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Climate change adaptation and water saving by innovative irrigation management applied on open field globe artichoke

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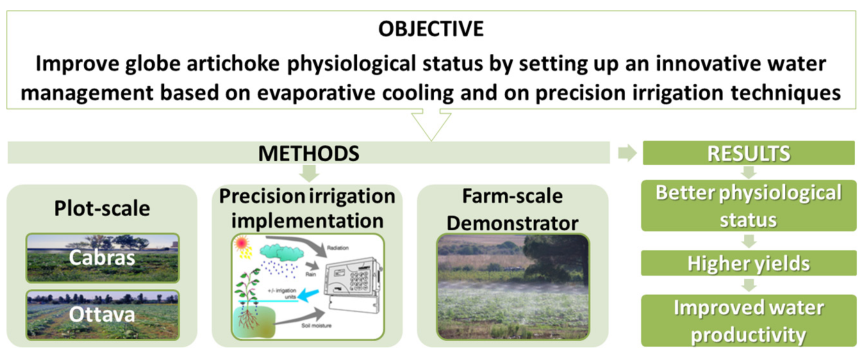
HIGHLIGHTS

- Heat waves are increasingly frequent and longer lasting in Mediterranean region.
- Farmers face the need to mitigate these issues and at the same time to save water.
- Innovative water management mitigates heat stress during the hottest daytime hours.
- Canopy-cooling in globe artichoke improved crop physiological status and earliness.
- Canopy-cooling increased marketable heads by 60%, saving 34% of the water applied.

GRAPHICAL ABSTRACT



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ABSTRACT

The setting up of innovative irrigation water management might contribute to the mitigation of negative issues related to climate change. Our hypothesis was that globe artichoke irrigated with a traditionally drip system could be converted to an innovative water management system based on precision irrigation techniques and on evaporative cooling application in order to improve crop physiological status with positive impacts on earliness, total heads yield and water saving. Over two experiments carried out at plot- and field-scale, two irrigation management systems, differing in type and application time, were compared: (i) conventional, and (ii) canopy-cooling. Plant physiological status at a weekly sampling interval and the head atrophy incidence (as the ratio of the total primary heads collected) were monitored. We also recorded and determined heads production, and yield components. In both experiments, throughout the application period of evaporative cooling (three months), canopy-cooling showed the lowest value of leaf temperature and the highest photosynthesis values compared with the conventional one (+3 °C and −30%, respectively). The physiological advantage gained by the crop with evaporative cooling has led to a higher production both in terms of total yield (+30%), and in terms of harvested first order heads that from an economic viewpoint are the most profitable for farmers. At farm-scale, the canopy-cooling treatment resulted in a higher earliness (35 days) and water productivity (+36%) compared with conventional one. Our findings show that by combining evaporative cooling practice with precision irrigation technique the heads yield can be optimized also leading to a relevant water saving (−34%). Moreover, the study proved that canopy-cooling set up might be a winning strategy in order to mitigate climatic changes and heat stress conditions.

