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Use of soil and vegetation spectroradiometry to investigate crop water use efficiency of a drip irrigated tomato

S. Marino[a,*], M. Aria[b], B. Basso[d], A.P. Leone[c], A. Alvino[a]

[a] Department of Agricultural, Environmental and Food Sciences (DAEFS), University of Molise, Via De Sanctis, I-86100 Campobasso, Italy
[b] Department of Economics and Statistics, University of Study of Napoli Federico II, via Cintia 26, 80126 Napoli, Italy
[c] Department of Geological Sciences, Michigan State University, 206 Natural Science Building, East Lansing, MI 48824-1115, United States
[d] CNR — Institute for Mediterranean Agriculture and Forest Systems (ISAFoM), via Patacca 85, 80056 Ercolano, Italy

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ABSTRACT

An agronomic research was conducted in Tuscany (Central Italy) to evaluate the effects of an advanced irrigation system on the water use efficiency (WUE) of a tomato crop and to investigate the ability of soil and vegetation spectroradiometry to detect and map WUE. Irrigation was applied following an innovative approach based on CropSense system. Soil water content was monitored at four soil depths (10, 20, 30 and 50 cm) by a probe. Rainfall during the crop cycle reached 162 mm and irrigation water applied with a drip system amounted to 207 mm, distributed with 16 irrigation events. Tomato yield varied from 7.10 to 14.4 $\mathrm{kg\,m^{-2}}$, with a WUE ranging from 19.1 to 38.9 $\mathrm{kg\,m^{-3}}$. The irrigation system allowed a high yield levels and a low depth of water applied, as compared to seasonal ET crop estimated with Hargraves' formula and with the literature data on irrigated tomato. Measurements were carried out on geo-referenced points to gather information on crop (crop yield, eighteen Vegetation indices, leaf area index) and on soil (spectroradiometric and traditional analysis). Eight VIs, out of nineteen ones analyzed, showed a significant relationship with georeferenced yield data; PVI maps seemed able to return the best response, before harvesting, to improve the knowledge of the area of cultivation and irrigation system. CropSense irrigation system reduced seasonal irrigation volumes. Some vegetation indexes were significantly correlated to tomato yield and well identify, a posteriori, crop area with low WUE; spectroradiometry can be a valuable tool to improve irrigated tomato field management.

1. Introduction

Agricultural water use plays the most critical role in water resources management all around the world (Köksal, 2008). The value of water will go up in the century for the severe competition for water from human beings, intensive agriculture, flora and fauna, etc. (Bouwer, 2000). Irrigated agriculture is a major consumer of water and accounts for about two thirds of the total fresh water assigned to human uses (Fereres and Evans, 2006). As a general rule, agriculture show often a low irrigation water use efficiency, for this reason irrigation scientists are forced to develop water saving irrigation strategies (Payero et al., 2009). Sustainable irrigation water management should simultaneously achieve two objectives: sustaining irrigated agriculture for food security and preserving the associated natural environment. A stable relationship should be maintained between these two objectives now and in the future, while potential conflicts between these objectives should be mitigated through appropriate irrigation practices. The sustainable use of water in agriculture has become a priority and the adoption of irrigation strategies which may allow saving irrigation water and maintaining satisfactory yields, thus improving water use efficiency (WUE), may contribute to the preservation of this even more restricted resource (Parry et al., 2005; Topcu et al., 2007).

Efficient use of water in any irrigation system is becoming important particularly in arid and semiarid region where water is a scarce commodity; in this area maximizing water productivity may be more profitable to the farmer than maximizing crop yield (Pereira et al., 2002). The economic and environmental benefits of improving the volumetric efficiency of irrigation are obvious in both the value of the water saved and the additional production possible with this water. Hence, there is a triple bonus for improving irrigation precision including: (a) maximizing yield and quality of production, (b) reducing water losses below the root zone, and (c) conserving the resource base, by minimizing the risk of groundwater salinity and thus enhancing sustainability. These

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* Corresponding author. Tel.: +39 0874404709; fax: +39 0874404713.
E-mail addresses: stefanomarino@unimol.it, stefanomarino@gmail.com (S. Marino).

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gains can only be achieved when all elements of precision operate synergistically within a given environment (Painter and Carren, 1978).

For improving WUE, Batchelor (1999) suggested several ways at the farm level, improving crop husbandry and cropping strategies (agronomic), installing an advanced irrigation system (technical), adopting demand-based irrigation scheduling systems and better maintaining equipment (managerial), introducing water pricing and improving the legal environment (institutional).

Water Use Efficiency can be optimized by the adoption of more efficient irrigation practices (Costa et al., 2007), in this regard, drip irrigation has contributed to improve WUE by significantly reducing runoff and crop evapotranspiration losses (Stanghellini et al., 2003; Jones, 2004; Kirnak and Demirtas, 2006). Drip irrigation in fact is one of the best techniques to use in applying water to vegetables and orchards (Çetin and Uygan, 2008). Proper irrigation timing and amount increases the water use efficiency; consequently the production per unit of water will be increased (Ismail et al., 2008). Improper irrigation timing can lead to the development of crop water deficit resulting in reduced yield due to water and nutrient deficiencies (Wright, 2002).

