Geotextiles and Geomembranes 29 (2011) 285–297

Contents lists available at ScienceDirect

Geotextiles and Geomembranes

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

Evaluation of the EUROSEM model for predicting the effects of erosion-control blankets on runoff and interrill soil erosion by water

T. Smets [a,*], L. Borselli [b], J. Poesen [a], D. Torri [c]

[a] Physical and Regional Geography Research Group, Catholic University of Leuven, Geo-Institute, Celestijnenlaan 200E, 3001 Heverlee, Belgium
[b] CNR-IRPI, Via Madonna del Piano 10, 50019 Sesto Fiorentino (Firenze), Italy
[c] CNR-IRPI, Research Institute for Geo-Hydrological Protection, Via Madonna Alta 126, 06128 Perugia, Italy

ARTICLE INFO

Article history:
Received 2 July 2010
Received in revised form
13 December 2010
Accepted 15 December 2010
Available online 8 February 2011

Keywords:
Geotextiles
Surface sealing
Hydraulic conductivity
Soil loss
EUROSEM
Simulated rainfall

ABSTRACT

The European Soil Erosion Model (EUROSEM, Morgan et al., 1998) is an event-based soil erosion model which predicts runoff and sediment discharge for different environmental conditions. Applying geotextiles or erosion-control blankets (ECB's) on the soil surface significantly affects surface seal formation and topsoil properties and therefore controls runoff and soil erosion rates during a rainfall event. Since these within-storm changes of soil surface characteristics and hydrological conditions are not incorporated in EUROSEM, errors in runoff and soil erosion predictions may occur for soil surfaces covered with ECB's.

Therefore, the objective of this paper is to evaluate and improve the performance of a research version of the physically-based erosion model EUROSEM (EUROSEM-2010; Borselli and Torri, 2010) for simulating the effects of ECB's on runoff and interrill soil erosion by water during intense simulated rainfall events. Results of model simulations are compared with experimental results of interrill erosion using biological (i.e. natural) ECB's and simulated rainfall. Because ECB's applied on the soil surface retard seal formation, the differences between observed and predicted runoff rates and sediment discharges are rather high during the first 20–30 min of the simulated rainstorm. Therefore, a simple approach is proposed to cope with the dynamic evolution of some soil characteristics, i.e. saturated hydraulic conductivity, soil erodibility and soil cohesion, during an intense rainfall event. This time-dependent approach improves the predictions of runoff rate and sediment discharge during the first 20–30 min of a rainfall event and increases the model efficiency (i.e. a measure for the goodness of fit) from 0.84 to 0.98 and from 0.48 to 0.68 for the total runoff volume and soil loss, respectively. For most conditions, the predicted final sediment discharge is still considerably larger than the observed values, which can be partly attributed to the deposition of sediment in the bare soil patches (i.e. inter-weave open areas) of the ECB's, which is not simulated by EUROSEM in this study. This model approach increases our understanding of the effects of ECB's on within-storm changes in hydrological conditions and soil surface characteristics.

1. Introduction

Several models have been developed for simulating various aspects of soil erosion phenomena, e.g. mean annual soil loss (Renard et al., 1997), sediment yield (Van Rompaey et al., 2001), ephemeral gully erosion (Nachtergaele et al., 2001). Models assist in the understanding of hydrological and erosion processes and provide a predictive tool for land use management. The EUROSEM model (Morgan et al., 1998), which is an event-based soil erosion model, is designed to operate for successive short time steps within a storm and has been validated for several environmental conditions, e.g. The Netherlands (Folly et al., 1999), Costa Rica, Mexico, Nicaragua (Veihe et al., 2001), China (Cai et al., 2005) and Kenya (Mati et al., 2006). These studies indicate that EUROSEM can reasonably well simulate total runoff volume and peak discharge in different environments and for different rainfall characteristics. However, similar to other physically-based models, the runoff and erosion predictions contain uncertainty. This uncertainty arises from a variety of sources and is most likely to be due to error in the conceptualisation and in the parameterisation of the model (Konikow and Bredehoeft, 1992). The EUROSEM evaluation studies point to some of the shortcomings of using EUROSEM for runoff and

* Corresponding author. Tel.: +32 16 326417; fax: +32 16 326400.
E-mail address: toon.smets@ees.kuleuven.be (T. Smets).

0266-1144/$ – see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.geotexmem.2011.01.012

soil erosion predictions. According to Quinton (1997), Folly et al. (1999), Veihe et al. (2001) and Mati et al. (2006) the largest part of the observed difference between the measured and predicted data is due to the model's inability to cope with changing hydrological conditions and soil properties during a rainfall event. Especially on a soil type susceptible to surface sealing, soil surface characteristics and hydrological conditions can change rapidly during a rain storm. Due to the raindrop impact, soil particles are compacted and rearranged in the disturbed upper layer of the soil (Poesen, 1981). Moreover, fine soil particles migrate in the topsoil during infiltration, leading to a sealed surface layer (Assouline, 2004). The development of a surface seal is affected by a large number of soil and rainfall properties, e.g. rainfall intensity, kinetic energy, soil texture and structure, aggregate stability, initial bulk density, initial water content and organic matter content (e.g. Farres, 1978; Luk, 1985; Le Bissonnais and Arrouays, 1997). The formation of a surface seal is often measured and predicted by a change in the bulk density or the saturated hydraulic conductivity of the soil during rainfall (Assouline, 2004). Tackett and Pearson (1965) measured a gradual increase in the bulk density of the upper 25 mm of a soil profile during rainfall, from 1.32 to 1.61 g cm^{-3}. Edwards and Larson (1969) observed and modelled an exponential decrease of the saturated hydraulic conductivity of 5 mm thick soil samples during the exposure to simulated rainfall. Since these within-storm changes of soil surface characteristics and hydrological conditions are not incorporated in EUROSEM, errors in runoff and soil erosion predictions may occur.

