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Are ditch networks optimised for mitigating rill erosion in cultivated Mediterranean landscapes? A numerical experiment

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ABSTRACT

Rill erosion frequently occurs in Mediterranean cultivated landscapes due to high rainfall intensities, low soil organic matter concentrations and low vegetation coverage. Among other rill erosion mitigation practices, farmers have historically built ditch networks to intercept runoff upstream of cultivated plots. However, the construction and maintenance of these ditches generate indirect costs for farmers and land managers. Therefore, a compromise must be found between these costs and the efficiency of the ditch network for mitigating erosion. Thus, tools and methods are required for determining an optimised cost-efficient compromise or for diagnosing existing ditch networks.

This paper proposes an experimental approach to test *in silico* how well an actual soil conservation practice (i.e., a ditch network) reaches a cost-efficiency compromise at the catchment scale. The costs are approximated from the density of the ditches, and the rill erosion mitigation efficiency is summarised using an aggregated modified stream power index. The actual ditch network is compared to a set of virtual ditch networks that are generated by a stochastic network simulator that optimises the network geometries with regard to preventing rill erosion. This approach was applied in four small vineyard sub-catchments located in the Peyne catchment in Languedoc, southern France. Actual ditch networks are compared to virtual networks, which present a large range of ditch network densities.

The ditch network highly mitigates rill erosion because the Stream Power Index (SPI) values exponentially decrease with the ditch network density and because the actual SPI maps are homogeneous. In addition, the results from the four different sub-catchments indicated that the rill erosion risk was mitigated by using minimal drainage network lengths, which suggested that the actual ditch networks that resulted from historical farmers were optimised.

The proposed approach can be used to determine if the efficiency of ditch networks for mitigating erosion can be improved.

1. Introduction

The erosion of cultivated soils poses a significant threat to communities and agricultural areas, especially in Mediterranean areas where high rainfall intensities, depleted topsoil organic matter contents and low vegetation coverage due to land use (e.g., vineyards and orchards) increase the erosion risks. Among the range of dis-services induced by erosion, the occurrence of rill erosion in cultivated fields is recognised by farmers because it indicates soil loss and could be costly to avoid and repair.

This clear perception of the effects of rill erosion may explain why Mediterranean farmers have historically adopted soil conservation practices to mitigate rill erosion, including building terraces that reduce slope and runoff velocity (Ramos and Porta, 1997; Roose and Sabir, 2002; Blondel, 2006; Bevan and Conolly, 2011; Stanchi et al., 2012; Tarolli et al., 2014), building ditches that intercept runoff (Ramos and Porta, 1997; Roose and Sabir, 2002; Tarolli et al., 2015) and benching terraces to stop runoff on hill-slopes (Wheaton, 2001; Nasri, 2007). However, these practices represent non-negligible settlement costs and generate indirect costs for farmers by reducing field sizes, decreasing field accessibility and inducing additional maintenance work (Martnez-Casasnovas and Ramos, 2006; Petanidou et al., 2008).

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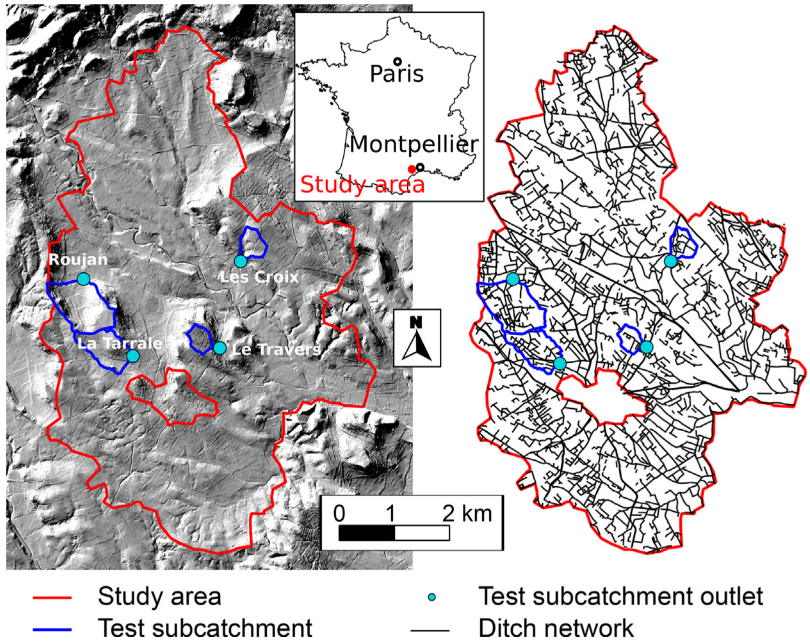