However, irrespective of the strategy employed, the benefits of scheduling will only be realized if the irrigation system can be controlled sufficiently well to apply only the exact amount required. Hence, control is a necessary component of any irrigation system aiming to apply water in precise amounts (Hoffman and Martin, 1993): "the accurate and precise application of water to meet the specific requirements of individual plants or management units and minimize adverse environmental impact" is defined Precision Irrigation (Raine et al., 2007).

Usually irrigation treatments are carried out following the evapotranspiration criterion according to the simplified soil water balance (Doorenbons and Pruitt, 1977), with a complete restoration of the calculated ETc (Hanson and May, 2004; Favati et al., 2009). Monitoring the water use and plant status in the field is important to develop effective precautions and for this purpose some indicators are required (Köksal et al., 2008). A very large body of research, spanning almost four decades, has demonstrated that much of the required agricultural information can be derived from remotely sensed data (Pinter et al., 2003). The ability to accurately assess water stress symptoms in vegetation using spectral reflectance measurements is an important goal for research (Jackson, 1986). Vegetation and water stress indices calculated based on visible-near infrared (vis-NIR) spectral reflectance and infrared surface temperature measurements from either the long (remote sensing) or short distance (proximal sensing) can provide spatial and temporal information to improve WUE. There are numerous studies addressing the use of spectral reflectance to obtain the leaf/canopy water status and water stress (Leone et al., 2007; Ceccato et al., 2001; Peñuelas et al., 1993, 1997).

Besides the new technologies to improve WUE, JDW has proposed CropSense® Soil Moisture Monitoring, a new near-real-time instrument to measure in-depth soil moisture levels from factors encompassing growth stage to environmental conditions. The instrument delivers data for a precision control of soil moisture, gives customizable reports, which accurately measure soil moisture levels in the field. By understanding the movement of water over time for the crop, provides information to determine the right amount of water to apply to properly fill the root zone and optimize the applied nutrients and to make decisions on irrigation programs and fertigation. The goal of JDW sensor is to increase crop water use efficiency (WUE) by reducing the amount of water applied by watering and by reducing the number of irrigation events (Kirda, 2002).

During the next years, simulation model development and application should (Consoli et al., 2006; D'Urso et al., 2010) focus on agricultural water savings, increase crop water productivity, monitoring of crop conditions (Bastiansen et al., 2007). The use of remote and proximal sensing has proved to be very important in monitoring the growth of agricultural crops and in irrigation scheduling. Spectral VIs, resulting from the combination of two or more spectral bands, are commonly used to enhance the vegetation signal, while minimizing solar irradiance and soil background effects (Jackson and Huete, 1991). They are indirectly related to plant stress, biomass, leaf area index, yield, N content, leaf chlorophyll concentration (Leone et al., 2007, 2001a; Peñuelas et al., 1997; Baret and Guyot, 1991; Basso et al., 2011; Marino and Alvino, 2014).

Tomato, an important crop in Mediterranean countries, is a high water demanding crop, thus requiring irrigation throughout the growing season in arid and semiarid areas (Patanè et al., 2011). Several comparisons between VIs reliability are presented in recent literature. However, to our knowledge, no indications are available for tomato WUE (Gianquinto et al., 2011). Furthermore water stress had a significant reduction yield (Pulupol et al., 1996; May and Gonzalerz, 1999) then the frequency and amount of irrigation play a crucial role on growth and yield of tomato (Obreza et al., 1996). The present paper reports the spatial variability of a tomato crop, drip irrigated by an automated system which maintained the soil water content within specific intervals. The aims were (i) to test the automated irrigation system as a tool to reduce seasonal irrigation water applied related to the Hargreaves method; (ii) assess the spatial variability, at field scale, of a tomato crop; (iii) to identify the Vegetation Indices significantly related to WUE.

2. Materials and methods

2.1. Experimental set-up

The studies were carried out in 2009 at Abbadia of Montepulciano (Central Italy), in a farm called Agrichiana Farming (Latitude N 43.15216, Longitude E 11.88747). The tomato cultivar Perfectpeel was transplanted on the 22nd of May in a twin row spacing of 150 cm, with a final plant density of 33,500 plants ha^{-1} (50 cm between rows and 20 cm plants on the row).

Fertilization was performed using fertilizers and doses commonly used for the cultivation of tomato in central Italy and weeds were controlled with recommended chemical herbicides.

The crop was drip irrigated by T-Tape® 708-30-250, a John Deere Water drip tape with spacing between drippers of 30 cm and a flow rate of 0.75 l/h at 0.55 bar. A CropSense® Soil Moisture Monitoring (by John Deere Water) was installed on 26th of June; CropSense® is a near-real-time soil moisture monitoring system, characterized by multilevel capacitance sensors that monitors water content changes at the soil depths of 10, 20, 30 and 50 cm. The system allow to optimize irrigation management at each crop stage, especially provides information so that it is possible to determine the right amount of water to apply to properly fill the root zone. A Graph is generated by collecting data from four depths; limits can be set on this graph (full point, full point warning, re-fill point warning, and re-fill point); these zones on the graph to help determine when and how often to irrigate, in order to ameliorate irrigations taking into account rainfall. The seasonal irrigation volume was 2070 m^3 ha^{-1} applied with 16 irrigation as reported in Fig. 1.

2.2. Meteorological and agronomic measurements

Daily maximum and minimum temperatures and rainfall were recorded through a standard agro-meteorological station by ARSIAT, the Extension Service of the Tuscany Region, and a few kilometers away from the farm. Crop yields and total seasonal irrigation water applied under the described irrigation technique