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Energy and evapotranspiration partitioning in a desert vineyard

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ABSTRACT

The challenge of partitioning energy and evapotranspiration (*ET*) components was addressed over a season (bud break till harvest) in a wine grape vineyard located in an extreme arid region. A below canopy energy balance approach was applied to continuously estimate evaporation from the soil (*E*) while system *ET* was measured using eddy covariance. Below canopy energy balance was assessed at the dry midrow position as well as the wet irrigated position directly underneath the vine row, with *E* calculated as the residual of measured net radiation, soil heat flux, and computed sensible heat flux. The variables used to compute sensible heat flux included soil surface temperature measured using infrared thermometers and below-canopy wind speed in a soil resistance formulation that required a modified wind factor. The *E* derived from below canopy energy balance was reasonable at daily intervals although it underestimated micro-lysimeter *E* measurements, suggesting there may have been advected energy from the midrow to the below-vine position. Seasonal partitioning indicated that total *E* amounted to 9–11% of *ET*. In addition, empirical functions from the literature relating crop coefficients (K_{cb}) to plant size, appeared to give reasonable results under full canopy, albeit with some day to day variation, but underestimated K_{cb} during the growing period.

1. Introduction

Partitioning of energy and water fluxes in vegetated systems can give valuable information on the productive use of water through plant transpiration (*T*) and losses due to evaporation from the soil (*E*), which is generally considered an unproductive form of water use. This is relevant for food production, ecosystem functioning, and climate; particularly in the light of increasing water scarcity and drought as a result of anthropogenic activity and projected climate change. In arid areas, *E* is potentially substantial due to high evapotranspiration (*ET*) dominating the water balance and the prevalence of sparse vegetation (Wilcox et al., 2003). As *E* and *T* differ in their response to environmental conditions, separate assessment is necessary to adequately determine ecosystem energy and water exchange under different weather and climate conditions (Kool et al., 2014a; Lawrence et al., 2007; Zhang et al., 2011).

For many agricultural row crops, determining *E* and *T* is critical for assessing water use efficiency. This is particularly true for grapevines which are one of the world's most economically important horticultural crops (Williams and Ayars, 2005) and are increasingly grown in arid regions (Li et al., 2009; Sene, 1994). Wine grape vineyards are generally characterized by relatively small canopy cover fractions designed to optimize grape cluster micro-climate and radiation availability (Pieri, 2010a). While vineyards are traditionally rain-fed, irrigated viticulture is becoming increasingly common (Ortega-Farías et al., 2010). Water supply strongly affects grape yield quantity and wine quality (Trambouze et al., 1998), where mild stress can improve quality but severe stress can result in reduced quality (Van Leeuwen et al., 2009) and, in severe cases, plant death. Optimal grape production therefore requires precise water management, which is expected to benefit from understanding of energy and water partitioning within the vineyard.

Knowledge of vineyard water status is required to understand mechanisms of vegetative versus reproductive growth (Shapland et al., 2012; Van Leeuwen et al., 2009), short and long-term effects of deficit irrigation (Zhang et al., 2011), and how drought stress

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affects specific stages in vine phenology and grape ripening (Van Leeuwen et al., 2009). Crop coefficients (K_c) which relate vineyard water requirements to atmospheric demand have been developed to determine optimal irrigation strategies, plant water status and severity of drought stress. Since vineyard K_c varies widely depending on vine training practices, plant cover, and grape variety and rootstock, K_c is often determined separately for plant (K_{cb}) and soil surface (K_e) components (Allen et al., 1998). In addition, efforts have been made to relate K_{cb} to plant canopy parameters such as leaf area index (LAI) or ground fraction cover (Ferreira et al., 2012; Netzer et al., 2009; Picón-Toro et al., 2012; Poblete-Echeverría and Ortega-Farias, 2009; Williams and Ayars, 2005). In order to obtain accurate water requirement parameters including K_c and K_{cb}, assessment of seasonal *ET* and its partitioning are of importance. Continuous assessment of *T* has been reasonably successful using sapflow or chamber measurements, though major challenges remain (Wullschleger et al., 1998). In contrast, continuous measurements of *E* are basically non-existent (Kerridge et al., 2013; Kool et al., 2014a).

The partitioning of vineyard energy balance components between the soil and the canopy is not easily predicted, although it is known that the soil contribution to system fluxes is considerable (Ortega-Farías et al., 2010; Sene, 1994; Spano et al., 2000). For example, there is evidence that soil sensible heat contributes to canopy *T*, (Heilman et al., 1994; Hicks, 1973) and may also contribute available radiation to berry clusters (Pieri, 2010a, 2010b). Available energy is also affected by surface shading which is not uniform across the inter-row (Horton, 1989; Horton et al., 1984; Pieri, 2010a). An additional unknown is how energy partitioning is regulated in drip-irrigated systems, where wet soil near the dripper and bare strips between vine rows have to be considered separately (Kool et al., 2014b; Poblete-Echeverría and Ortega-Farias, 2009). In addition, important micro-climate variables, such as below canopy wind speed in widely spaced vineyards with relatively sparse vegetation, are not yet well understood (Poblete-Echeverría and Ortega-Farias, 2009).

