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Variations in soil-water use by grapevine according to plant water status and soil physical-chemical characteristics—A 3D spatio-temporal analysis

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ABSTRACT

Understanding plant and soil-water relationships is crucial to optimise agricultural management. In this multidisciplinary work, soil geophysics and plant physiological measurements are coupled and a statistical method is proposed to visualising plant soil-water uptake in space and time. The method is applied in a vineyard context and shows differences in the use of tranpirable soil water by grapevine according to the type of soil and the time of the day (day/night).

During two years the water stress experienced by a single Chardonnay/SO4 grapevine clone was monitored both at pre-dawn and midday by leaf water potentials in two field plots exclusively differenced by soil properties. At the same time, variations of electrical resistivity were monitored through electrical resistivity tomography, and then transformed in fraction of tranpirable soil water by the use of pedotransfer functions appositely developed in these soils. Spatio-temporal variations of transpirable soil water was used to predict plant leaf water potentials and the contribution of each soil region to grapevine water status was evaluated by statistical-learning methods. Strong spatio-temporal variability was observed both vertically and laterally between the two plots and within each plot at a fine scale. Principal causes of such differences were the level of plant water stress, along the season and during the day, and differences in soil physical-chemical properties. Soil contribution to plant water status varies in space and time at a fine scale. This paper introduces a novel methodological approach, transposable in any field survey, and brings further insight in the description of plant and soil relationships.

1. Introduction

Soil-water movement is influenced by plants, which not only uptake but can also distribute water vertically (Prieto et al., 2012) and laterally (Smart et al., 2005). The reverse is also true: the spatial distribution of water greatly influences the plant water status by modifying the ABA signalling from the roots (Davies and Zhang, 1991). To account for the importance of root spatial distribution in the soil, the concept of Fraction of Transpirable Soil Water (FTSW), was introduced by Ritchie (1981) to empirically estimate the soil water availability and the root uptake by measuring plant water stress contemporary to soil water. This approach has been found useful to better understand and model plant water use according to soil water status, for both herbaceous (Liu et al., 2005) and woody species (Pellegrino et al., 2005; Sinclair et al., 2005; Marguerit et al., 2012). The estimation of FTSW needs the measurement of the soil water, generally obtained with in-soil devices such as Time Domain Reflectometry (TDR) which can be difficult to carry out in field conditions. Furthermore, these devices only measure a very small volume of the soil, and even when increasing the number of probes, no information is generally obtained about the lateral variation of FTSW, and only a vertical soil moisture profile can be established. In addition, the number of such devices cannot be increased indefinitely without major perturbations of the system and attaining prohibitive costs. The estimation of FTSW with such devices greatly depends on the position of access tubes or probes and can therefore be misleading. Recent works have shown that spatial variation of the FTSW could be measured by means of geophysical imaging

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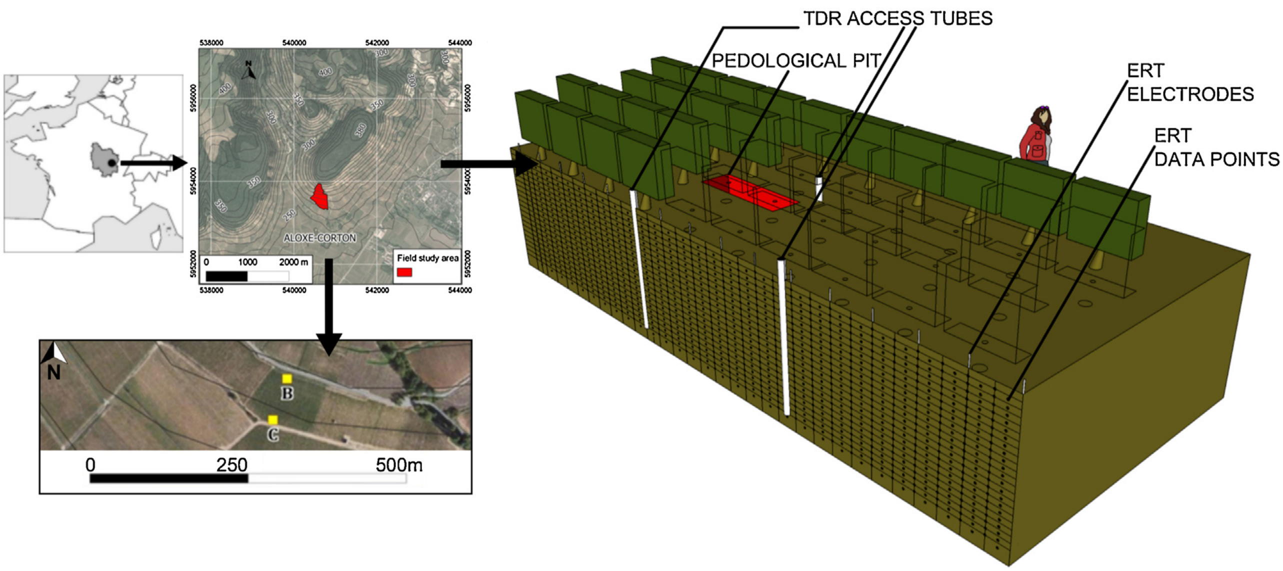

