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Spatio-temporal distribution of soil surface moisture in a heterogeneously farmed Mediterranean catchment

O. Hébrard [1], M. Voltz *, P. Andrieux, R. Moussa

INRA, Laboratoire d'étude des Intéractions Sol-Agrosystème-Hydrosystème UMR AgroM-INRA-IRD, 2 place Pierre Viala, 34060 Montpellier Cedex 1, France

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Summary Observation and interpretation of spatial soil surface moisture patterns are fundamental to spatially distributed modelling of runoff generation, soil evaporation, and plant transpiration. Compared to natural basins, man-made managements in farmed basins, such as field limits, agricultural practices and the networks of ditches, lead to great spatial heterogeneity in hydrological processes at the catchment scale. The aim of this study was to identify the factors controlling the spatio-temporal variability of the surface soil moisture in the farmed Mediterranean catchment of Roujan (0.91 km^2) located in southern France. Intensive measurements of soil moisture patterns were recorded during two drying sequences, respectively, in dry and wet seasons. Results show that the soil surface characteristics (SSC), which result in part from the agricultural practices such as soil tillage, chemical weed control or grass covering, are the main factors controlling the spatio-temporal distribution of the soil surface moisture during both the wet and dry drying sequences. However, in this study, none of the local factors such as the soil insolation (sunlight reaching soil surface through the plant canopy if there is one), the slope, the aspect and the soil texture is correlated to the soil moisture spatial variability. Only local factors control the spatio-temporal variability of soil surface moisture because agricultural operations like tillage influence greatly the local surface runoff by altering soil hydrologic properties. Also, the ditch networks influence the water transfer from the fields to the catchment outlet by routing runoff directly to the catchment outlet without modifying the soil surface moistures of downslope fields. Consequently, in farmed catchments the agricul-

* Corresponding author. Tel.: +33 0 4 99 61 23 40; fax: +33 0 4 67 63 26 14.
E-mail address: voltz@ensam.inra.fr (M. Voltz).
[1] Present address: Montpellier II University, Laboratoire Hydrosciences, Maison des Sciences de l'Eau, 300 avenue du Professeur Emile Jeanbrau, 34095 Montpellier Cedex 5, France.

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tural managements and practices strongly modify the spatio-temporal soil moisture distribution and must be taken into account in the understanding and in the modelling of hydrological processes.

Introduction

Soil moisture stored near the land surface exerts a major control on surface hydrological processes, especially runoff generation, soil evaporation and plant transpiration. The role of soil moisture spatial patterns in runoff producing processes was extensively studied during the past 40 years (Betson, 1964; Hewlett and Hibbert, 1967; Dunne and Black, 1970a,b). Runoff generation has been often correlated to initial soil moisture (e.g. Ceballos and Schnabel, 1998; Meyles et al., 2003), and, sensitivity analysis of distributed hydrological models have shown that simulated runoff is very sensitive to the estimated values of initial soil moisture (e.g. Merz and Plate, 1997; Bronstert and Bardossy, 1999; Castillo et al., 2003). There is therefore a need to understand the spatial patterns of soil moisture and their temporal evolution at the catchment scale and to find means to predict them according to catchment characteristics.

In accordance with this, over the last two decades, the spatial and temporal variability of moisture content of topsoil at the hillslope and catchment scales has received an increasing attention from the hydrological community (e.g. Hawley et al., 1983; Famiglietti et al., 1998; Western et al., 1999; Gomez-Plaza et al., 2001; Canton et al., 2004). Famiglietti et al. (1998) reviewed the main factors influencing soil moisture patterns. These include variations in topography, soil properties, mean moisture content. The dominant factors vary according to the soil wetness state (e.g. Grayson et al., 1997; Gomez-Plaza et al., 2001). Grayson et al. (1997) defined in temperate regions two preferred states of soil moisture distribution, controlled by different factors. These states switch from one to the other according to catchment wetness (Grayson et al., 1997; Fitzjohn et al., 1998). They are as follows.

Grayson et al. (1997) denote the first state as nonlocal control. It occurs when precipitation continually exceeds evapotranspiration. The patterns of soil surface moistures are generally controlled by the catchment topography, with downslope areas generally wetter than those up upslope (e.g. Henninger et al., 1976; Hawley et al., 1983; Moore et al., 1998; Nyberg, 1996; Meyles et al., 2003). The characteristic factor of nonlocal control is the upslope contributing area (e.g. Hawley et al., 1983; Moore et al., 1998; Nyberg, 1996; Crave and Gascuel-Odoux, 1997; Famiglietti et al., 1998).

The other state, denoted by Grayson et al. (1997) as local control, occurs on the contrary, when evapotranspiration continually exceeds precipitation. Then, the local soil moisture is mainly controlled by the local fluxes of evapotranspiration, infiltration, percolation and runoff. In this situation, the patterns of surface soil moisture are often irregular and highly heterogeneous and depend on the spatial variation of factors influencing the local fluxes. Field studies showed that the latter factors are: slope angle (Moore et al., 1998; Gomez-Plaza et al., 2001; Qiu et al., 2001) that influences local drainage possibilities, and thereby infiltration and runoff; slope orientation or aspect (Reid, 1973; Moore et al., 1998; Famiglietti et al., 1998) that modify soil insolation, and consequently soil evaporation; soil surface cover, soil texture and structure, organic matter content that modify soil hydraulic properties (e.g. Reynolds, 1970; Henninger et al., 1976; Canton et al., 2004); vegetation type and development that control evapotranspiration (Hawley et al., 1983; Mohanty et al., 2000; Qiu et al., 2001).

In case of farmed catchments, the factors controlling the spatial variation of soil moisture may change in space and time according to land management and land use. Terraces, hedges, networks of ditches and roads can largely influence within-catchment water pathways (e.g. Gallart et al., 1994; Bierkens et al., 1999; Moussa et al., 2002; Carluer and De Marsily, 2004), and thereby modify hydrological continuity at the catchment scale. Moreover, land use and related farming practices induce spatial and temporal variations in topsoil structure, soil crusting and soil cover, which are generally called soil surface characteristics (Le Bissonnais et al., 2005). This can lead in turn to changes with time in several of the factors that were mentioned above to control soil moisture patterns. The question then arises whether the variation of land use can explain soil moisture distribution. So far, only a few papers addressed this question. The results were variable. Hawley et al. (1983) showed from observations on a set of small catchments that the variations in land cover had less influence on soil moisture distribution than topography. Later, Qiu et al. (2001) observed soil moisture evolution over a 3.5 km^2 catchment with heterogeneous land use. They showed that land use exerts a significant influence on soil moisture variations. More recently, the study of Williams et al. (2003) which compared soil moisture variations at two dates between and within six sites with different land uses, did not suggest that land use had a dominant role, although there were some marked differences in soil moisture between several studied land uses. These varying results about the role of land use may be explained in part by the fact that, in these studies, the classification of land uses was almost expressed by land cover differences, and did not consider other important sources of variation in land use like cultivation practices and soil treatments.

In this paper, we study the spatial patterns of soil moisture and their evolution during two drying sequences in a Mediterranean farmed catchment in south-France with heterogeneous land use. One main objective is to analyse the