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Assessment of sustainable deficit irrigation in a Moroccan apple orchard as a climate change adaptation strategy

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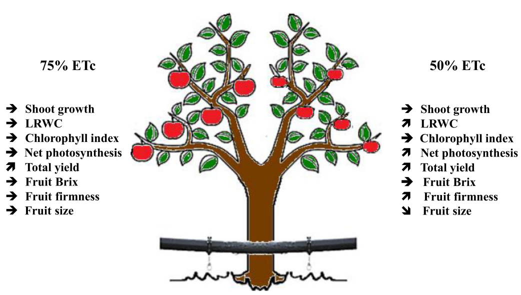
HIGHLIGHTS

- Mediterranean region is considered a "hot spot" for climate change.
- In many regions of Morocco, farmers overestimate plant water requirements.
- Smart irrigation for apple trees requires determination of a correct Kc.
- SDI of apple trees with 75% ETc shows an increase in crop yield.
- Fruit firmness increased with 50% of reduction of the applied water

GRAPHICAL ABSTRACT



Schema showing the effects of SDI (75 and 50 % ETc) in 2017 season on apple tree 'var. Gala'
(➔ Unchanged, ➚ Increase, ➘ Decrease)

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ABSTRACT

This study was conducted over three consecutive years, 2015, 2016 and 2017, in the Imouzzer Kander region located in northwestern Morocco. The main objective is to evaluate apple tree responses to two sustainable deficit irrigation strategies with 75% (T2) and 50% (T3) of calculated crop evapotranspiration (ETc), compared to a control irrigated with 100% ETc (T1). During the three experiment years, estimated reference evapotranspiration (ET_0) was 630, 684 and 728 mm, respectively, in 2015, 2016 and 2017. Under the two restricted regimes, shoot length and fruit size evolution were not significantly affected. During the fruit set of 2017, no significant effects of sustainable deficit irrigation on the relative water content were observed, whereas they increased significantly during the fruit-swelling stage for the T3 treatment. Likewise, net CO_2 assimilation (A_n) was not affected by the irrigation dose, whereas it increased significantly and inversely proportional to the amount of applied water during fruit swelling. Thus, under our experimental conditions, the trees subjected to extreme deficit irrigation (T3) were not stressed at either stage. Moreover, deficit irrigation at 75% ETc increased apple yield significantly. In contrast, deficit irrigation at 50% ETc throughout the cycle was not enough to maintain an acceptable fruit size for the three studied campaigns. However, the best qualitative performance, notably for fruit firmness and sugar content, was attributed to this irrigation regime (T3).

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1. Introduction

The Mediterranean region is considered a “hot spot” of climate change. Several investigations (Abouabdillah et al., 2010; Amengual et al., 2012; Brouzyine et al., 2018; Senatore et al., 2010) warn of significant impacts on both mean precipitation and variability of hydrological processes, some papers predicting a 20% decrease in water availability. Morrocco, as an integral part of this area, is highly vulnerable to the adverse effects of climate change. Additionally, water and environmental resources, which are already under extensive pressure from population growth, industrialization, tourism and agricultural extension, are at particular risk (WB, 2017). Most predictions show that, over the coming decades, the country will gradually display signs of increasing aridity due to higher temperatures and reduced rainfall (Balaghi, 2017).

Agriculture is the largest water-consuming sector in Morocco, accounting for about 75% of water use in 2012 (MAPMDREF, 2015), utilizing around 10^6 hm^3 per year, while the demand expressed is about 5 billion m^3. It plays an important role in the economy and comprises approximately 14% of the national Gross Domestic Product, with significant annual variations (11–18%) depending on weather conditions during the growing season. Fruit trees, in particular the apple (*Malus domestica*), are a high water-demanding crop, thus dependent on irrigation, which raises questions about the sustainability of the country's apple production. Currently occupying >30,000 ha, it is the second most important rosaceous fruit species, following the almond crop. This requires the implementation of rational irrigation and new techniques for more efficient water use. With a share of 22% of national production, the apples are the main crop of the mountainous areas in the Fès-Meknès region. The most commonly used irrigation methods are still surface irrigation and micro irrigation-systems, covering 61 and 39% of the irrigated area, respectively (MAPMDREF, 2015).

Irrigation scheduling in horticultural orchards is based on an estimation of the reference evapotranspiration (ET_0), multiplied by a set of crop coefficients related to crop response (Allen et al., 1998). Worldwide, these coefficients have undergone several corrections. In 2012, the Food and Agriculture Organization of the United Nations (FAO) compiled new research studies on crop coefficients in its newsletter number 66 (Steduto, 2012). These published crop coefficients nevertheless need to be adjusted in function of real-use conditions. It is well documented that for certain crops maximum biomass production causes no stress, whereas for other crops, including trees, stress may not affect economic yields. In many cases, tree water status reaches its optimal value, horticulturally speaking, below a certain level of stress, and thus ETc must be multiplied by a stress factor (Ks), which is expected to change in the course of the season in accordance with the optimal tree-water status (Naor, 2010).

