Agricultural Water Management xxx (2017) xxx-xxx

Contents lists available at ScienceDirect

Agricultural Water Management

journal homepage: www.elsevier.com

Deficit irrigation and emerging fruit crops as a strategy to save water in Mediterranean semiarid agrosystems

A. Galindo[a, *, 1], J. Collado-González[b, 1], I. Griñán[c, 1], M. Corell[d, e, 2], A. Centeno[f, 2], M.J. Martín-Palomo[d, e, 2], I.F. Girón[e, g,2], P. Rodríguez[h, 2], Z.N. Cruz[h, 2], H. Memmi[f, 2], A.A. Carbonell-Barrachina[b, 2], F. Hernández[c, 2], A. Torrecillas[i, 2], A. Moriana[d, e, 2], D. López-Pérez[f, 2]

[a] *Dept. of Water Engineering & Management, Faculty of Engineering Technology, University of Twente, P.O. Box 217, 7500 AE Enschede, The Netherlands*
[b] *Department of Agrofood Technology, Food Quality and Safety Research Group, Universidad Miguel Hernández de Elche. Ctra. de Beniel, km 3,2. E-03312 Orihuela, Alicante, Spain*
[c] *Department of Plant Sciences and Microbiology, Plant Production and Technology Research Group. Universidad Miguel Hernández de Elche, Ctra. de Beniel, km 3,2. E-03312 Orihuela, Alicante, Spain*
[d] *Dpto. Ciencias Agroforestales, ETSIA, Universidad de Sevilla, Crta de Utrera Km 1, E-41013 Sevilla, Spain*
[e] *Unidad Asociada al CSIC de Uso Sostenible del Suelo y el Agua en la Agricultura (US-IRNAS), Crta de Utrera Km 1, E-41013, Sevilla, Spain*
[f] *Departamento de Producción Vegetal, Fitotecnia, ETSIAAB, Technical University of Madrid, Ciudad Universitaria s/n, E-28040 Madrid, Spain*
[g] *Instituto de Recursos Naturales y Agrobiología (CSIC), P.O. Box 1052, E-41080 Sevilla, Spain*
[h] *Department of Physiology and Biochemistry, Instituto Nacional de Ciencias Agrícolas (INCA). Ctra. de Tapaste, km 3.5, San José de Las Lajas, Mayabeque, Cuba*
[i] *Centro de Edafología y Biología Aplicada del Segura (CSIC), P.O. Box 164, E-E-30100 Espinardo, Murcia, Spain*

ARTICLE INFO

Article history:
Received 16 May 2017
Received in revised form 31 July 2017
Accepted 15 August 2017
Available online xxx

Keywords:
Jujube
Loquat
Partial root drying
Pistachio
Pomegranate
Regulated deficit irrigation
Sustained deficit irrigation
Underutilized crops
Water stress
Water relations

ABSTRACT

Water scarcity in Mediterranean climate areas will be progressively aggravated by climate change, population increase and urban, tourism and industrial activities. To protect water resources and their integrity for future use and to improve biodiversity, besides following advanced deficit irrigation strategies in fruit cultivation, attention could well be directed towards what are at present underused plant materials able to withstand deficit irrigation with minimum impact on yield and fruit quality. To this end, the state of the art as regards deficit irrigation strategies and the response of some very interesting emerging fruit crops [jujube (*Zizyphus jujuba* Mill.), loquat (*Eriobotrya japonica* Lindl.), pistachio (*Pistacia vera* L.) and pomegranate (*Punica granatum* L.)] are reviewed. The strengths and weaknesses of deficit irrigation strategies and the mechanisms developed by these emerging fruit crops in the face of water stress are discussed. The response of these crops to deficit irrigation, with special attention paid to the effect on yield but also on fruit quality and health-related chemical compounds, was analysed in order to assess their suitability for saving water in Mediterranean semiarid agrosystems and to analyze their potential role as alternatives to currently cultivated fruit crops with higher water requirements. Finally, the factors involved in establishing an identity brand (*hydroSOS*) to protect fruits obtained under specific DI conditions are discussed.

1. Introduction

Mediterranean climate countries include not only those that border the Mediterranean Sea (from Spain to Turkey and Cyprus and from Morocco to Syria) but also other regions of the planet, including Southern California, Chile, South Africa and Southern Australia. All are characterized by hot dry summers, mostly rainy winters and partially wet spring and autumn. In these region, to ensure regular crop yields and for to reduce inter-annual yield variability, the scarce rainfall has to be supplemented by irrigation in order to avoid plant water deficits. Indeed, water scarcity in these sites is destined to gradually become worse because more frequent and severe droughts events driven by climate change (Collins et al., 2009). Moreover, as the population increases, leading to an increasing expansion of urban, touristic and industrial activities, tension and conflict between water users and pressures on the environment will be intensified.

Consequently, and considering that Mediterranean agrosystems are very important consumers of fresh water, it is of paramount importance to protect water resources and their integrity for future use (Katerji et al., 2008). In this sense, to overcome the problems associated to a boost in water prices, as the discouragement of farmers and ultimately land abandonment, García-Tejero et al. (2014) indicated that an alternative could be to provide correct incentives for farmers to adopt changes in their irrigation methods by implementing strategies and tools for sustainable water saving. Among the strate-

* Corresponding author.
Email address: a.galindoegea@utwente.nl, (A. Galindo)
[1] These authors contributed equally to this work. [2]These authors contributed equally to this work.

https://doi.org/10.1016/j.agwat.2017.08.015
0378-3774/© 2017.

gies that can be applied to attain water saving are the use of improved, innovative and precise deficit irrigation (DI) management practices able to minimize the impact on crop yield and quality (Fernandez and Torrecillas, 2012). In addition, in order to contribute to water saving, fruit culture should be directed towards the use of plant materials that are less water-demanding or able to withstand deficit irrigation with minimum impact on yield and fruit quality.

In this last respect, it is important to consider that in human history, 40–100,000 plant species have been regularly used for food, fiber and for industrial, cultural and medicinal purposes. Today, at least 7000 cultivated species are in use around the world. However, in recent centuries, agricultural systems have promoted the cultivation of a very limited number of crop species. While these have been the focus of attention of commerce and scientific research world-wide, many crops have been relegated to the status of neglected or underutilized crop species, and largely ignored (Padulosi et al., 2001; Chivenge et al., 2015). In addition, this reduction in the number of crop species used for food production throughout the world has a direct effect on biodiversity, which is fundamental for ecosystem functioning, sustainable agricultural production and the attainment of food and nutritional security (Toledo and Burlingame, 2006; Chappell and LaValle, 2011). Therefore, to improve not only biodiversity but also to saving water and hence protecting the integrity of water resources for the future, it is necessary the diversification of production and consumption habits, including the use of a broader range of plant species, in particular those currently identified as underutilized and needing a low input of synthetic fertilisers, pesticides and water. This option has to be compatible with the consolidation of the cultivation of other Mediterranean traditional crops, such as olive, almond or grapevine, which are low water demanding and profitable crops. In this sense, in some countries, during recent decades there has been a certain interest in diversifying fruit tree production by cultivating species with under-exploited potential. Among these emerging crops many are characterized by their attractive fruits and health-related qualities, so that they may attract consumer attention and contribute to producer profitability

For these reasons, the aim of this review was to present the state of the art of deficit irrigation strategies and the response to them of some very interesting emerging fruit crops [jujube (*Zizyphus jujuba* Mill.), loquat (*Eriobotrya japonica* Lindl.), pistachio (*Pistacia vera* L.) and pomegranate (*Punica granatum* L.)]. To this end, the following aspects were considered: (i) the strengths and weaknesses of deficit irrigation strategies, (ii) the mechanisms developed by these emerging fruit crops to confront water stress, and (iii) the response of these crops to deficit irrigation, paying special attention not only to the effect on yield but also to the effect on fruit quality and health-related chemical compounds.

2. Deficit irrigation. Concepts and strategies

To cope with water scarcity, Mediterranean agrosystems are increasingly looking to more efficient technological innovation and irrigation management approaches. In this respect, many countries have shifted from irrigating crops in order to satisfy their evapotranspiration requirements (ETc) or full irrigation (FI), the conventional norm which seeks to maximize crop yield per unit of land, to deficit irrigation (DI) strategies, which involve reducing the amount of water provided to the crop during the growing season by the soil moisture stock, rainfall and irrigation to a level below that needed for maximum plant growth. In most of cases DI induces a gradual water deficit, due depletion of soil water reserves, accompanied by a reduction in harvestable yields, especially in soils with a significantly low water storage capacity.

When water scarcity is the consequence of uncontrolled factors and water supply is not guaranteed, farmers find it difficult to schedule any reasonable DI strategy. In contrast, if growers have a guaranteed water supply for their crops during the growing season, it is possible to improve water productivity (WP) by drawing up DI strategies based on scientific principles, attempting to produce near-maximum yields even if crops are provided with less water than they would otherwise use (maintaining crop consumptive use below its potential rate). In other words, improving the marketable yield per unit of water used rather than attaining maximum yields (Kijne et al., 2003; Zhang, 2003) Complementary advantages of the same include a reduction of nutrient loss from the root zone and a decrease in excessive vegetative vigour, accompanied by a lower risk of crop diseases linked to high humidity (Goodwin and Boland, 2002; Ünlü et al., 2006) (Table 1). However, there is a shortage of research into the risk of soil salinization as a consequence of any decrease in the leaching of salts and the use of low quality irrigation water (Boland et al., 1996; Kaman et al., 2006) (Table 2).

Three main DI strategies can be mentioned; sustained deficit irrigation (SDI), in which irrigation water used at any moment during the season is below the crop evapotranspiration (ETc) demand, and two others, both based on physiological aspects of the response of plants to water deficit − regulated deficit irrigation (RDI) and partial root-zone drying (PRD) (Fig. 1).

2.1. Sustained deficit irrigation (SDI)

At the end of 1970s, trials applying irrigation water amounts below the ETc demand but at very frequent intervals took place with encouraging results. Called deficit high-frequency irrigation (DHFI),

Table 1
Key advantages of deficit irrigation (DI) strategies: sustained deficit irrigation (SDI), regulated deficit irrigation (RDI) and partial root drying (PRD) with a non-exhaustive list of references.

DI strategy	Advantage	References
SDI, RDI and PRD	Maximize the water use efficiency and water productivity (WP)	Liu et al. (2006a); Liu et al. (2006b); Saeed et al. (2008); Geerts and Raes (2009); Ahmadi et al. (2010).
	Minimum impacts on yields can be achieved when precision tools are used to manage mild DI	García-Orellana et al. (2007); Ortuño et al. (2009)
	Reduces nutrient loss from the root zone, improving ground water quality and lowering fertilizer needs on the field.	Ünlü et al. (2006); Goodwin and Boland (2002)
	Decrease the risk of crop diseases linked to high humidity	Goodwin and Boland (2002); Ünlü et al. (2006)
RDI	Improves water savings and even harvest quality	Chalmers et al. (1981); McCarthy et al. (2002)
	Reduces excessive vegetative vigour	Goodwin and Boland (2002).
	Can be scheduled using only trunk diameter sensors	Conejero et al. (2011); Girón et al. (2015).
PRD	It can be operated in furrow or drip-irrigated crops	Grimes et al. (1968); Samadi and Sepaskhah (1984).
	Despite a reduction in stomatal conductance, crops maintain a favourable water status	Santos et al. (2003); Kang and Zhang (2004)
	The quantity and quality of the harvest can be improved as a consequence of carbohydrates partitioning between the different plant organs	Kang and Zhang (2004)

Table 2
Key constraints of deficit irrigation (DI) strategies: sustained deficit irrigation (SDI), regulated deficit irrigation (RDI) and partial root drying (PRD) with a non-exhaustive list of references.

