with a 50 m^2 simulator with the same technological background.

2. Material and methods

Investigations of the runoff coefficients of different HRUs in alpine areas have mostly been conducted with irrigated areas of at least 50 m^2. Therefore, we investigated whether this newly designed rainfall simulator with an area of only 10 m^2 can produce similarly realistic approximations of surface runoff. The specifications of six different large plot rain simulators and two common small scale simulators were compared with the rainfall simulator presented here to enable the selection of the construction best suited for specific demands. The presented small-HRU rainfall simulator is basically constructed on the simulator of the Federal Forest Research Center (BFW, Innsbruck) and was after calibration comprehensively tested under field conditions at the experimental site 'Kaserstattalm', which is part of the long-term socio-ecological (LTSER) research site Stubai Valley (A) in the Austrian Alps, ranging from 1650 to 2200 m a.s.l. (N47.13°, E11.33°). The mean annual precipitation for this area amounts to 1097 mm at 1900 m a.s.l and the mean annual air temperature is 3.0 °C at 1900 m a.s.l. The investigated grasslands of high management intensity (vegetation dominated by *Leontodon hispidus*, *Agrostis capillaris*, *Plantago lanceolata*) are found on the soil type *Dystric cambisol*.

A plot with a homogenous vegetation composition and an even gradient was selected. Within a temporal period of 4 weeks, irrigations with the 50 m^2 simulator described in Kohl et al. (1997) and the 10 m^2 simulator described here were conducted on the same plot. Here we compare the results to demonstrate the functional capability of the new simulator.

2.1. Construction of the rainfall simulator

In the following the four main component parts of the refined and presented rainfall simulator are described in Sections 2.1.1–2.1.4 (water supply module; water input measurement and control module; sprinkling module; runoff collection/measurement module). In Sections 2.2.1 and 2.2.2, the calibration procedure and measurement setup for the analyses of uniformity of the precipitation are presented, respectively.

2.1.1. Water supply module

The nozzles used in this simulator do not require special water conditions, so a dammed brook or a water pool can be utilized as the water supply. Nevertheless, it is advisable to install a filter to avoid fouling of the nozzles. We recommend a small pool or basin holding slightly more water than needed for the irrigation to buffer the water and guarantee a continuous water supply. As a positive side effect of using a basin, particulate matter can settle out, reducing the danger of blocked nozzles. For the presented rainfall simulator, the input water pressure has to be higher than 2.5 bar (cf. Section 2.2). If the simulation takes place in a landscape with a vertical height difference of at least 25 m between the water basin and the investigated plot, the gravimetric pressure of the water will be ≥2.5 bar and therefore sufficient for the irrigation. If the gravimetric pressure is not high enough, a water pump is necessary. For that case, we tested a Rosenbauer® OTTER fire brigade pump (Lightweight Portable Pump with a weight of 58 kg). The water basin or pump is connected to the input measurement and control module using flexible fire hoses. Because the overall irrigated area was larger than the 10 m^2 of the experimental plot (cf. Section 2.1.3), more water than the nominal 1000 l for an intensity of 100 mm was required. A total quantity of 2000 l of water is needed for an experiment with 100 mm h^{-1}.

2.1.2. Input measurement and control module

To acquire repeatable results, detailed information about the quantity of water used during the whole experiment is important. For the used nozzles, the spraying distance and spraying quantity are directly connected to water pressure. The arrangement of the irrigator with the cited nozzles requires a constant water pressure of 2 bar. The regulation of the water pressure is realized with a regulation valve (Fig. 1 left), providing a constant water pressure for the rainfall simulator. Between the regulation valve and the irrigation module, a water counter (Fig. 1 right) with an electrical output (reed contact) is installed. Using a standard impulse data logger (e.g., Hobo H7 Event Logger/Onset Computer®), it is possible to record the water quantity continuously during the whole experiment. Because some of the water is sprayed outside of the irrigation plot (Fig. 2), the amount of water effectively sprayed onto the experimental plot is calculated with the help of a calibration factor depending on the number and type of nozzles spraying outside of the plot. This factor has to be determined for each simulator separately due to slight variations between individual nozzles. Details of this calibration procedure are provided in Section 2.2.

2.1.3. Sprinkling module

The sprinkling module (Fig. 3) is U-shaped with the open end facing downhill and has an area of 10 m^2 (2 × 5 m). It consists of 1 and 2 m long pipes with a diameter of 63 mm. The tubes are pressure resistant coupled with straight and rectangular bended pipe fittings (Plasson®). Based on information from specification sheets, Rainbird® U-type nozzles were selected to achieve a mostly homogenous distribution of the irrigation water. We used the Rainbird® type U10 with a reduced sprinkling distance from 2.5 to 2 m. The selected nozzles are available with a sprinkling angle of 90°, 180° or 360° leading to a water consumption of 0.18, 0.36 or 0.72 m^3 per nozzle per hour at 2 bar pressure, respectively. The different sprinkling angles enable one to define the irrigated area very precisely, fulfilling the following three criteria: (1) to prevent the lateral outflow of rainfall sprinkling had to be extended to the areas lateral to the investigation plot; (2) the adjacent area uphill from the rain simulator must not be sprinkled; and (3) water should not be applied at a high intensity to the lowest part of the investigated plot to prevent trickling from the vegetation into the recording module. This resulting theoretical sprinkling schema with different nozzles at 1 m distances is shown in Fig. 2.

2.1.4. Runoff collection/measurement module

A horizontal plastic channel was installed in the ground to collect the surface runoff water on the lower side of the simulator. Due to roughness of the soil surface, it was often not possible to collect the runoff directly at the soil surface; for this reason, the water was collected at a depth of 5 cm. If the installation of a channel is not or only barely possible (stones, rock), a stable plastic foil can be used as an alternative to channel the water and consequently minimize the damage to soil and vegetation. The collected water is piped to a calibrated sampling box with a scale, and the outflow is recorded every minute. In this way, it is possible to calculate the runoff coefficient, the ratio of rainfall to surface runoff.