Previous research has indicated that geotextiles or erosion-control blankets (ECB's) can be an effective soil conservation technique. For a range of environmental conditions, they can significantly reduce runoff and soil erosion rates (e.g. Ahn et al., 2002; Bhattacharyya et al., 2009; Lekha, 2004; Smets and Poesen, 2009). ECB's have several additional effects on hydrological and erosion processes, e.g. providing soil surface cover, reducing the kinetic energy of raindrops impacting the soil surface, reducing overland flow velocity, obstructing surface seal formation (Bhattacharyya et al., 2010; Gimenez-Morena et al., 2010; Rawal and Saraswat, in press.). A laboratory study indicates that soil surfaces covered with ECB's significantly affect the formation of a surface seal during a high intensity rainfall simulation (Smets and Poesen, 2009). Therefore, infiltration rates are higher and runoff and erosion rates are lower compared to a bare soil surface. However, so far the impacts of ECB's on hydrological and erosion processes are not incorporated in process-based soil erosion models.

Recently a new research version of EUROSEM (EUROSEM-2010; Borselli and Torri, 2010) has been applied to study the effect of root density in controlling soil loss (De Baets et al., 2008). This research version which incorporated some modifications discussed so far was recoded and built in an OBJECT PASCAL code (Free Pascal, fPC compiler www.freepascal.org) which makes it easier to adjust the program code. Hence the EUROSEM-2010 is used in this study, which aims to (i) investigate to what extent EUROSEM-2010 is capable of simulating runoff and soil erosion rates from bare interrill surfaces and soil surfaces covered with ECB's during intense rainfall events and; (ii) to propose and evaluate possible modifications for the hydrological and erosion equations in the EUROSEM-2010 model in order to account for the within-storm changes in hydrological conditions and soil surface characteristics.

2. Materials and methods

2.1. Experimental dataset

The predictions by the EUROSEM-2010model are all based on input data which originate from small-scale or even point-scale measurements. Therefore, the data used in this study to evaluate the EUROSEM-2010 model were collected using interrill laboratory experiments. In this series of experiments, rainfall was simulated during 60 min with an intensity of 45 and 67 mm h^{-1} on an interrill erosion plot (0.94 by 0.60 m) having two slope gradients (i.e. 15 and 45%) (Smets et al., 2007; Smets and Poesen, 2009). Two soil types, i.e. sandy loam and silt loam (sampled in central Belgium), were tested (Table 1). Experiments were conducted with five biological ECB's (Fig. 1): Borassus (*Borassus aethiopum*, Davies et al., 2006); Buriti (*Mauritia flexuosa*, Guerra et al., 2005); Bamboo (*Arundinaria gigantea*, Panomtaranichagul et al., 2006); Rice straw (*Zea mays*, Xing Xiangxin, 2008) and Maize stalk (*Oryza sativa*). These biological ECB's were recently produced as part of the BORASSUS-Project and will be commercially produced in the near future. Characteristics of the tested biological ECB's are given in Table 2. In total, 78 rainfall experiments were conducted (for an outline, see Table 3). During each experiment, runoff rate (mm h^{-1}) and interrill soil loss (kg m^{-2}) were measured. For each treatment, two to three replicates were performed. For a detailed description of the soil pre-treatment and the measurement procedures we refer to Smets and Poesen, 2009.

2.2. The EUROSEM-2010 model

The European Soil Erosion Model (EUROSEM) is a dynamic distributed model, capable of simulating erosion, sediment transport and deposition over the land surface by rill and interrill processes in single storms for both individual fields and small catchments (Morgan et al., 1998). Compared with other soil erosion models, EUROSEM has explicit simulation of interrill and rill flow, plant cover effects on interception of rainfall and rock fragment effects on infiltration. The computation of runoff and soil loss is based on the dynamic mass balance equation (Morgan et al., 1998):

Surface runoff (Q, $m^3\ s^{-1}$) continuity equation:

$$\frac{\partial A_w}{\partial t} + \frac{\partial Q}{\partial x} = w[r_i(t) - f(t)] \tag{1}$$

where A_w is the cross-sectional area of the flow (m^2), t is time (s), x is horizontal distance (m), w is flow width (m), $r_i(t)$ is rainfall rate less the interception (m s^{-1}) and $f(t)$ is the local infiltration rate (m s^{-1}).

Sediment continuity equation:

$$\frac{\partial (A_w q_s)}{\partial t} + \frac{\partial (Q q_s)}{\partial x} - e(x,t) = q_s(x,t) \tag{2}$$

where q_s is the sediment concentration ($m^3\ m^{-3}$) and e is net detachment rate or rate of erosion of the bed per unit length of flow ($m^3\ s^{-1}\ m^{-1}$). Since on the short bare interrill laboratory plots (i.e. < 1 m) no deposition of sediment occurs, only soil detachment is assumed in this study. In EUROSEM the term e is subdivided into two components, i.e. soil detachment rate by raindrop impact and soil detachment rate by the flow.

Table 1
Soil types tested in the interrill laboratory experiments.

Soil textural class (USDA)	Sandy loam	Silt loam
Clay (%) (<0.002 mm)	13	12
Silt (%) (0.002–0.05 mm)	24	80
Sand (%) (0.05–2 mm)	63	8
SOM (%)	0.2	1.9
Coordinates of origin	50°50'20"N 04°44'21"E	50°52'12"N 04°39'01"E
Depth at origin (m)	1.0–1.5	0.0–0.5