DI strategy	Constraint	References
SDI, RDI and PRD	At all times it is essential to access to a minimum quantity of water, below which DI has no significant beneficial effect	Zhang (2003)
	Shortage of research on soil salinization risks as a consequence of the decrease of leaching of salts and the use of low quality irrigation water.	Boland et al. (1996); Kaman et al. (2006)
	Crops sustain some degree of water deficit and some yield reduction except when soil water depletion supplements irrigation to reaching ETc	Fereres et al. (1978); Costa et al. (2007)
SDI	Yield decrease is due mainly to decrease in fruit weight	Castel and Buj (1990)
RDI	The maintenance of plant water status within narrow limits of water deficit during non-critical phenological periods. Sudden change in evaporative demand risks severe losses of yield and fruit quality	Jones (2004)
	New and more precise criteria for defining water deficit are needed, because criteria based on ETc can have unpredictable final effect on the rhythm of water deficit development across a range of different growing conditions (species, weather, soil depth, fruit load, rootstock).	Shackel et al. (1997); Marsal et al. (2008)
	Irrigation management in heavy and deep soils because soil water depletion and refill can take place too slowly	Girona et al. (1993)
	Scarcity of detailed studies to know the effect of water deficit on bud development	Naor et al. (2005); Marsal et al. (2008)
PRD	Do not exist definite solid criteria on defining the optimum timing of irrigation for each root system side	Saeed et al. (2008)
	It is not possible to have absolute control of root drying under field conditions and hydraulic redistribution from deeper to shallower roots may prevent the clear results that can be obtained in potted plants	Bravdo (2005)

this strategy proved unsuccessful when little water was stored in the soil. It was only possible to use DHFI and obtain maximum yields when ETc was reached through the combination of irrigation water applied and soil water depletion (Fereres et al., 1978).

In fact, the DHFI strategy is very similar to SDI (Fig. 1), which is based on the idea of allotting the water deficit uniformly over the whole fruit season, thus avoiding the occurrence of serious plant water deficit at any crop stage that might affect marketable yield or fruit quality, or distributing the irrigation water proportionally to irrigation requirements throughout the season.

2.2. Regulated deficit irrigation (RDI)

RDI works on the premise that transpiration is more sensitive to water deficit than photosynthesis and fruit growth, and water deficit-induced root-sourced chemical signals like ABA. Thus, fruit trees cope with a reduced water supply by reducing transpiration (stomata regulation or reducing leaf surface area through reducing leaf growth) (Wilkinson and Hartung, 2009). In this sense, fruit tree sensitivity to water deficit is not constant during the whole growing season, and a water deficit during particular periods may benefit WP by increasing irrigation water savings, minimizing or eliminating negative impacts on yield and crop revenue and even improving harvest quality (Chalmers et al., 1981; McCarthy et al., 2002; Domingo et al., 1996) (Table 1). Therefore, when a RDI strategy is applied, full irrigation is supplied during the drought-sensitive phenological stages (critical periods) of fruit trees and irrigation is limited or even unnecessary if rainfall provides a minimum supply of water during the drought-tolerant phenological stages (non-critical periods) (Chalmers et al., 1981; Mitchell and Chalmers, 1982; Geerts and Raes, 2009) (Fig. 1).

Stone fruit growth follows a double-sigmoidal pattern with two periods of rapid growth separated by a period during which little or no expansive growth occurs. The first growth period, stage I, is due to cell division and cell expansion; stage II is the period in which sclerification of the fruit endocarp takes place and fruit growth is extremely slow or null, and stage III is the second period of fruit

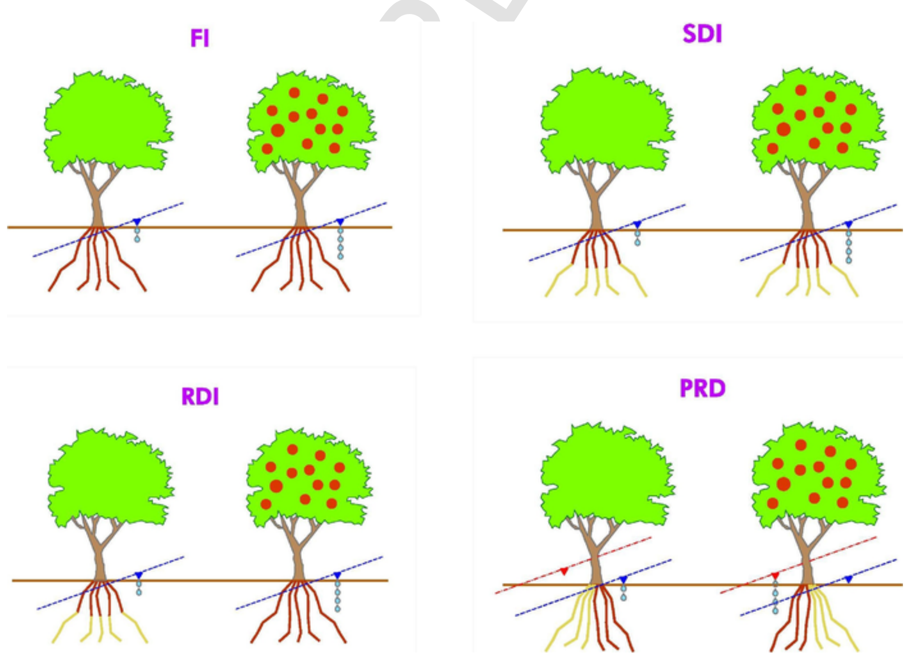

Fig. 1. Graphic pattern of full irrigation (FI), sustained deficit irrigation (SDI), regulated deficit irrigation (RDI) and partial root drying (PRD) strategies in fruit trees.

growth, which is rapid due to the expansion of existing cells and extends from the onset of this second growth period until maturity. Pome and *Citrus* fruits show only a phase of rapid fruit growth (single-sigmoidal pattern), which takes place after the initial period of cell division and minimal expansion, and is due mainly to a cell expansion process even though some cell division may also take place at the beginning (Rodríguez et al., 2017).

In stone fruit trees, two critical periods have been identified. The first one corresponds to the second rapid fruit growth period (stage III), when drought stress induces a reduction in yield due to the smaller fruit size at harvest, and the second critical period is the early postharvest period, when drought stress affects flower bud induction and/or the floral differentiation processes that occur at this time. This leads to a lower germination potential in the pollen of the next bloom and encourages young fruit to drop in the following season (Uriu, 1964; Ruiz-Sánchez et al., 1999; Torrecillas et al., 2000). In other *Prunus* species, such as almond (*Prunus dulcis* (Mill.) D.A. Webb), flowering and rapid vegetative and fruit growth stages (stages II and III) and postharvest (stage V) have been reported as critical periods because water deficit affects yield (Goldhamer and Smith 1995; Goldhamer and Viveros, 2000; García-Tejero et al., 2017).

In pome and *Citrus* fruits rapid fruit growth can be considered as a common critical period. In an experiment in Fino lemon (*Citrus limon* (L.) Burm. fil.) trees over four seasons, Domingo et al., (1996) showed that the main critical period corresponds to the rapid fruit growth phase, when water deficit causes a delay in attaining marketable fruit size, whereas moderate water deficit applied during flowering-fruit set-fruit cell division period is not critical in terms of yield. In fact, the effect of water deficit applied during this last phenological period on yield is related not only with the water deficit level achieved but also with the plant species. In Salustiana orange trees (*Citrus sinensis* (L.) Osbeck) on sour orange rootstock (*Citrus aurantium* L.), Castel and Buj (1990) attained a decrease in yield of only 4%, whereas Ginestar and Castel (1996) observed that Clementina de Nules (*Citrus clementina* Hort ex Tan) on Carrizo citrange (*Citrus sinensis* Osb. × *Poncirus trifoliata* (L.) Raf.) were extremely sensitive to water restrictions (yield decrease) during this period.

In very early maturing fruit trees, with a very short period from fruit set to harvest and a very long post-harvest phenological period, deficit irrigation should be applied only during the post-harvest period even though avoiding affect bud induction and floral differentiation processes (Torrecillas et al., 2000; Conejero et al., 2011).

Taking into consideration that the effects of water deficit depend not only on the timing but also on the duration and magnitude of the same, the plant water status during non-critical periods has to be maintained within certain levels of water deficit in order to prevent a moderate, potentially beneficial, drought stress from becoming too severe and ending in reduced yield (Table 2) (Johnson et al., 1992; Kang and Zhang, 2004). In this sense, problems have been found in maintaining a certain level of plant water deficit because, when low amounts of irrigation water are applied, adverse situations such as a sudden increase in temperature may result in severe losses of yield and quality, (Table 2) (Jones, 2004). Other problems have been found when applying RDI in heavy and deep soils because soil water depletion and refill frequently take too long (Table 2) (Girona et al., 1993). Under this situation, the success of RDI depends strongly on the appropriate use of microirrigation techniques and sensors able to provide real time information on soil and plant water status (Dichio et al., 2007; Ortuño et al., 2009).

In recent years, the use of plant-based water status indicators has become very popular for planning more precise irrigation programmes, because it is recognized that the tree itself is the best indicator of its water status (Table 1) (Shackel et al., 1997; García-Orellana et al., 2007; Fernandez and Cuevas, 2010). In this sense, sensors like linear variable displacement transducers (LVDTs) are able to measure daily trunk diameter fluctuations (TDF) with great precision, generating sensitive parameters which strongly correlate with established plant water status parameters (Fernandez and Cuevas, 2010; Ortuño et al., 2010). The most common and useful TDF parameters for the irrigation scheduling of woody crops are maximum daily trunk shrinkage (MDS) and trunk growth rate (TGR) (Ortuño et al., 2010; Moriana et al., 2013). Moreover, the operational advantages of TDF measurements in adult trees, such as the possibility of connecting remotely operated irrigation automatic devices, and the ability to rapidly adjust schedules in response to the daily signal, make them very suitable tools for precise RDI scheduling (Conejero et al., 2011; Girón et al., 2015).

2.3. Partial root drying (PRD)

This DI strategy, which has also been called partial root-zone irrigation, can be applied through alternate furrow irrigation (Grimes et al., 1968) and by surface and subsurface drip irrigation (Table 1) (Samadi and Sepaskhah, 1984), and is based on irrigating only one part of the root zone, leaving another part to dry to a certain soil water content before rewetting by shifting irrigation to the dry side (Dry and Loveys, 1998; Sepaskhah and Ahmadi, 2010) (Fig. 1).

The strategy is based in the idea that, in PRD, roots sense soil drying, triggering the synthesis of the plant hormone abscisic acid (ABA), which reduces leaf expansion and stomatal conductance, while, simultaneously, the roots of the watered side of the soil absorb sufficient water to maintain a favourable plant water status (Table 1) (Liu et al., 2006a; Zegbe et al., 2006; Ahmadi et al., 2010). In addition, other complementary physiological responses to PRD can favour stomatal closure such as lower cytokine levels (Stoll et al., 2000; Davies et al., 2005) and higher xylem pH (Davies and Zhang, 1991; Stoll et al., 2000). Other results in grapevine (*Vitis vinifera* L.) indicated that PRD may also increase root growth (Dry et al., 2000)

Currently, no definitive solid criteria exist for deciding the optimum timing of irrigation for each side (Table 2), probably due to the diversity of factors involved, such as evaporative demand, soil characteristics, soil water status at any precise moment, crop phenological stage, etc., any of which may determine the plant response to wetting or drying of each side of roots (Saeed et al., 2008). In this sense, the time when soil water extraction from the dry side is negligible has been proposed as the optimum time to switch wetting from the irrigated root side to the non-irrigated side (Kriedmann and Goodwin, 2003). Also, the threshold soil water content at which the maximum xylem ABA concentration is produced was proposed by Liu et al. (2008) as a criterion for switching irrigation.

Some authors showed that crops under PRD gave better yields than the same crops under DI when the same amount of water is applied. This resulted in higher WP and even better fruit quality (Kriedmann and Goodwin, 2003; Kang and Zhang, 2004; Liu et al., 2006a,b). However, Wakrim et al. (2005) reported no significant difference in water use efficiencies (WUE) between PRD and DI, but a substantial increase in WUE when PRD was compared with FI.