Moreover, in semi-arid areas, often characterized by increased evapotranspiration, high soil salinity and limited water availability, water-use efficiency needs to be increased (Lo Bianco et al., 2012). This situation requires that stricter irrigation control levels be tested which could save more water without sacrificing fruit-orchard productivity (Ro, 2001). It is therefore necessary to apply deficit irrigation in order to obtain a better ratio of irrigation-water quantity to optimum yield. In general, two types of deficit irrigation can be applied: 1) continuous water reduction throughout the entire crop cycle (SDI: Sustainable Deficit Irrigation), or 2) a targeted reduction during a given stage or period (RDI: Regulated Deficit Irrigation). SDI is generally applied to young plantations to assess the effect of possible moisture stress on vegetative growth and the fruiting of young trees (De Oliveira et al., 2017; Petillo et al., 2009; Treder et al., 2004; Ucar et al., 2016). This method can be also applied to adult orchards in order to readjust the predefined Kc models (Allen et al., 1998) based on actual orchard conditions (O'Connell and Goodwin, 2007; Naor et al., 2008; Sharma et al., 2003).

This paper discusses the effect of two levels of SDI on young apple trees. The underlying objective of the study is to readjust the Kc model, proposed by Girona et al. (2010), and published in the FAO bulletin 66, to the real conditions of the Imouzzer Kander region in Morocco.

2. Materials & methods

2.1. Experimental site and plant material

This study was conducted over three growing seasons (2015–2017) on a privately owned farm located at Imouzzer Kander in the Fès-Meknès region, Morocco (33°767′ Lat., −05°013′ Lon. and 900 m Alt.) (Fig. 1). Royal Gala' trees on M9 rootstock were planted in a north-south orientation in 2011 at a spacing of 1.25 m × 4 m and trained to the vertical axis system. The percentage of soil covered by tree canopy was 20, 25 and 30% for the first, second and third year of the experiment, respectively. The soil is a silty clay loam with 32% clay, 50% silt and 18% sand in the top soil (0–40 cm) which was expected to contain the effective root system considering tree age and the dwarf nature of the M9 rootstock. It has a water-holding capacity of about 166 mm in the top meter of the soil profile. During the three years of experimentation, average air temperature (°C) in the area was around 20 °C. The sum of reference evapotranspiration ET_0 during the irrigation season (from bud break to harvest) was around 630, 752 and 728 mm, respectively, for 2015, 2016, and 2017. Rainfall during the irrigation season was 70, 72, and 39 mm, respectively, for 2015, 2016 and 2017. Rainfall was considered in the allocation of irrigation water to each treatment. Except for the irrigation regimes (amounts of water) as described below, the trees were subject to the same farming practices such as fertilization, pest management, etc. The fruit thinning operation was carried out in the same way for all tree treatments.

The experiment plots were equipped with a localized drip irrigation system. Each planting line has a single polyethylene drip line (16 mm), equipped with integrated drippers uniformly spaced 60 cm apart on the drip line and delivering 1.6 l per hour. The irrigation dose was calculated using the following formula (1):

$$ET_c\ (mm) = (ET_0 * K_c) - \text{effective rainfall} \quad (1)$$

where ET_0 (mm) is the reference daily evapotranspiration calculated by the modified Penman-Montheith formula (Snyder et al., 1987). The estimation of ET_0 was based on climatic parameters obtained from the weather station installed on the farm, with Kc as the crop coefficient for apple trees proposed by Girona et al. (2010) (Table 1).

Effective rainfall consists of the amount of rainfall stored in the effective root zone and that lost by surface runoff, deep percolation or evaporation. The USDA SCS method (USDA, 1967) was used to estimate effective rainfall, taking into account the total rainfall corresponding to 80% of occurrence probability, the cultural evapotranspiration and the water available in the soil. In addition, a capacitance probe installed in the experimental trial was used to monitor the soil moisture at different layers so as to adjust the estimation of the total amount of water stored in the root zone after every rain or irrigation event.

2.2. Treatments and experimental design

Two SDI treatments were tested: irrigation with an application of 75 (T2) and 50% (T3) of ETc throughout the cycle. Trees irrigated with 100% of ETc were considered a control (T1). A randomized complete block design was used with four block replicates. Each block replicate housed the three treatments. Each treatment gathered 10 trees within the same block; three of them with the same trunk diameter were chosen for monitor parameters while the others were considered guard trees.

2.3. Irrigation and climatic conditions

In order to calculate the reference evapotranspiration required to schedule the irrigation for each treatment on a daily basis, all climatic