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Soil water monitoring in a vineyard and assessment of unsaturated hydraulic parameters as thresholds for irrigation management

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ABSTRACT

Monitoring soil water status is a well-known method to efficiently control irrigation in order to optimally meet plant water requirements and at the same time avoid unproductive water losses through deep percolation. A common approach is to keep soil water status within a certain range that is defined via soil-specific unsaturated hydraulic parameters. In this study, water content and matric potential were monitored in a soil profile in a vineyard. The soil hydraulic properties required for irrigation control were determined by water retention analyses using a pressure plate apparatus, and estimated by means of pedotransfer functions. While the soil matric potential sensors delivered calibrated absolute values, their range was limited and soil water dynamics were not always reflected properly. The soil water content probe, on the other hand, properly illustrated soil water dynamics, but the readings were possibly inaccurate as no onsite calibration was executed. Furthermore, the determined unsaturated hydraulic parameters differed considerably depending on the applied method. Alternatively, a modified approach was applied. It was based on measurements of a sensor pair in a representative depth and should combine the advantages of both sensors types. The respective thresholds for irrigation management were determined based on sensor data using in-situ soil water retention functions. The main advantages were that neither field calibration of soil water content sensors nor laborious soil analyses were required. Furthermore, data interpretation was more plausible compared to the standard approach. Due to the reduced sensor setup and the omitted soil sampling and analyses, the modified approach represented a practical and economical alternative as basis for irrigation control.

1. Introduction

Crops require sufficient water and nutrient supply for optimal production, or else farmers have to face an increasing risk of economic losses due to minor yield and quality. The latter is particularly important when growing grapes for high quality wine production (Jones, 2004; Van Leeuwen et al., 2009). If rainfall does not satisfy plant water requirements, irrigation becomes obligatory to prevent severe water deficit stress. At a time of rising drought and water shortage, efficient irrigation is becoming more and more important for sustainable water use (Fraga et al., 2012). It is generally agreed that subsurface drip irrigation is the most efficient irrigation principle, providing that irrigation control is based on plant water requirements along with minimal water applications. Strategies to optimally operate an irrigation system are manifold, including observations of plant water status that is directly related to plant functions and vintage quality (Van Leeuwen et al., 2009). However, plant-based sensing has several practical difficulties of implementation that have so far limited the development and commercial availability of monitoring systems (Jones, 2004). Alternatively, monitoring soil water status – which is related to plant water status (Centeno et al., 2010; Intrigliolo and Castel, 2004; Thompson et al., 2007a) – is a common approach to schedule irrigation and improve water use efficiency (Pudney and McCarthy, 2004; Thompson et al., 2007a,b).

Irrigation should be controlled in such a way that soil water status is kept within a certain range that is optimal for plant development. In this regard, soil water status can be described either by soil water content (SWC) or by soil matric potential (SMP) or by both. Plant available water (PAW) is that fraction of soil water that is available for plant uptake in a certain soil profile. The latter

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corresponds more or less with the (main) rooting depth. SWC can theoretically range from saturation (where all pores are filled with water) to dryness (where all pores are filled with air). SMP represents the energy that is needed to withdraw water from the soil matrix. It is zero at saturation and getting more negative when soil becomes dryer. In natural conditions SWC ranges from field capacity (FC), where usually a SMP between −6 and −33 kPa (expressed as negative soil water pressure) is supposed to occur, to permanent wilting point (PWP). The latter represents a status where plant roots are not able to extract water from the soil anymore, which is commonly assumed to occur at a SMP less then −1.5 MPa. Upper and lower thresholds for irrigation scheduling are usually defined based on the PAW, calculated as SWC at FC minus the SWC at PWP (Allen et al., 1998). A management allowed depletion of typically 50% of PAW (depending on the crop) delimits the range where no stress is supposed to occur (Allen et al., 1998; Doorenbos et al., 1979). Below this certain crop-specific trigger irrigation is required. Generally, thresholds depend on the type of the soil and its pore size distribution. The relation between SWC and SMP describes one part of the hydraulic properties of a certain soil type, illustrated as typical soil water retention function (RTF).