3. Emerging fruit crops response to deficit irrigation

3.1. Jujube (Zizyphus jujuba Mill.)

Jujube tree (family Rhamnaceae) is native to China, where it has been cultivated for more than 5000 years, and to neighbouring areas of Mongolia and the Central Asian Republics. With time, its cultivation has spread to other regions of the world, including to Mediterranean countries. Jujube fruit is an integral part of the culture and way of life of millions of people and has also become important for many regions of the world following its introduction (Azam-Ali et al., 2006); indeed, it can be considered a so-called functional food, since it has nutritional as well as medicinal uses (Choi et al., 2011). Nevertheless, until now jujube has been considered of minor importance and, from a research and development point of view, it has received little attention from most governments.

Jujube is able to withstand severe drought during the growing season (Fig. 2A) and to tolerate very low winter temperatures during its dormancy (Dahiya et al., 1981; Ming and Sun, 1986). In this sense, jujube trees are able to maintain leaf turgor under severe water deficit ($\Psi_{stem} < -3.0$ MPa), essentially by developing two complementary mechanisms – leaf active osmoregulation (stress tolerance mechanism) and the control of water loss via transpiration (stress avoidance mechanism), while allowing substantial gas exchange rates and, as a consequence, good leaf productivity (Ma et al., 2007; Cruz et al., 2012; Galindo et al., 2016). The gradual recovery of leaf conductance after re-watering previously stressed plants can also be considered as a mechanism for promoting leaf rehydration (Cruz et al., 2012). Moreover, the high leaf relative apoplastic water content (RWC_a) levels and the possibility of increasing the accumulation of water in the apoplasm in response to water stress supports a steeper gradient in the water potential between the leaf and soil (Cruz et al., 2012).

Galindo et al. (2016) showed that in contrast with the axiom that expansive cell growth requires the presence of cell turgor, no direct relation between turgor and growth rate exists in jujube fruits. This could be due to an enhancement of a cell elasticity mechanism (elastic adjustment), which would maintain fruit turgor even at severe water stress levels by reducing fruit cell size, or to the fact that jujube fruit growth depends on fruit growth-effective turgor rather than just on turgor pressure. These authors also reported that during most of the fruit ripening stage water can enter the fruits via the phloem rather than via the xylem. This could be related with the increase in sensitivity to drought during this phenological period, when moderate and severe water deficits induce a significant reduction in total marketable fruit yield (number of fruits and/or average fruit weight). In contrast with this last idea, Cui et al. (2008, 2009) concluded that the jujube fruit maturation stage is the optimal stage to implement water deficit strategies and that while water deficit during the fruit growth slightly reduced the growth rate, re-watering had an over-compensatory effect, thus reducing the negative influence on fruit size.

The same authors (Cui et al., 2008, 2009) mentioned the relatively low water requirements of around 360 mm and showed that jujube fruit maturation can be advanced and the fruit yield and quality enhanced if appropriate RDI is applied at certain growth stages (bud

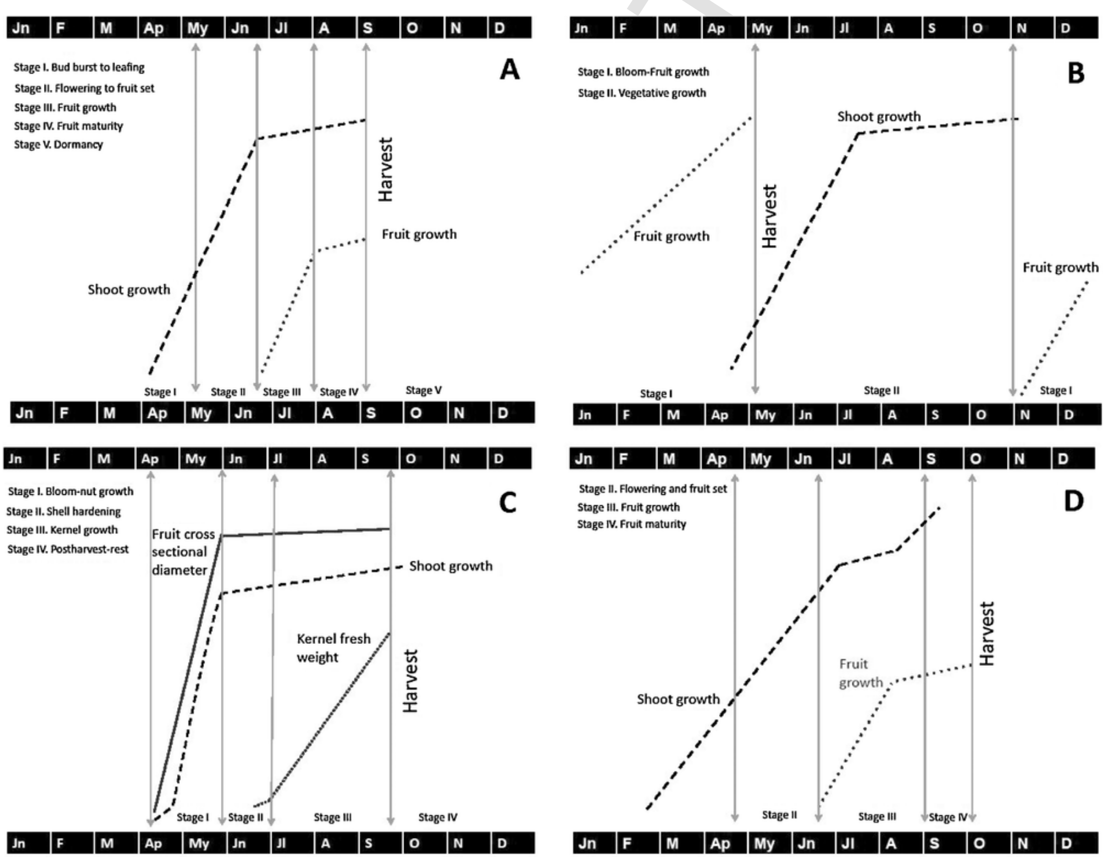

Fig. 2. Seasonal pattern of fruit and shoot growth of jujube (*Z. jujuba*, cv Grande de Albatera) (A), loquat (*E. japonica*, cv Algerie) (B), pistachio (*P. vera*, cv Kerman) (C) and pomegranate (*P. granatum*, cv Mollar de Elche) (D) plants in the southeast (A, B and D) and central (C) Spain conditions. Sources: Hernández et al. (2015), Cuevas et al. (2007a), Memmi et al. (2015) and Melgarejo et al. (1997), respectively.

burst to leafing and fruit maturation). Also, Gao et al. (2014) showed that jujube fruit responded positively to irrigation practices, the concentration of some taste-related (e.g. glucose, fructose, TSS and malic acid) and health-related (e.g. catechin and epicatechin) compounds being generally much higher in drip irrigated fruits. In this sense too, Collado-González et al. (2013) demonstrated that water deficit did not affect the tendency of procyanidins to self-aggregate but increased the content of procyanidins of low molecular mass (Table 3), improving their potential bioavailability and possible physiological effects on human health. The procyanidin content of fruit from well-watered trees increased during domestic cold storage, whereas the fruits from trees suffering severe water stress lost some of their procyanidin content. Moreover, in a subsequent paper, Collado-González et al. (2014) pointed to a certain proportionality in the response of jujube fruits to moderate and severe deficit irrigation during fruit maturation. So, when plants were exposed to moderate water deficit (Ψ_{stem} from −1.40 to −2.28 MPa) during this phenological period there was no change in fruit size, moisture content, firmness, or fruit peel and flesh colour compared with fully irrigated trees. Only when a more severe water stress (Ψ_{stem} from −1.40 to −3.14 MPa) was reached, there were significant increases in the sucrose and arabinose contents measured (Table 3). In addition, the response of fruit amino acids to water deficit was not as sensitive as expected, since there was no direct relationship with the magnitude of the water deficit. However, the decrease in fruit asparagine content as a result of severer water deficit is a positive aspect, because this amino acid is the major precursor of acrylamide, a potentially toxic compound formed during the heat-processing of some plant foods. However, severe water deficit produced smaller fruit, with a lower moisture content and yield, accompanied by changes in firmness and peel and flesh colour.

3.2. Loquat (*Eriobotrya japonica* Lindl.)

Loquat is a subtropical evergreen tree that belongs to the family Rosaceae, subtribe Pyrinae (formerly subfamily Maloideae) (Potter et al., 2007). Some of the common names of loquat include Japanese plum, Japanese medlar, Maltese plum, etc. It is considered indigenous to southeastern China and possibly southern Japan, because it is said to have been cultivated there for over 1000 years. Actually, more than 30 countries in subtropical and mild-temperate regions of the world are cultivating selections of loquat cultivars performed during the 19th century (Feng et al., 2007; Ferreres et al., 2009; He et al., 2011).

It is important to point out that loquat is characterized by an unusual phenology that makes it different of the traditional temperate fruit crops. It blooms in autumn on apical panicles formed on current year wood, developing fruits during winter and ripening in early spring (Fig. 2B). Moreover, this fruit as other pomes presents a sigmoidal pattern of fruit growth (Dennis, 1988; Cuevas et al., 2003) and arrives at markets before any other spring fruit (Cuevas et al., 2007a; Hueso and Cuevas, 2008).

Table 3
Effect of different deficit irrigation (DI) strategies (SDI, sustained deficit irrigation; RDI, regulated deficit irrigation) on health-related compounds content (↑, increased; ↓, decreased; ≈, no affected) in the edible portion of jujube, pistachio and pomegranate fruits with a non-exhaustive list of references.

Fruit Crop	DI strategy	Compound		Response to moderate water deficit	Response to severe water deficit	References
Jujube (Ziziphus jujubaMill.)	SDI/RDI	Epicatechin		↑	↑	Collado-González et al. (2013)
		Total B type procyanidins		↑	↑	
		Self-aggregated procyanidins		≈	≈	
	SDI/RDI	Vitamin C		≈	↑	Collado-González et al. (2014)
		Sugars	Sucrose or arabinose	↑	↑	
			Glucose	↑	↑	
		Organic acids	Malic or oxalic	↑	↑	
			Citric	≈	↓	
		Proline		≈	↑	
		Asparagine		≈	↓	
		Other amino acids		No uniform behaviour	No uniform behaviour	
	SDI	Flavonoids	Epicatechin or catechin	↓	↓	Gao et al. (2014)
			Procyanidins	≈	≈	
			Rutin	↓	↑	
			Quercetin	↑	≈	
		Total phenolic compounds		≈	≈	
		Sugars (sucrose, glucose or fructose)		↓	↓	
		Organic acids (malic, succinic or citric)		↓	↓	
		Ascorbic acid		≈	≈	
Pistachio (Pistacia veraL.)	RDI	Fatty acids	Oleic or palmitic	≈	≈	Carbonell-Barrachina et al. (2014)
			Linoleic	↑	↑	
		Volatile compounds	Aldehydes	↓	↑	
			Pyrazines and terpenes	↑	↓	
Pomegranate (Punica granatumL.)		Anthocyanins		≈	↓	Mena et al. (2013)
	SDI	Phenolic compounds		↓	↓	
		Punicalagin		↓	↓	
		Ellagic acid		≈	≈	

Research on mechanisms developed by loquat plant to resist drought is very scarce, mainly at plant water relations levels. Diurnal and seasonal gas exchange values in loquat plants respond to changes in plant water status and to changes in evaporative demand, showing minimum values in summer. Moreover, the diurnal trend of photosynthetic rate in loquat, at least during autumn and winter, was characterized by a double-picked curve, suggesting the predominance of genotype over the environmental factors on the loquat gas exchange behaviour (Stellfeldt et al., 2011), because this last behaviour diverges from that indicated for woody Mediterranean vegetation, which is characterized by a maximum value in the morning, declining towards midday, and remaining more or less constant afterward. Recently, Zhang et al. (2015) observed some loquat drought stress tolerance mechanisms: i) the increase in chlorophyll content, which can enhances photosynthesis under water deficit, ii) the increase in the content of soluble sugars and proline of roots, which increased the osmotic adjustment and the favourable water potential gradient for water into the roots, iii) the increase in the ABA content of leaves, which induced the stomata closing and improved the water-use efficiency, and iv) the increase in the levels of antioxidant enzyme activities mainly at leaf level. The ability of loquat plants to develop leaf active osmoregulation was earlier suggested by García-Legaz et al. (2005) who studied the effect of salinity on the water relations of loquat plants on two different rootstocks. Luo et al. (2007) studied the response of two different loquat cultivars to water deficit and concluded that 'Changhong No. 3', the more water deficit resistant cultivar, responds to water deficit with a higher increase in stomatal density and reducing stomatal size than 'Jiefangzhong' cultivar. In addition, in 'Jiefangzhong' cultivar, leaf photosynthetic pigment concentrations decrease in response to drought stress, while in 'Changhong No. 3' the concentrations of photosynthetic pigments increased markedly under light drought stress.