Fig. 1. Localization of the study site at the hillslope of Corton Hill, Burgundy, France.
Letters B-C indicate the experimental plot location. The 3D scheme illustrates the equipment of each experimental plot in the vineyard with devices for soil water measurement and geophysical field-data acquisition. The calibration pit were soil properties were acquired is also shown. This image was modified from Brillante et al., 2014a courtesy of Elsevier.

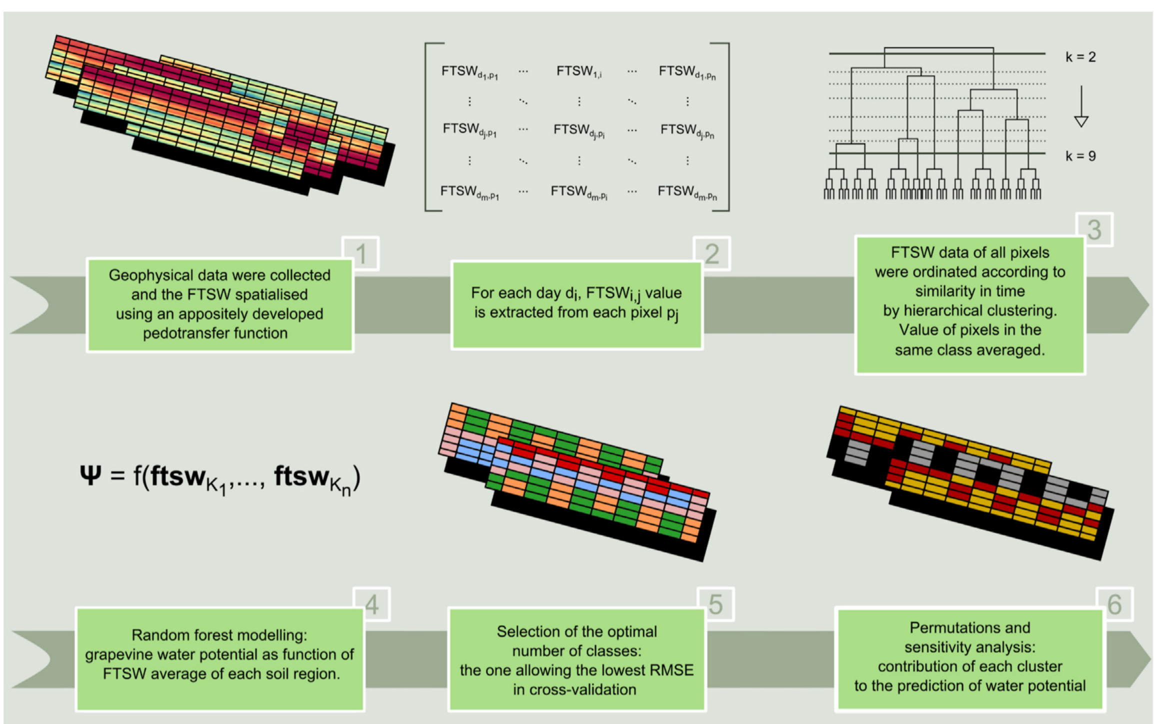

Fig. 2. Flow chart of the analysis described in Section 2.4.

techniques (Brillante et al., 2015, 2016). Geophysical techniques have been used for a long time in Earth sciences. Some techniques, such as TDR and neutron probes, have already found useful applications in plant sciences. The use of geophysical imaging techniques has entered these domains more recently and is now being tested in many research fields such as ecology (Jayawickreme et al., 2014), plant science (Attia Al Hagrey, 2007) and agronomy (Samouelian et al., 2005). Among the many geophysical imaging techniques, electrical resistivity tomography (ERT), is being widely used to better understand plant-soil relationships because of its capacity to produce high quality images of water distribution in the soil (Michot et al., 2003; Besson et al., 2010; Beff et al., 2013). An interesting approach was, however, brought by (Srayeddin and Doussan, 2009) who spatialised the hydraulic conductivity and then the root water uptake in maize and sorghum using ERT.

This article focuses on 3D spatio-temporal variations (2 space dimensions and time) of FTSW in an undisturbed agroecosystem to evaluate the contribution of each soil region to plant water status. Two plots located in a commercial vineyard were monitored during two vintages by weekly measurements of grapevine leaf water potentials, at both pre-dawn, and solar noon, while at the same