Consequently, there are two ways to control irrigation based on soil water monitoring. Measuring SMP is the straighter option, as it is directly related to water stress and the irrigation thresholds are independent from soil characteristics (Centeno et al., 2010; Thompson et al., 2007a). Watermark® granular matrix sensors (Irrometer Co., USA) are widely available and have some favorable characteristics, e.g., low costs, easy installation, and little maintenance, thus they are commonly used for irrigation scheduling (Centeno et al., 2010; Intrigliolo and Castel, 2004; Thompson et al., 2006, 2007a). However, they have technical limitations that narrow their measuring range or their accuracy in rapidly drying soils (Centeno et al., 2010; Thompson et al., 2006). This may become a disadvantage especially in horticulture and viticulture, where irrigation strategies that allow SMP values of −140 kPa and lower (e.g., deficit irrigation, regulated deficit irrigation or partial rootzone drying) may be applied in order to improve fruit quality and increase water use efficiency (Centeno et al., 2010; Fraga et al., 2012; Goodwin, 2002; Leib et al., 2006). Furthermore, granular matrix sensors are very sensitive to soil salinity and they often need to be recalibrated (Muñoz-Carpena et al., 2005). The second option is to monitor SWC. EnviroSCAN® multi-sensor capacitance probes (Sentek Pty., Ltd., Australia) have proved to deliver reliable readings that allow sufficient interpretation of SWC as basis for irrigation management (Cepuder and Nolz 2007; Fares and Alva, 2000; Thompson et al., 2007a,b), and even for deficit irrigation strategies (Girona et al., 2002; Leib et al., 2006; Pudney and McCarthy, 2004). On the other hand, the PAW-approach requires quantitative measurement of SWC, for which an accurate soil-specific calibration of SWC sensors is necessary (Kargas and Soulis, 2012). For multi-sensor probes like the EnviroSCAN and similar downhole probes this is however impractical for on-farm applications as it is a laborious, time-consuming and destructive process (Leib et al., 2003; Thompson et al., 2007a). Other inconveniences can arise from stones or highly compacted soil layers that complicate the installation and uninstallation of access tubes. Hence, focusing measurements on the uppermost few decimeters of a soil would facilitate both installation and calibration from a practical point of view. Furthermore, using only as few sensors as necessary is also advantageous from an economical point of view. In this regard, a key question is whether measuring water status in a certain depth of a soil profile is accurate and representative (Dabach et al., 2015; Soulis et al., 2015).

Implemented into wireless networks, soil water sensors deliver frequently data, and thus provide a sound basis to efficiently control irrigation. However, setting irrigation thresholds in a proper way is generally not as simple since the determination of soil hydraulic properties is laborious and implicates some shortcomings. For example, values determined in laboratory do not necessarily reflect field conditions, and considering rooting depth changes is difficult (Girona et al., 2002; Sadras and Milroy, 1996). Few authors addressed such problems in particular and tried to solve them. Thompson et al. (2007a), for instance, described a method of how to interpret SWC data with regard to irrigation requirement. However, the presented method seems rather complex and requires some additional data, e.g., reference evapotranspiration, as well as expert knowledge of soil water data interpretation.

The overall objective of this study was to assess a practical approach using a pair of sensors to monitor soil water status in a certain depth and determine irrigation management thresholds in-situ, thus without laborious soil analyses. Subtasks were (1) to monitor soil water content and matric potential and interpret the data regarding irrigation scheduling, (2) to assess thresholds for irrigation management based on soil properties, (3) to interpret soil water status considering the standard PAW-approach (Allen et al., 1998; Doorenbos et al., 1979), (4) to determine a measurement depth that is representative for plant water uptake in the soil profile, (5) to define in-situ irrigation management thresholds based on sensor readings and interpret the data regarding irrigation scheduling from a practical point of view.

2. Materials and methods

2.1. Site description

The research site was located in the eastern part of Austria near the border to Hungary (position: 47°48′16″N, 17°01′57″E; elevation: 118 m). Advantageous environmental conditions allow the production of agricultural goods with a high quality, mainly vegetables and grapes for wine production. The region is characterized by a mean annual temperature of 10.6 °C and an annual precipitation of about 570 mm (period 1996–2011). Weather data were obtained from a weather station of the Central Institute for Meteorology and Geodynamics, Austria (ZAMG) in 3 km distance, and also directly on the study plot (Nolz and Cepuder, 2011).

The study plot was an area of about 20 × 20 m within a vineyard, containing six rows of *Vitis vinifera* L. cv. Chardonnay crafted on a *Kober 5BB* rootstock; row spacing was 2.8 m. Early in 2010 the vines were planted and subsurface drip lines with 16 mm diameter and 1 m distant pressure compensating drippers (outflow: $2.2\,\mathrm{l\,h^{-1}}$) were installed on both sides of each row at about 50 cm distance and about 30 cm depth (exact positioning of the drip lines was difficult due to surface roughness and employment of heavy machinery for the installation).

Soil type was Chernozem, texture sandy loam, and humus content in topsoil 2%. The study period was March to September 2011.

2.2. Soil water content monitoring

A plastic access tube for the EnviroSCAN® (ES) probe was installed vertically between the plant row and a drip line at a distance of 20 cm to the former and 30 cm to the latter, near an emitter. The positioning of the access tube in this distance from the row was necessary as the tensioning wires restricted handling directly in the vine row. A probe consisting of seven sensors on a mounting rail was inserted into the tube to measure soil water content down the soil profile at 10, 20, 30, 40, 50, 60, and 70 cm. The sensor in 30 cm depth was nearest to the dripper. ES capacitance sensors operate based on the Frequency Domain Resonance-principle (FDR), where a high-frequency electric field is induced in a certain volume of soil by means of a capacitor. The frequency of oscillation