Hueso and Cuevas (2008) estimated relatively high loquat water needs of around 724 mm, and demonstrated observing the long term response of this crop to postharvest RDI that this crop can be considered as a model for the continuous application of RDI strategies, mainly for the economic benefits of saving water during summer, increasing fruit size and grading and fruit value and gross revenue without affecting yield (Hueso and Cuevas, 2008; Cuevas et al., 2009). This positive response of loquat to RDI is based in two main facts; the clear separation between vegetative and reproductive growth, allowing the application of postharvest RDI without affecting fruit growth, and the improving of fruit value when postharvest RDI is applied because important advancing harvest time in the next season can be achieved. In this sense, the most profitable RDI strategy is the complete suppression of watering from around one month after the end of previous harvest (early June) up to reach a Ψ_{stem} value circa – 2.2 MPa (8–9 weeks), because do not alter the formation of the floral organs and increase the advancement of bloom next season (Cuevas et al., 2007a,b, 2009, 2012), while prolonging the water deficit period during one additional month (August) may impair flower development in loquat (Rodríguez et al., 2007).

Due to the fact that research on loquat response to RDI has been always focusses on fruit earliness due to its enormous importance in loquat price and commercialization and the high susceptibility of mature loquat fruits to mechanical damage during harvest and postharvest handling, to the best of our knowledge, do not exist publications on the effect of deficit irrigation on loquat quality. Since loquat is a non-climacteric fruit, premature picking is inadvisable because fruits are excessively acid and taste unpalatable to consumers. Thus, research has been focussed to stablish fruit maturity indices in order to optimize harvesting. Pinillos et al. (2011) suggested that at every picking date, only those fruits with a skin colour that corresponds to a minimum TSS and TSS/TA values should be harvested, especially at the earliest harvests of the season. Also, a TSS/TA of 0.7 was previously proposed as minimum value for harvest (Pinillos et al., 2007). Recently, Cañete et al. (2015) showed the consumers preference for light orange skin fruits rather than fully ripe ones due to their greater firmness, fewer skin defects and better balance between sweetness and acidity, and proposed harvesting loquat fruits with a minimum value of TSS of 10 Brix and a TSS/TA ratio close to 1.0 to guarantee eating quality and consumer satisfaction.

3.3. Pistachio (Pistacia vera L.)

Pistachio tree is native to western Asia and Asia Minor, from Syria to the Caucasus and Afghanistan. They are mentioned in the Old Testament. Archaeological evidence from Turkey indicates that the nuts were being used for food as early as 7000 B.C. Pistachio is a member of the Anacardiaceae or cashew family, and is the only commercially edible nut among the eleven species in the genus *Pistacia* and by far the most economically important. The pistachio was introduced into Italy from Syria early in the first century A.D., and subsequently its cultivation spread to other Mediterranean countries.

Pistachio trees are considered one of the most drought resistant fruit species, because they can survive under extreme drought conditions. Spiegel-Roy et al. (1977) observed that under desert conditions pistachio trees were able to differentiate sufficient flower buds to provide an appreciable yield and that roots were uniformly spread down to a depth of 2.40 m even if soil moisture in all the horizons was below the permanent wilting point of soil. Related with this last characteristic, some authors, e.g. Lin et al. (1984) and Germana (1997), suggested that pistachio drought resistance mainly depends on extensive root system development, because, despite it commonly being though a xerophyte, it does not present the morphological characteristic of such in the leaves, showing, instead, high values of net photosynthesis (Pn) and leaf conductance (g_{leaf}). Furthermore, the leaves can be considered as *isolaterals* since their upper and lower pages are structurally similar, with almost identical stomatal density and conductance. Also, Kanber et al. (1993) showed that root activity is confined to shallower soil depths in short interval irrigation conditions. Another singularity of pistachio trees is that both yield and the water stress level regulate the flower bud drop that occurs before the beginning of kernel growth. So, the following year's pistachio yield can decrease considerably as a consequence of a higher percentage of flower buds dropped i) in years of higher yield or ii) when a severe water deficit during fruit stage II takes place (Pérez-López et al., 2017).

Pistachio plants exposed to water stress also develop stress avoidance and stress tolerance mechanisms. As regard the first sort of mechanism, during pistachio fruit stages I and II (Fig. 2C), when the soil water content is quite high and the evaporative demand of the atmosphere is low, these plants show higher Pn and g_{leaf} values. In contrast, during fruit stage III, at which the evaporative demand of the atmosphere is higher, the pistachio plants show lower Pn and g_{leaf} values (Gijón et al., 2011; Memmi et al., 2016a,b). When plants are under water deficit, g_{leaf} values decrease in order to limit water loss through transpiration, and at very pronounced levels of water deficit, the daily pattern of g_{leaf} is modified, showing maximum values in the early morning and decreasing gradually, whereas Pn values remain fairly constant until sunset because this parameter is less sensitive to water deficit than g_{leaf} (D. Pérez-López, unpublished data). In this respect, Behboudian et al. (1986) established that pistachio plants are able to continue their photosynthetic activity even when Ψ_{leaf} reaches extremely low values of −5.0 to −6.0 MPa. Moreover, this crop has an outstanding capability for leaf thermoregulation, even at sever water stress levels, because pistachio canopies can transpire water at rates far higher than those normally found in mesophytes, and are able to rapidly compensate water losses without showing visible stress condition symptoms (Germana, 1997). In addition, when previously water stressed plants are re-watered, the gradual and slow recovery of the plant water status observed can be considered as a mechanism for promoting leaf rehydration (Memmi et al., 2016b). As regard the development of stress tolerance mechanisms, Gijón et al. (2011) identified changes in the leaf bulk modulus of elasticity during pit hardening (stage II) and active osmotic adjustment at any phenological period. Similarly, Behboudian et al. (1986) showed that pistachio plants at a Ψ_{leaf} value of −6.0 MPa exhibited very high Ψ_p values (3.0 MPa).

Pistachio's water relations are significantly affected by rootstock. According to Gijón et al. (2010), the hybrid from crossbreeding *P. atlantica* Desf. × *P. vera* L. may be the best rootstock for adequately irrigated pistachios since it induces the highest leaf conductance and vigour, whereas in rainfed or deficit irrigated conditions, *P. terebinthus* might be a good choice for its drought tolerance, as it is able to maintain a greater leaf area than non-stressed plants with lower Ψ_{stem} and g_{leaf} values. However, in contrast with these results and the widespread belief, Memmi et al. (2016b) suggested that *P. atlantica* could be a suitable rootstock for deficit irrigated plants.

Because of its reputation for being very resistant to water stress, pistachio is mainly cultivated worldwide under rain-fed conditions. Despite the good crop performance under these dryland conditions, there is a clear tendency to increase the area dedicated to irrigation because the benefits derived from irrigation in this crop are probably higher than in other crops. Irrigation increases yield, nut size and splitting, reduces the alternate bearing pattern and incidence of blank nuts, but has no effect on the hull to kernel ratio (Monastra et al., 1998; Ak and Agackesen, 2006). Sedaghati and Alipour (2006) suggested that early hull splitting, a process that decreases the quality of the yield because the kernel is exposed to invasion by fungi and insects, is related with plant water status from late April to early June. However, Gijón et al. (2009) suggested that early splitting incidence is not related to plant water status but to temperatures below 13 °C.

Pistachio's irrigation water requirements are quite high, varying from 547 to 600 mm when calculated according to Memmi et al. (2016b) or Kermani and Salehi (2006) to 842–1000 mm when calculated according to Testi et al. (2008) or Goldhamer (1995). Taking into account that water is a scarce resource and in future only the most efficient agricultural systems will receive inputs of irrigation water (Fereres et al., 2003), studies into optimizing pistachio deficit irrigation strategies are in progress. For example, Memmi et al. (2014) studied the pistachio response to different levels of water deficit and time of application, concluding that irrigation when kernel weight is increasing (stage III) results in a higher fruit size than when the same amount of irrigation water is distributed between stages I (rapid nut growth) and III. Moreover, these authors showed that shell hardening (stage II) starts when the fruit reaches its maximum external diameter and finishes a short time before the kernel reach its final weight, both processes being simultaneous at the end of hardening and beginning of kernel growth.

Gijón et al. (2009) showed that SDI provided at 50 and 65% of the fully irrigated trees during the growing season reduced total yield and kernel size, even though differences in kernel dry weight were unaffected. Memmi et al. (2016b) showed that RDI during stage II or postharvest does not reduce yield even though it may reduce tree vegetative growth. These authors also indicated that full irrigation and RDI in pistachio trees growing in shallow soils can be successfully scheduled using Ψ_{stem} measurements. Hence, RDI using a Ψ_{stem} threshold value of −1.5 MPa during stage II induced similar yield and production values to full irrigated trees, whereas a Ψ_{stem} threshold value of −2.0 MPa resulted in an extensive delay in the recovery of g_{leaf} values, with concomitant negative effects on long-term pistachio production. Guerrero et al. (2005) studied the recovery of pistachio water relations under RDI and concluded that in order to avoid any adverse effect of water deficit during stage III, irrigation should be increased toward the end of stage II or be clearly higher than 100% ETc from the beginning of stage III.

Pérez-López et al. (2017) showed that stages I and III are critical because water deficit reduces the quantity and quality of the yield. However, the effects of different water stress levels at each stage have not been sufficiently studied. In this sense, RDI trees (receiving 50% of the water received by control trees during stages I and II, and the same amount of water as control trees during stage III) provided a similar total yield and percentage of split nuts as full irrigated trees and did not show an alternate bearing pattern, even though they received around 20% less water (Gijón et al., 2009).

Okay and Sevin (2011a,b) studied the effect of irrigation on some pistachio fruit characteristics and concluded that differences among cultivars were more significant under non-irrigated conditions. Irrigation increased kernel weight but did not have a significant impact on shell and kernel colours (Guerrero et al., 2005). Carbonell-Barrachina et al. (2014) showed that the more severe the water stress level achieved during stage II, the harder and crunchier the resulting pistachios.

The kernel fatty acid content of pistachio is also affected by plant water status (Okay and Sevin, 2011a), the oleic acid content increasing and the linoleic acid content decreasing in fruits of well irrigated trees. In contrast, Carbonell-Barrachina et al. (2014) indicated that the fatty acid profile of pistachios is dominated by three main compounds: oleic acid (~50%), linoleic acid (~33%), and palmitic acid (~13%) and showed (Table 3) that moderate RDI during stage II significantly increased the oil content of the nuts, whereas more severe RDI reduced the oil content, inducing in both cases a significant increase in the content of linoleic acid, which is an essential fatty acid for humans. These authors also studied the effect of RDI on pistachio volatile compounds and concluded that severe RDI during stage II increased the contents of aldehydes (associated with green and vegetable notes) and reduce those of pyrazines (nut and toasted notes) and terpenes (citric notes) (Table 3).

A descriptive analysis of pistachios showed that moderate RDI during stage II leads to an intense "green pistachio" colour, accompanied by higher intensities of nutty and pistachio notes in harder, crunchier nuts with a longer aftertaste. Also, an international consumer study about the opinion of European consumers on pistachios grown under RDI indicated that the kernels resulting from moderate RDI applied during stage II obtained a higher intensities of characteristic sensory attributes and a greater level of satisfaction among international consumers than kernels from FI trees or from those exposed to severe RDI during stage II (Carbonell-Barrachina et al., 2014; Noguera-Artiaga et al., 2016).