Fig. 1. Study area. Left: hillside view of the study area. Right: ditch network map. The location of the four sub-catchments and corresponding outlets used for the network simulation.

As pressures from the market continue to increase, the search for a good compromise between these costs and the efficiency of measures for protecting soils from erosion is accelerating (Douglas et al., 1996). Tarolli et al. (2015) proposed a morphometric index derived from LiDAR as a support for scheduling a correct ditch network to reduce erosion. In their work they proposed only a few simple examples of different ditch systems. To extent this approach, numerical experiment can be proposed to explore the effects of a wide range of ditch network geometries on soil erosion. In this case, numerical experiment consists in coupling a soil conservation features simulator and an erosion model. It has been successfully used by Gumiere et al. (2015) to optimise the location of vegetative filters regarding their efficiency in reducing erosion.

This paper proposes a numerical experiment-based approach that tests actual soil conservation practices for their closeness to a cost-efficiency compromise. This approach is applied to the ditch networks of the Languedoc vineyard catchments (Levavasseur et al., 2014). In this experiment, the costs are approximated based on the densities of the ditches, and the rill erosion risks are summarised by a modified stream power index (Moore et al., 1991). In four small sub-catchments located in the Peyne catchment (Languedoc – southern France), the actual ditch networks are compared to a set of virtual networks that are produced by a network simulation algorithm that browses a large range of densities and optimises the network geometries with regard to rill erosion protection. Finally, the approach is completed by quantifying the role of the ditch network in reducing erosion over the entire Peyne catchment.

2. Study area

2.1. Main characteristics

The study area is located in the downstream portion of the Peyne catchment in southern France (Fig. 1, left), which covers an area of 40 km^2 and is mainly covered by vineyards (60%) with shrubs, cereal fields and fallow fields occupying the remaining areas. The average field area is approximately 0.5 ha. The altitude varies between 28 m and 128 m, and three main geomorphological units can be distinguished, plateaus in the southern and north-western areas, hill-slopes with slopes greater than 10% in the centre of the area and an alluvial plain. The climate is Mediterranean with an annual precipitation of 600 mm to 800 mm and two short, intense rainy seasons in the autumn and spring. Given the characteristics of the catchment, soil erosion can be high, with an average erosion rate of 10.5 t/ha/y and a high spatial variability (Paroissien et al., 2010). Four headwater sub-catchments were selected within the study area (Fig. 1, right) for hosting the numerical experiments. These catchments have various areas, slopes, land cover and ditch network densities (Table 1).

2.2. Ditch networks

The ditch network of the study area was exhaustively mapped during previous studies (Bailly and Levavasseur, 2012; Levavasseur et al., 2012, 2014). The width and depth of the ditches varied from approximately 50 cm to several meters. The mean density of the ditch networks was 96 m/ha. The minimum and maximum values of the ditch network density, calculated using 250 m × 250 m pixels, were 0 m/ha and 231 m/ha, respectively. This ditch network mainly consisted of agricultural and roadside ditches, but also included sunken paths and channelised rivers that were considered as 'ditches' for simplification. In the Languedoc vineyard plain, the ditch networks are often associated with terraces and were built over a century ago to remove excess water from fields and eliminate the highly visible threat of rill erosion. This assumption was recently confirmed by surveying farmers in the study area (Levavasseur, 2012), which indicated that 50% of the ditches were perceived as erosion-limiting landscape features and 80% of the ditches were declared as being yearly maintained for preventing the overflow that generates rill erosion. This driver is clearly illustrated in Fig. 2 for a particular event.

2.3. Spatial data

Three types of spatial data were involved in the proposed approach. (i) A stereo-photogrammetric 5 m resolution Digital