Modeling of sparse-canopy crops often relies on energy balance to describe system water use. Such modeling requires a good understanding of the complex interaction between vine, soil and atmospheric conditions (Colaizzi et al., 2012; Ding et al., 2015; Ortega-Farías et al., 2010; Poblete-Echeverría and Ortega-Farias, 2009). While studies regarding water requirements tend to focus on seasonal data (Ferreira et al., 2012; Yunusa et al., 2004; Zhang et al., 2011), detailed studies regarding canopy energy balance and interactions between soil and vine components have generally been conducted for only brief periods under well-watered conditions and full canopy cover (Heilman et al., 1994; Li et al., 2009; Pieri, 2010a; Sene, 1994). The assessment of energy partitioning at a seasonal scale, taking into account variability across the soil surface as well as between the surface and the canopy, is a novel aspect of the current approach. The objectives of this research were: to study the effects of canopy growth, irrigation, and changes in atmospheric conditions on energy partitioning; to assess productive and unproductive allocation of water through *ET* partitioning and; to determine the utility of the below canopy energy balance approach toward obtaining continuous estimation of *E*.

2. Methods

2.1. Site description

A field experiment was conducted in a ~10 ha drip-irrigated commercial vineyard in the arid central Negev highlands, Israel (30.7°N, 34.8°E, altitude 550 m) from bud break until harvest during the growing season of 2012. Vineyard row orientation was approximately north-south, with 3 m distance between rows. The vines were planted 1.5 m apart and were trained on a vertical-shoot-positioned system, with 1 m cordon height and vines attaining a maximum height of ~1.8 m. The 10-year-old Cabernet Sauvignon (*Vitis vinifera* L., on 140 Ruggeri rootstock) vineyard formed an isolated irrigated area in a dry bare surrounding on level terrain. Long-term average daily temperature minima and maxima for the region range from 4.4 to 14.8 °C in January and 18.1 to 32.7 °C in July. During the early growing season, temperatures range between 10.5 and 25.1 (April), 13.5 and 28.7 (May) and 16 and 31.2 (June). Precipitation at the site is erratic and mostly occurs between November and April, averaging <100 mm y^{-1} (Israel Meteorological Service). In the winter prior to the 2012 growing season a total of 48.3 mm rainfall was recorded with the last rain event in the spring consisting of 2.5 mm on 16 March. The growing season started with bud break on 1 April 2012 and continued through July without a single rain event.

2.2. Measurement set-up

A detailed description of the experimental set-up as well as the site meteorological conditions is reported in Kool et al. (2014b). In brief, standard meteorological measurements included solar radiation, air temperature and humidity, precipitation, and wind speed and direction. Other measurements included irrigation amounts and hourly measurements of *E* using micro-lysimeters (MLs) during three 24-h intensive observation periods (IOPs). In brief, the MLs were 100 mm deep, had a diameter of 110 mm and were made of PVC. The MLs were pushed into the soil, excavated, capped to prevent losses other than evaporation, weighed and placed in a preformed hole with the same position relative to the vine-row as the original sample location. The installed MLs were removed and weighed hourly (± 0.1 g ≈ 0.011 mm) from pre-dawn to after sunset. The LAI was measured using an LAI-2000 (Li-Cor Bioscience Inc., Lincoln, NE[1]) following recommendations for row crops. Plant canopy height and width were measured during each site visit, about once a week. Surface temperatures were measured using four infrared radiometers (IRTS-P, field-of-view 28° half angle, Apogee Instruments Inc., Logan, UT). The composite (system) temperature was assessed by two IRTs deployed at the top of a 7 m tall arch, positioned directly above the vine row and midrow, respectively. The other two IRTs were positioned with their field-of-view directly below the vine at 0.3 m height, and above the midrow at 2.5 m height. Air temperature was measured at 3.3 m above the soil surface (HMP45C, Vaisala Inc., Woburn, MA and 10-Plate Gill Radiation Shield, R.M. Young, Traverse City, MI) and directly below the vine at 0.06 m height, where air was drawn to a shielded Beta-Therm thermistor through a 4.3 mm-i.d. rigid metal/plastic composite tube (Synflex Type 1300, Eaton Synflex, Mantua, OH) using a 12 VDC pump (NMP 830, KNF Neuberger Inc., Trenton, NJ) and rotameter (PMR1-01065S, Cole Parmer, Vernon Hills, IL) to control the flow rate (<1 L $\min^{-1}$). Data were logged at 10 s intervals, and 15 min averages were stored using CR23X and CR5000 dataloggers (Campbell Scientific Inc., Logan, UT). Hourly reference *ET* (ET_0) was calculated using solar radiation, wind speed, air temperature, and humidity at 2 m height data from a nearby weather station, following the FAO Penman–Monteith model (Allen et al., 1998; Kool et al., 2014b).

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