3.4. Pomegranate (Punica granatum L.)

Pomegranate, one of the oldest known edible fruits and one of the seven kinds of fruit mentioned in the Bible, is mainly grown in semi-arid mild-temperate to subtropical climates (Blumenfeld et al., 2000). This species and *Punica protopunica* are the two species that make up the Punicaceae family. *P. granatum* is believed to be a native to the southern Caspian belt (Iran) and northern Turkey, whereas

P. protopunica is generally accepted as being endemic of the Socotra Island (Yemen) (Janick, 2007).

Pomegranate is considered to be a drought-resistant crop because it supports heat and thrives in arid and semiarid areas, even under desert conditions (Aseri et al., 2008), the mechanisms developed by this crop to confront water stress being mainly stress avoidance and stress tolerance (Rodríguez et al., 2012). More precisely, from the beginning of water deficit conditions, leaf conductance decreases in order to control water loss via transpiration and to avoid leaf turgor loss (stress avoidance mechanism) and when sever water stress levels are reached, active osmotic adjustment is triggered, contributing to the maintenance of leaf turgor (stress tolerance mechanism). Other drought tolerance characteristics commonly seen in xeromorphic plants can be also observed in pomegranate, such as a high relative apoplastic water content (42–58%), which would contribute to the retention of water at low leaf water potentials (Rodríguez et al., 2012).

Despite its good resistance to drought, pomegranate for commercial production requires regular irrigation throughout the season, especially when it is cultivated in arid and semiarid areas, to reduce the incidence of fruit physiopathies (e.g. fruit splitting) (Galindo et al., 2014b; Rodríguez et al., 2017) and to reach optimal growth, yield and fruit quality (Levin, 2006; Holland et al., 2009). In this sense, the period corresponding to the end of pomegranate fruit growth and ripening is clearly critical for the incidence of fruit splitting. Galindo et al. (2014b) showed that at very severe water deficit levels, despite leaf turgor being maintained, fruit turgor is lost inducing a reduction in fruit expansion. Then, when an important rainfall event takes place, previously water stressed pomegranate fruits are rehydrated asymmetrically because aril turgor increases to a much greater extent than peel turgor, the pressure of the arils on the peel favouring splitting.

Intrigliolo et al. (2013) estimated pomegranate evapotranspiration to be around 412–514 mm, but reports on the effect of irrigation management on pomegranate fruit yield and quality are relatively scarce. The first results indicated that it is possible to control the desired ripening time in pomegranates by applying different irrigation regimes (Sonawane and Desai, 1989). Recently, Galindo et al. (2014a) indicated that SDI applied throughout the pomegranate season to achieve pronounced water deficit levels reduces total yield per tree, the number of fruits per tree and the size of the fruits; however, such a strategy can bring forward the availability of fruits resulting from late flowerings, which, despite their smaller size, are of great interest for the pomegranate transformation industry due to their very high content of bioactive compounds. In contrast, other studies mention ambiguous results concerning the effect of SDI on the chemical characteristics of pomegranate fruit. In this sense, Mellisho et al. (2012) concluded that SDI, under moderate water stress, produced some changes in colour and chemical characteristics, which reflected earlier ripening. However, Mena et al. (2013) indicated that pomegranate juice from trees submitted to SDI regimes that produce severe water stress levels was of lower quality and less healthy than the juice from fully irrigated trees. This reduction in quality was due to the fact that the water stress levels caused a dramatic decrease in bioactive phenolic compounds, especially anthocyanins and punicalagin (Table 3); besides, the pomegranates were less attractive for consumers due to their pale red colour. On the other hand, Laribi et al. (2013) showed that pomegranates from SDI trees, submitted to mild water stress during flowering and fruit set and more severe water stress during the linear stage of fruit growth and ripening, had a redder peel and higher level of total soluble solids in the juice.

Intrigliolo et al. (2013) and Laribi et al. (2013) studied the pomegranate response to RDI involving irrigation water restrictions during different fruit stages and concluded that the period comprised by flowering and fruit set could be regarded as non-critical from the yield point of view and that irrigation water restriction during pomegranate fruit growth and ripening enhances peel redness and TSS in the juice. However, restricting the irrigation water during the linear fruit growth period increased the concentration of many bioactive compounds in the juice, such as anthocyanins, that are related to health and taste. Recently, Galindo et al. (2017) showed that a short period of irrigation restriction at the end of ripening period brings the harvest time forward, saves irrigation water, enhances the fruit bioactive compounds content (anthocyanins, phenolic compounds, punicalagin and ellagic acid) and increases the price of the fruit without affecting marketable yield and fruit size.

Studies on the response of pomegranate trees to PRD have been performed by Parvizi et al. (2014, 2016) and Parvizi and Sepaskhah (2015). These authors compared the following strategies: SDI (50% and 75% of ETc), irrigating only one side of trees (north) throughout the growing season and keeping the other side (south) of the tree dry, PRD (50% and 75% of ETc) and FI, maintaining both sides of the tree wetted. The first authors showed that both SDI strategies and PRD at 50% ETc induced a decrease in pomegranate yield, and recommended PRD (75% ETc) because, in addition to saving water, yield, intrinsic water use efficiency (WUE) and transpiration efficiency increased. As regard pomegranate fruit quality attributes, Parvizi and Sepaskhah (2015) indicated that both PRD strategies increased the pomegranate fruit juice content and maturity index and decreased the titratable acidity values compared with FI fruits, while the response of fruits to both SDI strategies was the opposite of that observed in response to PRD.

Deficit irrigation can be considered as a tool that significantly improves the postharvest performance of pomegranate. Several authors reported that the fruits resulting from SDI and RDI treatments showed better postharvest behaviour than those from FI because of retarded chilling injury incidence (Peña et al., 2013), higher sensory and nutritional quality and longer shelf life (Laribi et al., 2013; Peña et al., 2013; Peña-Estévez et al., 2016). Moreover, in a study of the effect of different irrigation treatments and the efficacy of a vapour treatment (7–10 s at 95 °C) and using NaClO as sanitizing agents on the quality and shelf life of fresh-cut pomegranate arils, Peña-Estévez et al. (2015) observed a synergistic effect of the water deficit treatment and the postharvest thermal treatment. Best results were obtained for arils from pomegranates grown on trees from which irrigation was withheld for 16 or 26 days prior to harvest, for which a shelf life of 18 days at 5 °C was established.

4. Summary, conclusions and future research needs

Bearing in mind the characteristics of the emerging crops considered in this review, it is clear that they present different mechanisms to confront water deficit situations, and that different levels of resistance are achieved. In this sense, pistachio trees can be considered the most drought resistant because they can survive under very extreme drought conditions. Their water stress resistance is based on morphological characteristics such as a very extensive root system and the development of stress avoidance and tolerance mechanisms. Pomegranate and jujube trees are also able to withstand severe drought during the growing season and the mechanisms developed by these crops to confront drought are also predominantly stress avoidance and stress tolerance mechanisms. In contrast, an entirely different strategy to confront water deficit is shown by loquat. Its (loquat) strategy can be considered as a drought escape mechanism because it is based on an atypical phenology, completely different from that of traditional Mediterranean temperate fruit crops, blooming in autumn, developing fruits during winter and ripening in early spring. So, fruit growth accounts when Mediterranean climate is wetter and evaporative demand of the atmosphere reaches minimum values, thus avoiding the effects of hot and dry summers.

The irrigation water requirements of these emerging crops were not related with the resistance to water stress. So, loquat trees pre-

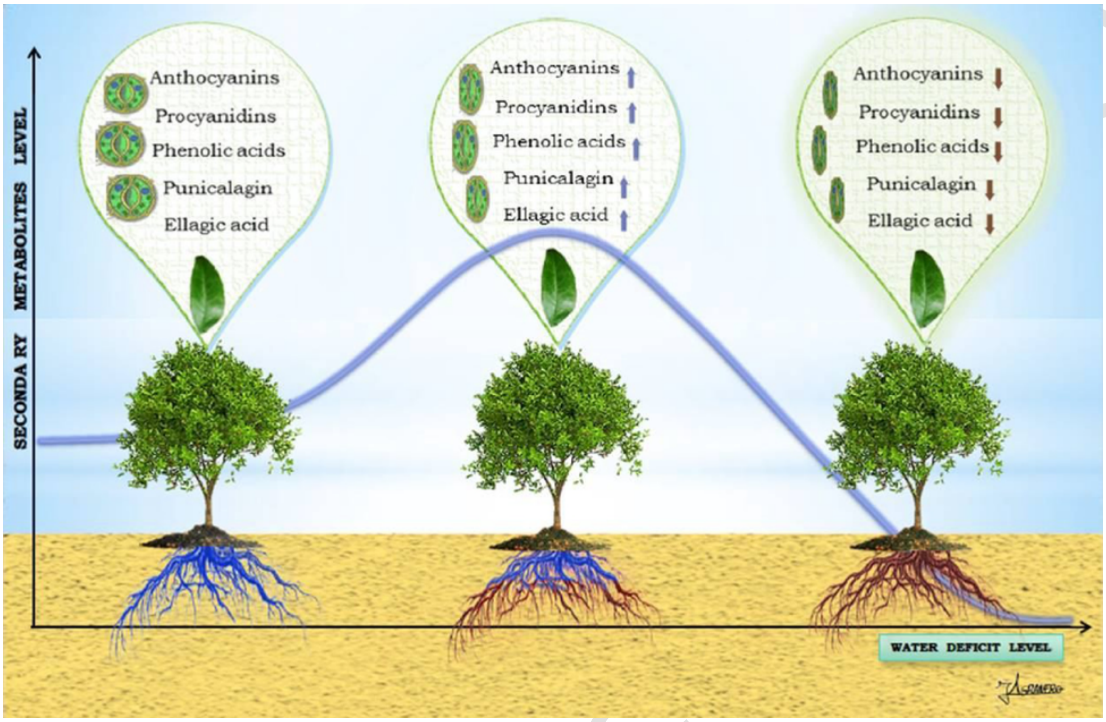

Fig. 3. Quadratic relationship between secondary metabolites content in the fruits and plant water status (quadratic line) (Horner, 1990). Under mild water deficit, stomatal regulation may leads to a reduction in plant growth, increasing concentration of nonnitrogenous secondary metabolites (central tree). When water deficit increases (right tree), CO_2 assimilation is reduced and carbon is preferentially allocated to the synthesis of primary metabolites, which do not exceeded the amount used for fruit growth to the detriment of the synthesis of carbon-based secondary metabolites. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

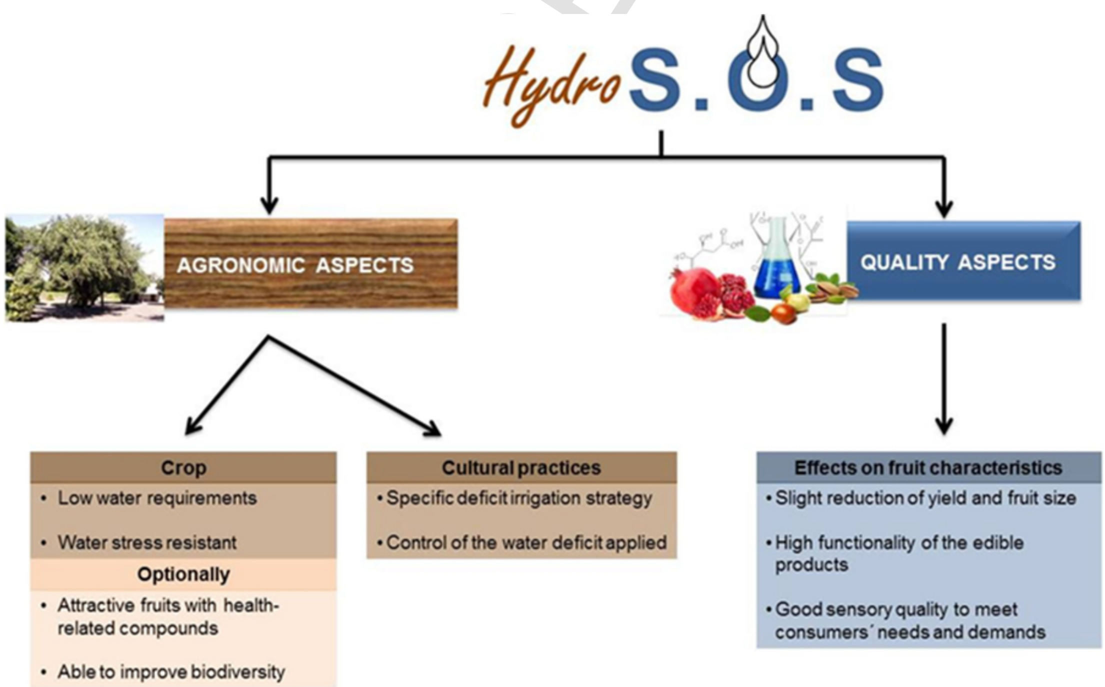

Fig. 4. Main agronomic and fruit quality aspects needed to obtain a *hydroSOS* fruit certification.

sented the highest seasonal ETc, which was slightly higher than that observed in pistachio and pomegranate trees, and clearly higher than that observed in jujube trees. It is clear that loquat can be considered an outstanding crop for its response to the continuous application of RDI, but there are good reasons to conclude that the other emerging crops studied are able to cope with water scarcity due to their positive response to DI strategies, including minimal impact on yields and improved WP.

