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Accounting for temporal variation in soil hydrological properties when simulating surface runoff on tilled plots

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Abstract

Tillage operations are known to greatly influence local overland flow, infiltration and depressional storage by altering soil hydraulic properties and soil surface roughness. The calibration of runoff models for tilled fields is not identical to that of untilled fields, as it has to take into consideration the temporal variability of parameters due to the transient nature of surface crusts. In this paper, we seek the application of a rainfall-runoff model and the development of a calibration methodology to take into account the impact of tillage on overland flow simulation at the scale of a tilled plot (3240 m^2) located in southern France. The selected model couples the (Morel-Seytoux, H.J., 1978. Derivation of equations for variable rainfall infiltration. Water Resources Research. 14(4), 561-568). Infiltration equation to a transfer function based on the diffusive wave equation. The parameters to be calibrated are the hydraulic conductivity at natural saturation K_s, the surface detention S_d and the lag time ω. A two-step calibration procedure is presented. First, eleven rainfall-runoff events are calibrated individually and the variability of the calibrated parameters are analysed. The individually calibrated K_s values decrease monotonously according to the total amount of rainfall since tillage. No clear relationship is observed between the two parameters S_d and ω, and the date of tillage. However, the lag time ω increases inversely with the peakflow of the events. Fairly good agreement is observed between the simulated and measured hydrographs of the calibration set. Simple mathematical laws describing the evolution of K_s and ω are selected, while S_d is considered constant. The second step involves the collective calibration of the law of evolution of each parameter on the whole calibration set. This procedure is calibrated on 11 events and validated on ten runoff inducing and four non-runoff inducing rainfall events. The suggested calibration methodology seems robust and can be transposed to other gauged sites.

Keywords: Runoff model; Flood event; Infiltration; Plot scale; Calibration; Tillage; Stormflow generation; Farmed catchments

1. Introduction

Farming operations greatly influence local surface runoff, infiltration and surface storage by altering soil hydraulic properties and soil surface roughness (e.g. Larson, 1964; Mwendera and Feyen, 1993, 1994;

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Andrieux et al., 1996; Earl, 1997; Ahuja et al., 1998; Léonard and Andrieux, 1998; Sillon, 1999; Van Dijck, 2000). In this respect, tillage is certainly the operation that provokes the greatest changes in topsoil structure. These occur at the time of tillage, but also afterwards due to the soil reconsolidation process. When modelling runoff on farmed catchments, the impact of tillage operations on the topsoil hydraulic properties should therefore be considered. This paper will seek means to achieve that goal.

The direct impact of tillage practices on the water storage and transmission properties of soils are dependent on the natural soil structure (Xu and Mermoud, 2001), on the type of tool used and on the initial soil moisture condition (Ahuja et al., 1998). According to Papy and Boiffin (1988); Léonard and Andrieux (1998), a tillage operation on a crusted soil may increase infiltration capacity by one order of magnitude. However, in some instances, tillage can also reduce infiltration since it may disrupt the continuity of pores between the top and subsoils (e.g. Logsdon et al., 1990; Reynolds et al., 1995; Coutadeur et al., 2002). Tillage is also known to increase surface roughness or the surface depressional capacity, which in turn controls surface runoff (Auerswald, 1992; Mwendera and Feyen, 1993; Hansen et al., 1999; Guzha, 2004). For example, measurements done on Mediterranean vineyards and orchards show that the mean ratio of before to after rain random roughness can vary between 0.52 and 0.76 for freshly tilled fields (Van Dijck, 2000). Tillage also influences runoff direction (Ludwig et al., 1995; Souchère et al., 1998; Ndiaye et al., 2005) and has an important impact on erosion process (Ludwig et al., 1995; Poesen and Hooke, 1997) especially under Mediterranean climatic conditions characterised by very high rainfall intensities (Wainwright, 1996).

After tillage, the newly created soil porosity and surface roughness gradually evolve due to natural reconsolidation by raindrop impact and redistribution of soil particles by splash and flow (e.g. Dexter, 1977; Cassel, 1983; Onstad, 1984; Mapa et al., 1986; Zobeck and Onstad, 1987; Bridge and Silburn, 1995). These mechanisms often contribute to the formation of surface seals, which reduce infiltration by decreasing the saturated hydraulic conductivity of the soil (Römkens et al., 1990; Assouline and Mualem, 1997).

Many studies have looked into the impact of tillage on soil structure and soil hydrodynamic characteristics (Mukhtar et al., 1985; Mwendera and Feyen, 1993; Ahuja et al., 1998; Roger-Estrade et al., 2000; Takken et al., 2001), but to our knowledge only Yu et al. (2000) have tried to take into account this impact when simulating flood hydrographs over large periods. However, their study was done mostly to compare tillage practices and not to suggest modelling or calibration guidelines.

This paper presents a calibration strategy to take into account the temporal variability of parameters for rainfall runoff modelling on tilled fields. The model used herein considers the plot as a homogeneous unit and uses physically-based equations. Hydrographs are simulated at the plot outlet by coupling a production function based on the Morel-Seytoux (1978) infiltration model to a transfer function based on the diffusive wave equation (Moussa and Bocquillon, 1996). The main three calibrated parameters are the hydraulic conductivity at natural saturation K_s of the soil surface, the surface detention and the lag time. These parameters are variable in time according to the date of tillage and the soil surface features. The model calibration strategy is two fold. The first step involves the individual calibration of flood events and the derivation of a response time variation function for each of the three parameters. The second step involves the multi-event calibration of these functions and the validation of the model on observed flood events.

2. The study zone

2.1. General characteristics

The study plot is located on the Roujan experimental catchment (40° 30′ N, 3° 19′ E) in southern France and is operated by the French National Institute for Agricultural Research (INRA) (Voltz et al., 1994). The climate is of Mediterranean type characterised by high intensity and short duration storms causing hortonian overland flow (Andrieux et al., 1993). The plot (cadastral no. aw54) has an area A of 3240 m^2 with a mean length of 105 m and a mean width of 31 m, and its slope varies between 2 and 10% with a mean value of 8%. It is isolated from all external water input. Hydrogeological investigations