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1. Introduction

Climate change and extreme weather events, such as prolonged droughts combined with increasingly frequent heat waves, raised the interest about the need to put in place new mitigation strategies (Dono et al., 2013a, 2013b; IPCC, 2014). Extreme high-temperature events strongly impact on growth and development of crops (Fahad et al., 2017). The significance of the impact of high temperatures and heat waves on crops varies from species to species and in any case is closely connected to the combination of both high temperature and increased water vapor demand (Hatfield and Prueger, 2011). Indeed, the extreme high temperature determines an increase in the water vapor demand that lead to a higher leaf transpiration rate, and to stomatal closure; this results in a raise of leaf temperature and a decline of net photosynthesis rate (Hatfield and Prueger, 2015). Specifically, extreme high temperature may affect the functionality of the CO_2 photosynthetic enzyme causing a decline in carboxylation, an increase in oxygenase activity and also in photorespiration at the expense of photosynthesis (Ara et al., 2013). Frequency and lasting of heat stress have to be properly accounted for when the objective is to study plant response to this type of abiotic stresses (Driedonks et al., 2016). Indeed, the study of this kind of stresses at open-field condition is an important challenge, since, as underlined by other studies (e.g. Koscielny et al., 2018), the options to modify microclimate at the canopy level are scarce. However, it is widely recognized that, high value agricultural sectors, such as horticultural one, are highly dynamic and more willing to invest in new technologies and in precision agriculture (Balafoutis et al., 2017; Schrijver et al., 2016; Shoji, 2017). At this regard, both precision irrigation techniques and water canopy-cooling are well-known practices that might represent, once combined, a winning solution in order to tackle the above-mentioned issues (Houston et al., 2018; Iglesias and Garrote, 2015). Precision irrigation has been the subject of a great advance in research in the last decade both in open-field and in greenhouse conditions, and it is likely the most recognized and applicable practice/technology aimed to foster water saving through increasing of water use and irrigation efficiency (Montesano et al., 2015; Pascual-Seva et al., 2016; West and Kovacs, 2017). Furthermore, water canopy-cooling is to date an agronomic practice mostly confined to particular situations as orchards or little fruit fields (Evans, 2004), vineyards (Caravia et al., 2017) and controlled environments (Leyva et al., 2015; Max et al., 2009). Water canopy-cooling takes place because the water evaporative process requires energy (Taiz et al., 2015). Many open-field horticultural crops cultivated in temperate environments are intensively grown during the spring-summer months, from the end of March onwards, and some of them are susceptible to heat stress (Camejo et al., 2005; Cavaiuolo et al., 2017; El-Bassiony et al., 2012). However, to address the need to improve the microclimate also in vegetable crops grown under open-field condition and susceptible to heat stress, the development of an innovative irrigation system should also be able to control the climate (Liu and Kang, 2006) at the canopy level, allowing the crop to benefit of a better physiological status with positive impact on crop production. In some Mediterranean areas, as Southern Italy, globe artichoke, is one of the most important horticultural crop (Martin et al., 2016; Nouraei et al., 2018; Shinohara et al., 2017) being largely appreciated all over the world for the nutritional, organoleptic and functional characteristics of its fresh and fleshy heads (Di Venere et al., 2005a; Di Venere et al., 2009; Mileo et al., 2015; Spanu et al., 2018). The globe artichoke growth cycle can be poliannual or annual according to the varietal-type, the suitability of the growing area, the adopted agronomic technique, and the market requirements (Calabrese, 2009). Indeed, the early flowering artichoke is grown with the forced technique (De Menna et al., 2016; Ledda et al., 2013), namely by forcing the vegetative organs (offshoots) to start growing at a time when (the summer one) they should be dormant according to their natural growing cycle (Pisanu et al., 2009). The primary purpose of adopting the forcing technique is to meet the market requirement for early productions, also ensuring to farmers higher incomes (Sgroi et al., 2015). The climate change perspective, where extreme weather events, such as hot waves, last several days, puts farmers in front of new and serious challenges to face in order to guarantee food security (Bita and Gerats, 2013). In the case of globe artichoke, the challenge is double due to its susceptibility to heat stress, especially during the early stages of growth and during the hottest hours of the day, and to low efficiency in irrigation water use during the summer months. Studies carried out on globe artichoke crop, until today, were aimed to study new methods to cope with the head atrophy incidence by combining various aspects of crop management (Koçer and Eser, 2005; Ledda et al., 2003; Mauro et al., 2008) rather than deeply investigate water management in order to improve the general physiological status of the crop. However, due to the interaction of multiple factors, there is no single conclusion regarding the effect of evaporative cooling on crop physiological status, yield and water productivity, especially under current climate change scenarios. Hence, investigation at different scale and in more focused way of innovative water management strategies, also on the basis of new technologies, would allow the acquisition of adequate results in terms of yield and water productivity. Thus, the aim of the present paper was to develop a new water management system suitable to be extended to a great number of crops, able to ensure mitigation against heat stress, and able to increase the productivity, and the water saving. We hypothesized that the physiological status of the artichoke crop would benefit from an adjustment of the canopy microclimate, resulting in increased harvesting earliness and heads yield and in the decline of the onset of physiopathologies caused by high temperature values.

2. Material and methods

Two experiments were carried out, the first, during which the system was developed and set up, was conducted at the plot-scale, the second experiment was implemented within the framework of a H2020 project (http://maslowaten.eu/) and enabled us to replicate, improve and validate the water management at a real scale in a private horticultural farm as project Italian demonstrator.

2.1. Plot-scale experiment

The plot-scale experiment was conducted during 2010–2011 and 2011–2012 growing seasons at two different locations in Southern Italy (Sardinia). A trial was set up at the experimental station of the University of Sassari in Ottava (40° N, 8° E, 81 m asl) and the other one was carried out at a private farm located in the globe artichoke productive district of Cabras (39° N, 8° E, 3 m asl). The site of Ottava is characterized by medium deep soils (Eutric and Leptic Cambisols; WRB, 2014) with a clay-loam texture, a high limestone content (>40%), and a water retention capacity of 30%. The site of Cabras is characterized by soils of ancient floods origin (classified as Haplic Luvisols and Gleyic Luvisols; WRB, 2014), deep over 100–120 cm, with a clay-loam texture, and a water retention capacity of 33%. The climate of the Sardinia region is Mediterranean (Kottek et al., 2006) characterized by fall-winter rains (535 mm and 581, at Ottava and Cabras, respectively) and summer droughts. The annual mean temperature trends are in the range 10 °C–11.9 °C in January and 23.1–24.8 °C in August, at Ottava and Cabras, respectively.

2.1.1. Experimental design and treatment description

For both sites and growing seasons, the experiment was set up according to a randomized block design with three replications. A 6 m wide unsampled zone was maintained among plots (5 m wide and 15 m long, 75 plants) and blocks to avoid interactions between treatments. Conventional (CV) drip irrigation and canopy-cooled (CC) irrigation treatments were compared. The CV treatment was managed, according to local farming practice, with a drip irrigation system (drip