Taking into consideration the effect of DI strategies on fruit quality and the health-related compounds they contain, it is important to underline that research needs to be directed at some very important aspects including: (i) the effect of deficit irrigation on loquat fruit quality, for which, to the best of our knowledge no information exists, and (ii) identifying the optimal water deficit level, its timing and duration for each crop in order to optimize fruit quality and their health-related compounds content. This last consideration is based on the fact that the literature in most cases suggests that fruit quality and the health-related compounds content can be improved by specific DI strategies, but fruit response to moderate and severe water deficit is not proportional in many cases. It is not possible to establish a linear correlation between water stress and some fruit characteristics, especially in the case of some secondary metabolites (Mattson and Haack, 1987; Gobbo-Neto and Lopes, 2007). In an attempt to predict the concentration of phenolic compounds as a function of water status, Horner (1990) proposed a model based on a quadratic relationship between both variables (Fig. 3). When plants are under mild osmotic stress there is a reduction in plant growth and the concentration of non-nitrogenous secondary metabolites increase. When plants are under severe water stress, strong stomatal regulation takes place and CO_2 assimilation is much reduced; carbon is preferentially allocated to the synthesis of primary metabolites, which do not exceed the amount used for fruit growth and to the detriment of the synthesis of carbon-based secondary metabolites (Fig. 3).

Bearing in mind all the previous considerations, it is evident that farmers who adopt specific DI strategies and cultivate underutilized plant species should be rewarded for (i) making sustainable use of irrigation water, (ii) improving crop biodiversity, (iii) having to accept a slight reduction in their fruit and vegetable yields, and (iv) producing fruits with higher contents of bioactive compounds. Fortunately, consumers are willing to pay for *special foods*, particularly those associated with environmental friendly farming practices that use no chemicals (Martínez-Ruiz and Gómez-Cantó, 2016) – which is the case of the fruits and vegetables grown under DI. However, consumers need to identify such products, which should be clearly labeled and displayed separate from other products of the same type, otherwise their potential will be lost in a sea of products. Very few groups have studied consumer opinion concerning DI fruits (Lopez et al., 2016; Fernandes-Silva et al., 2013), but Noguera-Artiaga et al. (2016) even proposed an identity brand to protect this type of product, which might be called *hydroSOStainable* or, in abbreviated and easier to remember form, *hydroSOS*. According to these authors, *hydroSOS* products will have a solid identity based on two main factors: (i) water deficit can increase the plant secondary metabolite content and, thus, the functionality of the edible products (Ripoll et al., 2014), and (ii) the products are environmentally friendly because of the sustainable use of a very scarce resource, water (Fig. 4).

Noguera-Artiaga et al. (2016) also found that consumers are willing to pay a reasonably higher price for *hydroSOS* pistachios, if they are properly labeled and identified. However, further research is needed to check whether this greater willingness to pay is the similar for all fruits. Finally, it is essential to establish a *hydroSOS* index to certify that the products using the *hydroSOS* logo have been evaluated for their sustainable use of irrigation water and/or their contents of bioactive compounds. This index is under construction and will be based, among other factors, on farmers and traders being able to demonstrate: (i) knowledge of the cultural practices involved, including water management during the non-critical periods, (ii) the timing, level and duration of the applied water deficit, (iii) that suitable monitoring and control of the stress applied has taken place by measuring, for example, the water potential, (v) the precise composition and contents of bioactive compounds, e.g. increased levels of proline (an amino acid used as indicator of plant water stress), and (vi) the good sensory quality of the product in question. If these rules are followed, it should be possible to ensure consumer satisfaction, strengthen their willingness to pay a reasonably higher price, and guarantee their future fidelity to these products (Fig. 4). If the index can guarantee all the above, consumer demand will increase, as will the price of *hydroSOS* products and the possible profit for farmers. Hopefully, farmers will become increasingly convinced about the economic benefits of DI and dedicate larger areas to the cultivation of even more crops.

Acknowledgments

On the occasion of the retirement of Prof. Dr. Félix Moreno (IRNAS-CSIC), the authors of this paper should like to take this opportunity to thank him for his scientific knowledge, his tireless activity and his willingness to help others during his professional career. We are also grateful to the Ministerio de Economía y Competitividad de España (MINECO) (CICYT/FEDER AGL2013-45922-C2-1-R, AGL2013-45922-C2-2-R, AGL2016-75794-C4-1-R and AGL2016-75794-C4-4-R) for grants to the authors. AG and JC-G acknowledge the postdoctoral financial support received from the Ramón Areces Fondation and the Juan de la Cierva program, respectively. Also, this work is a result of the PR internship (19925/IV/15) funded by the Fundación Séneca – Agencia de Ciencia y Tecnología de la Región de Murcia (Seneca Foundation – Agency for Science and Technology in the Region of Murcia) under the Jiménez de la Espada Program for Mobility, Cooperation and Internationalization.

References

Ahmadi, S.H., Andersen, M.N., Plauborg, F., Poulsen, R.T., Jensen, C.R., Sepaskhah, A.R., Hansen, S., 2010. Effects of irrigation strategies and soils on field grown potatoes: gas exchange and xylem [ABA]. Agric. Water Manage. 97, 1486–1494.
Ak, B.E., Agackesen, N., 2006. Some pomological fruit traits and yield of Pistacia vera grown under irrigated and unirrigated conditions. Acta Hort. 726, 165–168.
Aseri, G.K., Jain, N., Panwar, J., Rao, A.V., Meghwal, P.R., 2008. Biofertilizers improve plant growth fruit yield, nutrition, metabolism and rhizosphere enzyme activities of Pomegranate (Punica granatum L.) in Indian Thar Desert. Sci. Hortic. 117, 130–135.
Azam-Ali, S., Bonkoungou, E., Bowe, C., deKock, C., Godara, A., Williams, J.T., 2006. Ber and Other Jujubes. International Centre for Underutilised Crops, Southampton, UK, 289.
Behboudian, M.H., Walker, R.R., Törökfalvy, E., 1986. Effects of water stress and salinity on photosynthesis of pistachio. Sci. Hort. 29, 251–261.
Blumenfeld, A., Shaya, F., Hillel, R., 2000. Cultivation of Pomegranate. CIHEAM: Options Méditerranées, (http://ressources.ciheam.org/om/pdf/a42/00600264.pdf).
Boland, A.M., Jerie, P.H., Mitchell, P.D., Irvine, J.L., Nardella, N., 1996. The effect of saline and non-saline water table on peach tree water use growth, productivity and ion uptake. Aust. J. Agric. Res. 47, 121–139.
Cañete, M.L., Hueso, J.J., Pinillos, V., Cuevas, J., 2015. Ripening degree at harvest affects bruising susceptibility and fruit sensorial traits of loquat (Eriobotrya japonica Lindl.). Sci. Hortic. 187, 102–107.
Carbonell-Barrachina, A.A., Memmi, H., Noguera-Artiaga, L., Gijón-López, M.C., Ciapa, R., Pérez-López, D., 2014. Quality attributes of pistachio nuts as affected by rootstock and deficit irrigation. J. Sci. Food Agric. 95, 2866–2873.
Castel, J.R., Buj, A., 1990. Response of Salustiana oranges to high-frequency deficit irrigation. Irri. Sci. 11, 121–127.

Chalmers, D.J., Mitchell, P.D., Van Heek, L., 1981. Control of peach tree growth and productivity by regulated water supply, tree density and summer pruning. J. Amer. Soc. Hort. Sci. 106, 307–312.

Chappell, M.J., LaValle, L.A., 2011. Food security and biodiversity: can we have both? An agroecological analysis. Agric. Hum. Values 28, 3–26.

Chivenge, P., Mabhaudhi, T., Modi, A.T., Mafongoya, P., 2015. The potential role of neglected and underutilised crop species as future crops under water scarce conditions in sub-Saharan Africa. Int. J. Environ. Res. Public Health 12, 5685–5711.

Choi, S.H., Ahn, J.B., Kozukue, N., Levin, C.E., Friedman, M., 2011. Distribution of free amino acids, flavonoids, total phenolics, and antioxidative activities of jujube (Ziziphus jujuba) fruits and seeds harvested from plants grown in Korea. J. Agric. Food Chem. 59, 6594–6604.

Collado-González, J., Cruz, Z.N., Rodríguez, P., Galindo, A., Díaz-Baños, F.G., García de la Torre, J., Ferreres, F., Medina, S., Torrecillas, A., Gil-Izquierdo, A., 2013. Effect of water deficit and domestic storage on the procyanidin content, size and aggregation process in pear-jujube (*Z. jujuba*) fruits. J. Agric. Food Chem. 61, 6187–6197.

Collado-González, J., Cruz, Z.N., Medina, S., Mellisho, C.D., Rodríguez, P., Galindo, A., Egea, I., Romojaro, F., Ferreres, F., Torrecillas, A., Gil-Izquierdo, A., 2014. Effects of water deficit during maturation on amino acids and jujube fruit eating quality. Maced. J. Chem. Chem. Eng. 33, 105–119.

Collins, R., Kristensen, P., Thyssen, N., 2009. Water Resources Across Europe-Confronting Water Scarcity and Drought. European Environment Agency, Copenhague, 57.

Conejero, W., Mellisho, C.D., Ortuño, M.F., Moriana, A., Moreno, F., Torrecillas, A., 2011. Using trunk diameter sensors for regulated deficit irrigation scheduling in early maturing peach trees. Environ. Exp. Bot. 71, 409–415.

Cruz, Z.N., Rodríguez, P., Galindo, A., Torrecillas, E., Ondoño, S., Mellisho, C.D., Torrecillas, A., 2012. Leaf mechanisms for drought resistance in Zizyphus jujuba trees. Plant Sci. 197, 77–83.

Cuevas, J., Salvador-Sola, F.J., Gavilán, J., Lorente, N., Hueso, J.J., González-Padierna, C.M., 2003. Loquat fruit sink strength and growth pattern. Sci. Hortic. 98, 131–137.

Cuevas, J., Cañete, M.L., Pinillos, V., Zapata, A.J., Fernández, M.D., González, M., Hueso, J.J., 2007. Optimal dates for regulated deficit irrigation in 'Algerie' loquat (Eriobotrya japonica Lindl.) cultivated in southeast Spain. Agric. Water Manage. 89, 131–136.

Cuevas, J., Romero, I.M., Fernández, M.D., Hueso, J.J., 2007. Deficit irrigation schedules to promote early flowering in 'Algerie' loquat. Acta Hort. 750, 281–286.

