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Analysis of the dynamics of soil infiltrability of agricultural soils from continuous rainfall-runoff measurements on small plots

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Abstract

In this study, data from continuous measurement of natural rainfall and runoff rates on nine 2 m^2 runoff plots were used to analyse the dynamics of infiltration and how it relates to the evolution of the soil surface state. All measurements were performed on two cropped sites in northern France on low slope loess soils, with low rainfall intensities. Crops represented were maize, wheat and sugar beet. Infiltrability was characterized at the scale of the plot and of the rainfall event by a single parameter, the constant infiltrability that yields an excess rainfall hyetograph with a volume equal to the measured runoff volume (ϕ index). Results indicated that: (1) even if the runoff plots were installed on two catchments where water erosion was important, the observed runoff volumes and intensities were very small. The runoff to rainfall ratio was typically less than 5% at the season to year scale; (2) the apparent infiltrability ϕ cannot be defined independently from rainfall intensity when runoff at the outlet of a plot comes from only a subset of the plot area. The relationship between rainfall intensity and apparent infiltrability can be used to estimate the relative runoff contributing area ($\approx$0.10–0.35 in ourcase); (3) the development and nature of surface crusting has a major influence on the apparent infiltrability: there is a progressive shift of ϕ toward low values when crusting develops, which is predominantly due to an increase in the relative contributing area. From a methodological point of view, failure to include the rainfall intensity dependence of infiltrability in runoff modelling could introduce large errors on runoff predictions. This relationship between rainfall intensity and apparent infiltrability should thus be analysed when possible, and soil surface state characterization should include more information about connection between the different parts of a plot and its outlet.

Keywords: Runoff; Infiltrability; Connectivity; Soil surface state; Rainfall intensity

1. Introduction

In many cultivated areas of the loessian belt in Northern Europe, erosion by water causes both intense soil degradation and severe crop and off-site damage. One main cause of intense water erosion is the large volumes of runoff generated on agricultural fields (Auzet et al., 1993, 1995). Because of the progressive concentration of runoff due to topography or to linear features associated to agricultural practices, a large volume of runoff can lead to very high local flow rates and to the creation of rills and

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gullies (Ludwig et al., 1995; Takken et al., 2001). Across Northern Europe rainfall intensities rarely exceed 10 mm/h (Cerdan et al., 2002). Large runoff volumes are thus generally associated to the presence of large soil areas with a low infiltrability (Auzet et al., 1993, 1995; Ludwig et al., 1995). It is well known that the degradation of the structure of the topsoil under rainfall, which leads to soil sealing and crusting, can cause an important decrease of the soil infiltrability of agricultural soils, particularly under conventional tillage (McIntyre, 1958; Morin and Benyamini, 1977; Boiffin, 1984; Casenave and Valentin, 1989). Research efforts have thus been carried out to evaluate the infiltrability of agricultural soils in different situations, in particular for different soil surface states (Le Bissonnais et al., 1998; Cerdan et al., 2001), either in the laboratory or in the field and at various scales. However, it is still difficult to estimate soil infiltrability and its variations in order to run soil erosion models, which are always very sensitive to parameters related to infiltration.

Most of the difficulties arise from methodology: there are many ways to estimate the infiltration properties of soils, which can yield significantly different results. Infiltration tests have been extensively used (Youngs, 1991). In most cases, a constant pressure is imposed at the soil surface. The pressure may be positive, or negative, which limits water flow to pores smaller than a pre-determined diameter. Depending on the size of the water source, on the presence and depth of insertion of borders, the flow may be completely three-dimensional to quasi-one dimensional (Youngs, 1991). Additional variations arise from the way infiltration data are analysed. The analysis can rely on the assumption that a steady state has been reached (Wooding, 1968), or can take advantage of the full transient flow data (Smettem et al., 1994; Haverkamp et al., 1994; Angulo-Jaramillo et al., 2000). The nature and the number of infiltration parameters may also vary, depending on the infiltration theory on which the analysis of the infiltration test is based. During the last 20 years, a growing attention has been paid to soils subject to sealing and crusting. Most agricultural soils actually belong to this category. When a crust develops at the soil surface, the soil becomes vertically non uniform, and additional difficulties are encountered with most infiltration tests. If borders are inserted into the soil to force one-dimensionality of the flow, the crust is usually broken, which strongly affects infiltration rates. On the other hand, if the flow is not constrained by borders, its three-dimensional nature makes difficult to derive one-dimensional flow rates from the data, because three-dimensional flow theories have been developed for homogeneous soils (Vandervaere et al., 1997).

Because of such limitations, the estimation of soil infiltrability under rainfall and over larger areas (typically 1 m^2 or more) has gained more and more interest. Simulated rainfall allows for a complete control of experimental conditions, and the wetted area is often of the order of a few square meters, which ensure a quasi one-dimensional flow. In addition, the destruction of the crust at the plot border has only a limited impact because of the low ponding depth and the limited quantity of runoff drained toward the edges of the plot. Simulated rainfall has thus been often used to evaluate the infiltration properties of agricultural soils, their variability, and how they relate to soil properties and soil tillage practices for example (Casenave and Valentin, 1992; Léonard and Andrieux, 1998). However, limitations arise when dealing with the dynamics of soil infiltrability, because it becomes rapidly time consuming to multiply the number of measurements. Measurements have often been made only immediately after tillage, or at 3–4 dates during the crop cycle (Cerda, 1996; Dimanche and Hoogmoed, 2002; Rhoton et al., 2002), or on well defined soil structural states (Boiffin, 1984). In this paper, the continuous measurement of natural rainfall and runoff rates on several small cultivated plots along the crop cycle is used to analyse the dynamics of infiltration and how it relates to the evolution of the soil surface state. That should help to improve the estimation of infiltration and runoff for use in soil erosion models through a better knowledge of their temporal and spatial variations.

2. Material and methods

2.1. Experimental sites

All experiments were performed on two sites in northern France (Fig. 1) on low slope, cultivated, loess soils. Rainfall intensity is generally less