Cuevas, J., Pinillos, V., Cañete, M.L., González, M., Alonso, F., Fernández, M.D., Hueso, J.J., 2009. Optimal levels of postharvest deficit irrigation for promoting early flowering and harvest dates in loquat (Eriobotrya japonica Lindl.). Agric. Water Manage. 96, 831–838.

Cuevas, J., Pinillos, V., Cañete, M.L., Parra, S., González, M., Alonso, F., Fernández, M.D., Hueso, J.J., 2012. Optimal duration of irrigation withholding to promote early bloom and harvest in 'Algerie' loquat (Eriobotrya japonica Lindl.). Agric. Water Manage. 111, 79–86.

Cui, N., Du, T., Kang, S., Li, F., Zhang, J., Wang, M., Li, Z., 2008. Regulated deficit irrigation improved fruit quality and water use efficiency of jujube trees. Agric. Water Manage. 95, 489–497.

Cui, N., Du, T., Du, T., Li, F., Tong, L., Kang, S., Wang, M., Liu, X., Li, Z., 2009. Response of vegetative growth and fruit development to regulated deficit irrigation at different growth stages of pear-jujube tree. Agric. Water Manage. 96, 1237–1246.

Dahiya et al., 1981. S.S. Dahiya, O.P. Dhankar, A.P. Khera, Studies on the effect of soil salinity levels on seed germination of ber (Ziziphus rotundifolia), Haryana J. Hortic. Sci. 10 (1981) 20–23.

Davies, W.J., Zhang, J.H., 1991. Root signals and the regulation of growth and development of plants in drying soil. Ann. Rev. Plant Physiol. Plant Mol. Biol. 42, 55–76.

Davies, W.J., Kudoyarova, G., Hartung, W., 2005. Long-distance ABA signaling and its relation to other signaling pathways in the detection of soil drying and the mediation of the plant's response to drought. J. Plant Growth Regul. 24, 285–295.

Dennis Jr., F.G., 1988. Fruit development. In: Tesar, M.B. (Ed.), Physiological Basis of Crop Growth and Development. American Society of Agronomy, Madison, pp. 265–289.

Dichio, B., Xiloyannis, C., Sofo, A., Montanaro, G., 2007. Effects of postharvest regulated deficit irrigation on carbohydrate and nitrogen partitioning, yield quality and vegetative growth of peach trees. Plant Soil 290, 127–137.

Domingo, R., Ruiz-Sánchez, M.C., Sánchez-Blanco, M.J., Torrecillas, A., 1996. Water relations, growth and yield of Fino lemon trees under regulated deficit irrigation. Irrig. Sci. 16, 115–123.

Dry, P.R., Loveys, B.R., 1998. Factors influencing grapevine vigour and the potential for control with partial rootzone drying. Aust. J. Grape Wine Res. 4, 140–148.

Dry, P.R., Loveys, B.R., Düring, H., 2000. Partial drying of the rootzone of grape: II. Changes in the pattern of root development. Vitis 39, 9–12.

Feng, J.J., Liu, Q., Wang, X.D., Chen, J.W., Ye, J.D., 2007. Characterization of a new loquat cultivar 'Ninghaibai'. Acta Hortic. 750, 117–124.

Fereres, E., Amry, B., Faci, J.M., Kamgar, A., Henderson, D.W., Resende, M., 1978. A closer look at deficit high-frequency irrigation. Calif. Agric. 32, 4–5.

Fereres, E., Goldhamer, D.A., Parsons, L.R., 2003. Irrigation water management of horticultural crops. Hortscience 38, 1036–1042.

Fernandes-Silva, A.A., Falco, V., Correia, C.M., Villalobos, F.J., 2013. Sensory analysis and volatile compounds of olive oil (cv. Cobrançosa) from different irrigation regimes. Grasas Aceites 64, 59–67.

Fernandez, J.E., Cuevas, M.V., 2010. Irrigation scheduling from stem diameter variations: a review. Agric. For. Meteorol. 150, 135–151.

Fernandez, J.E., Torrecillas, A., 2012. For a better use and distribution of water. An introduction. Agric. Water Manage. 114, 1–3.

Ferreres, F., Gomes, D., Valentão, P., Gonçalves, R., Pio, R., Chagas, E.A., Seabra, R.M., Andrade, P.B., 2009. Improved loquat (Eriobotrya japonica Lindl.) cultivars: variation of phenolics and antioxidative potential. Food Chem. 114, 1019–1027.

Galindo, A., Calín-Sánchez, , Collado-González, J., Ondoño, S., Hernández, F., Torrecillas, A., Carbonell-Barrachina, Á.A., 2014. Phytochemical and quality attributes of pomegranate fruits for juice consumption as affected by ripening stage and deficit irrigation. J. Sci. Food Agric. 94, 2259–2265.

Galindo, A., Rodríguez, P., Collado-González, J., Cruz, Z.N., Torrecillas, E., Ondoño, S., Corell, M., Moriana, A., Torrecillas, A., 2014. Rainfall intensifies fruit peel cracking in water stressed pomegranatetrees. Agric. Forest Meteorol. 194, 29–35.

Galindo, A., Cruz, Z.N., Rodríguez, P., Collado-González, J., Memmi, H., Moriana, A., Torrecillas, A., López-Pérez, D., 2016. Jujube fruit water relations at fruit maturation in response to water deficits. Agric. Water Manage. 164, 110–117.

Galindo, A., Calín-Sánchez, A., Rodríguez, P., Cruz, Z.N., Girón, I.F., Corell, M., Martínez-Font, R., Moriana, A., Carbonell-Barrachina, A.A., Torrecillas, A., Hernández, F., 2017. Water stress at the end of pomegranate fruit ripening produces earlier harvesting and improves fruit quality. Sci. Hortic.(https://doi.org/10.1016/j.scienta.2017.08.029).

Gao, Q.H., Yu, J.G., Wu, C.S., Wang, Z.S., Wang, Y.K., Zhu, D.L., Wang, M., 2014. Comparison of drip, pipe and surge spring root irrigation for jujube (Ziziphus jujuba Mill.) fruit quality in the loess plateau of China. PLoS One 9, e88912. https://doi.org/10.1371/journal.pone.0088912.

García-Legaz, M.F., López Gómez, E., Mataix Beneyto, J., Torrecillas, A., Sánchez-Blanco, M.J., 2005. Effects of sallnity and rootstock on growth, water relations, nutrition and gas exchange of loquat. J. Hort. Sci. Biotechnol. 80, 199–203.

García-Orellana, Y., Ruiz-Sánchez, M.C., Alarcón, J.J., Conejero, W., Ortuño, M.F., Nicolás, E., Torrecillas, A., 2007. Preliminary assessment of the feasibility of using maximum daily trunk shrinkage for irrigation scheduling in lemon trees. Agric. Water Manage. 89, 167–171.

García-Tejero, I.F., Durán-Zuazo, V.H., Muriel-Fernández, J.L., 2014. Towards sustainable irrigated Mediterranean agriculture: implications for water conservation in semi-arid environments. Water Int. 39, 635–648.

García-Tejero, I.F., Moriana, A., Rodríguez-Pleguezuelo, C.R., Durán-Zuazo, V.H., Egea, G., 2017. Sustainable deficit-irrigation management in almonds (*Prunus dulcis* L.): different strategies to assess the crop-water status. In: García-Tejero, I.F., Durán, V.H. (Eds.), Water Scarcity and Sustainable Agriculture in Semiarid Environment: Tools, Strategies and Challenges for Woody Crops. Elsevier, (in press).

Geerts, S., Raes, D., 2009. Deficit irrigation as an on farm strategy to maximize crop water productivity in dry areas. Agric. Water Manage. 96, 1275–1284.

Germana, C., 1997. The response of pistachio trees to water stress as affected by two different rootstocks. Acta Hortic. 449, 513–519.

Gijón M.C., Guerrero J., Couceiro J.F., and Moriana A., Deficit irrigation without reducing yield or nut splitting in pistachio (Pistacea vera cv Kerman on Pistacia terebinthus L.), Agric. Water Manage. 96 (2009) 12–22.

Gijón, M.C., Giménez, C., Pérez, D., Guerrero, J., Couceiro, J.F., Moriana, A., 2010. Rootstock influences the response of pistachio (Pistacia vera L. cv Kerman) to water stress and rehydration. Sci. Hortic. 125, 666–671.

Gijón, M.C., Giménez, C., Pérez-López, D., Guerrero, J., Couceiro, J.F., Moriana, A., 2011. Water relations of pistachio (Pistacia vera L.) as affected by phenological stagesand water regimes. Sci. Hortic. 128, 415–422.

Ginestar, C., Castel, J.R., 1996. Response of young 'Clementine' in citrus trees to water stress during different phenological periods. J. Hortic. Sci. 71, 551–559.

Girón, I.F., Corell, M., Martin-Palomo, M.J., Galindo, A., Torrecillas, A., Moreno, F., Moriana, A., 2015. Feasibility of trunk diameter fluctuations in the scheduling of regulated deficit irrigation for table olive trees without reference trees. Agric. Water Manage. 161, 114–126.

Girona, J., Mata, M., Goldhammer, D.A., Johnson, R.S., DeJong, T.M., 1993. Patterns of soil and tree water status and leaf functioning during regulated deficit irrigation scheduling in peach. J. Am. Soc. Hortic. Sci. 118, 580–586.

Gobbo-Neto, L., Lopes, N.P., 2007. Plantas medicinais: factores de influencia no conteúdo de metabólitos secundários. Quím. Nova 30, 374–381.

Goldhamer D.A., Smith T., Single season drought irrigation strategies influence almond production, Calif. Agric. 49 (1995) 19–22.
Goldhamer, D.A., Viveros, M., 2000. Effects of preharvest irrigation cutoff durations and postharvest water deprivation on almond tree performance. Irri. Sci. 19, 125–131.
Goldhamer, D.A., 1995. Irrigation management. In: Ferguson, L. (Ed.), Pistachio Production Manual. Center for Fruit and Nut Research and Information, University of California, Davis, pp. 71–81.
Goodwin, I., Boland, A.M., 2002. Scheduling deficit irrigation of fruit trees for optimizing water use efficiency. Deficit Irrigation Practices. Water Reports Publication n. 22. FAO, Rome, 67–79.
Grimes, D.W., Walhood, V.T., Dickens, W.L., 1968. Alternate-furrow irrigation for San Joaquin valley cotton. Calif. Agric. 22, 4–6.
Guerrero, J., Moriana, A., Pérez-López, D., Couceiro, J.F., Olmedilla, N., Gijón, M.C., 2005. Regulated deficit irrigation and the recovery of water relations in pistachio trees. Tree Physiol. 26, 87–92.
He, Q., Li, X.W., Liang, G.L., Ji, K., Guo, Q.G., Yuan, W.M., Zhou, G.Z., Chen, K.S., Weg, W.E., Gao, Z.S., 2011. Genetic diversity and identity of Chinese loquat cultivars/accessions (Eriobotrya japonica) using apple SSR markers. Plant Mol. Biol. Rep. 29, 197–208.
Hernández, F., Legua, P., Melgarejo, P., Martínez, R., Martínez, J.J., 2015. Phenological growth stages of jujube tree (Ziziphus jujube): codification and description according to the BBCH scale. Ann. Appl. Biol. 166, 136–142.
Holland, D., Hatib, K., Bar-Yàakov, I., 2009. Pomegranate: botany, horticulture, breeding. Hortic. Rev. 35, 127–191.
Horner, J.D., 1990. Nonlinear effects of water deficits on foliar tannin concentration. Biochem. Syst. Ecol. 18, 211–213.
Hueso, J.J., Cuevas, J., 2008. Loquat as a crop model for successful deficit irrigation. Irrig. Sci. 26, 269–276.
Intrigliolo, D.S., Bonet, L., Nortes, P.A., Puerto, H., Nicolás, E., Bartual, J., 2013. Pomegranate trees performance under sustained and regulated deficit irrigation. Irri. Sci. 31, 959–970.
Janick, J., 2007. Fruits of the bibles. HortScience 42, 1072–1076.
Johnson, S.R., Handley, D.F., DeJong, T.M., 1992. Long-term response of early maturing peach trees to postharvest water deficits. J. Am. Soc. Hortic. Sci. 117, 881–886.
Jones, H.G., 2004. Irrigation Scheduling: advantages and pitfalls of plant based methods. J. Exp. Bot. 55, 2427–2436.
Kaman, H., Kirda, C., Cetin, M., Topcu, S., 2006. Salt accumulation in the root zones of tomato and cotton irrigated with partial root-drying technique. Irrig. Drain. 55, 533–544.
Kanber, R., Yazar, A., Önder, S., Köksal, H., 1993. Irrigation response of pistachio (Pistacia vera L.). Irrig. Sci. 14, 7–14.
Kang, S., Zhang, J., 2004. Controlled alternate partial root-zone irrigation: its physiological consequences and impact on water use efficiency. J. Exp. Bot. 55, 2437–2446.
Katerji, N., Mastrorilli, M., Rana, G., 2008. Water use efficiency of crops cultivated in the Mediterranean region. Review and analysis. Eur. J. Agron. 28, 493–507.
Kermani, M.M., Salehi, F., 2006. Determination of pistachio crop evapotranspiratation (ETc). Acta Hort. 726, 441–447.
Kijne, J.W., Barker, R., Molden, D., 2003. Improving water productivity in agriculture: editor's overview. In: Kijne, J.W., Barker, R.M.D. (Eds.), Water Productivity in Agriculture: Limits and Opportunities for Improvement. International Water Management Institute, Colombo, Sri Lanka, pp. xi–xix.
Kriedmann, P.E., Goodwin, I., 2003. Regulated deficit irrigation and partial rootzone drying. Irrigation Insights No. 4. Land and Water Australia, Canberra, 102.
Laribi, A.I., Palou, L., Intringliolo, D.S., Nortes, P.A., Rojas-Argudo, C., Taberner, V., Bartual, J., Pérez-Gago, M.B., 2013. Effect of sustained and regulated deficit irrigation on fruit quality of pomegranate cv. 'Mollar de Elche' at harvest and during cold storage. Agric. Water Manage. 125, 61–70.
Levin, G.M., 2006. In: In: Bare, B.L. (Ed.), Pomegranate Roads: A Soviet Botanist's Exile from Eden, vol 1, Floreat Press, Forestville, pp. 5–183.
Lin, T.S., Crane, C.J., Ryugo, K., Polito, V.S., DeJong, T.M., 1984. Comparative study of leaf morphology, photosynthesis, and leaf conductance in selected Pistachia species. J. Am. Soc. Hortic. Sci. 109, 325–330.
Liu, F., Shahanzari, A., Andersen, M.A., Jacobsen, S.-E., Jensen, C.R., 2006. Effects of deficit irrigation (DI) and partial root drying (PRD) on gas exchange biomass partioning, and water use efficiency in potato. Sci. Hortic. 109, 113–117.
Liu, F., Shahnazari, A., Andersen, M.N., Jacobsen, S.E., Jensen, C.R., 2006. Physiological responses of potato (Solanum tuberosum L.) to partial root-zone drying: ABA signaling leaf gas exchange, and water use efficiency. J. Exp. Bot. 57, 3727–3735.
Liu, F., Song, R., Zhang, X., Shahnazari, A., Andersen, M.N., Plauborg, F., Jacobsen, S.E., Jensen, C.R., 2008. Measurement and modeling of ABA signaling in potato (Solanum tuberosum L.) during partial root-zone drying. Environ. Exp. Bot. 63, 385–391.
Lopez, G., Echeverria, G., Bellvert, J., Mata, M., Behboudian, M.H., Girona, J., Marsal, J., 2016. Water stress for a short period before harvest in nectarine Yield, fruit composition, sensory quality, and consumer acceptance of fruit. Sci. Hortic. 211, 1–7.
Luo, H.J., Zheng, Z.B., Luo, S., Pan, Y.S., Liu, X.H., 2007. Changes in leaf characters of loquat under repeated drought stresses. Acta Hort. 750, 417–422.
Ma, F., Kang, S., Li, F., Zhang, J., Du, T., Hu, X., Wang, M., 2007. Effect of water deficit in different growth stages on stem sap flux of greenhouse grown pear-jujube tree. Agric. Water Manage. 90, 190–196.
Martínez-Ruiz, M.P., Gómez-Cantó, C.M., 2016. Key external influences affecting consumersí decision regarding food. Front. Psychol. 7, (article 1618).
Mattson, W.J., Haack, R.A., 1987. The role of drought in outbreaks of plant-eating insects. Bioscience 37, 110–118.
McCarthy, M.G., Loveys, B.R., Dry, P.R., 2002. Regulated deficit irrigation and partial rootzone drying as irrigation management techniques for grapevines. Deficit Irrigation Practices. Water Reports Publication n. 22. FAO, Rome, 79–87.
Melgarejo, P., Martínez-Valero, R., Guillamón, J.M., Miró, M., Amorós, A., 1997. Phenological stages of the pomegranate tree (Punica granatum L.). Ann. Appl. Biol. 130, 135–140.
Mellisho, C.D., Egea, I., Galindo, A., Conejero, W., Rodríguez, P., Rodríguez, J., Romojaro, F., Torrecillas, A., 2012. Pomegranate (Punica granatum L.) fruit response to different deficit irrigation conditions. Agric. Water Manage. 114, 30–36.
Memmi, H., Gijón, M.C., Guerrero, J., Couceiro, J.F., Pérez-López, D., 2014. Characterization of pistachio fruit growth stages as a base for irrigation scheduling. Acta Hortic. 1028, 381–384.
Memmi, H., Couceiro, J.F., Gijón, M.C., Pérez-López, D., 2016. Impacts of water stress, environment and rootstock on the diurnal behaviour of stem water potential and leaf conductance in pistachio (Pistacia vera L.). Span. J. Agric. Res. 14 (2), 0804. https://doi.org/10.5424/sjar/2016142-82077.
Memmi, H., Gijón, M.C., Couceiro, J.F., Pérez-López, D., 2016. Water stress thresholds for regulated deficit irrigation in pistachio trees: rootstock influence and effects on yield quality. Agric. Water Manage. 164, 58–72.
Mena, P., Galindo, A., Collado-González, J., Ondoño, S., García-Viguera, C., Ferreres, F., Torrecillas, A., Gil-Izquierdo, A., 2013. Sustained deficit irrigation affects the colour and phytochemical characteristics of pomegranate juice. J. Sci. Food Agric. 93, 1922–1927.
Ming, W., Sun, Y., 1986. Fruit trees and vegetables for arid and semi-arid areas in northwest China. J. Arid Environ. 11, 3–16.
Mitchell, P.D., Chalmers, D.J., 1982. The effect of reduced water supply on peach tree growth and yields. J. Am. Soc. Hortic. Sci. 107, 853–856.
Monastra, F., Avanzato, D., Martelli, S., D'Ascanio, R., 1998. Irrigation of pistachio in Italy: ten years of observation. Acta Hortic. 470, 516–522.
Moriana, A., Corell, M., Girón, I.F., Conejero, W., Morales, D., Torrecillas, A., Moreno, F., 2013. Regulated deficit irrigation based on threshold values of trunk diameter fluctuation indicators in table olive trees. Sci. Hortic. 164, 102–111.
Noguera-Artiaga, L., Lipan, L., Vázquez-Aráujo, L., Barber, X., Pérez-López, D., Carbonell-Barrachina, A.A., 2016. Opinion of Spanish consumers on hydrosustainable pistachios. J. Food Sci. 81, 2559–2565.
Okay, Y., Sevin, M., 2011. The effect of irrigation on protein, fat and fatty acids amounts in pistachio. Acta Hort. 912, 211–216.
Okay, Y., Sevin, M., 2011. The effect of irrigation on some fruit characteristics in pistachio. Acta Hortic. 912, 691–698.
Ortuño, M.F., Brito, J.J., Conejero, W., García-Orellana, Y., Torrecillas, A., 2009. Using continuously recorded trunk diameter fluctuations for estimating water requirements of lemon trees. Irrig. Sci. 27, 271–276.
Ortuño, M.F., Conejero, W., Moreno, F., Moriana, A., Intrigliolo, D.S., Biel, C., Mellisho, C.D., Pérez-Pastor, A., Domingo, R., Ruiz-Sánchez, M.C., Casadesus, J., Bonany, J., Torrecillas, A., 2010. Could trunk diameter sensors be used in woody crops for irrigation scheduling? A review of current knowledge and future perspectives. Agric. Water Manage. 97, 1–11.
Pérez-López, D., Memmi, H., Gijón-López, M.C., Moreno, M.M., Couceiro, J.F., Centeno, A., Martín-Palomo, M.J., Corell, M., Noguera, L., Galindo, A., Torrecillas, A., Moriana, A., 2017. Irrigation of pistachio; strategies under water scarcity. In: García-Tejero, I.F., Durán, V.H. (Eds.), Water Scarcity and Sustainable Agriculture in Semiarid Environment: Tools, Strategies and Challenges for Woody Crops. Elsevier, (in press).
Padulosi, S., Hodgkin, T., Williams, J.T., Haq, N., 2001. Underutilized crops: trends, challenges and opportunities in the 21st century. In: Engels, J.M.M., Ramanatha Rao, V., Brown, A.H.D., Jackson, M.T. (Eds.), Managing Plant Genetic Diversity. Bioversity International, Maccarese, Italy, pp. 323–338.
Parvizi, H., Sepaskhah, A.R., 2015. Effect of drip irrigation and fertilizer regimes on fruit quality of a pomegranate (Punica granatum (L.) cv. Rabab) orchard. Agric. Water Manage. 156, 70–78.
Parvizi, H., Sepaskhah, A.R., Ahmadi, S.H., 2014. Effect of drip irrigation and fertilizer regimes on fruit yields and water productivity of a pomegranate (Punica granatum (L.) cv Rabab) orchard. Agric. Water Manage. 146, 45–56.

Parvizi, H., Sepaskhah, A.R., Ahmadi, S.H., 2016. Physiological and growth responses of pomegranate tree (Punica granatum (L.) cv. Rabab) under partial root zone drying and deficit irrigation regimes. Agric. Water Manage. 163, 146–158.

Peña, M.E., Artés-Hernández, F., Aguayo, E., Martínez-Hernández, G.B., Galindo, A., Artés, F., Gómez, P.A., 2013. Effect of sustained deficit irrigation on physicochemical properties, bioactive compounds and postharvest life of pomegranate fruit (cv. 'Mollar de Elche'). Postharvest Biol. Technol. 86, 171–180.

Peña-Estévez, M.E., Gómez, P.A., Artés, F., Aguayo, E., Martínez-Hernández, G.B., Otón, M., Galindo, A., Artés-Hernández, F., 2015. Quality changes of fresh-cut pomegranate arils during shelf life as affected by deficit irrigation and postharvest vapour treatments. J. Sci. Food Agric. 95, 2325–2336.

Peña-Estévez, M.E., Artés-Hernández, F., Artés, F., Aguayo, E., Martínez-Hernández, G.B., Galindo, A., Gómez, P.A., 2016. Quality changes of pomegranate arils throughout shelf life affected by deficit irrigation and pre-processing storage. Food Chem. 209, 302–311.

Pinillos, V., Cañete, M.L., Sánchez, R., Cuevas, J., Hueso, J.J., 2007. Fruit development and maturation phenological stages of 'Algerie' loquat. Acta Hortic. 750, 331–336.

Pinillos, V., Hueso, J.J., Marcon-Filho, J.L., Cuevas, J., 2011. Changes in fruit maturity indices along the harvest season in 'Algerie' loquat. Sci. Hortic. 129, 769–776.

Potter, D., Eriksson, T., Evans, R.C., Oh, S., Smedmark, J.E.E., Morgan, D.R., Kerr, M., Robertson, K.R., Arsenault, M., Dickinson, T.A., Campbell, C.S., 2007. Phylogeny and classification of Rosaceae. Plant Syst. Evol. 266, 5–43.

Ripoll, J., Urban, L., Staudt, M., Lopez-Lauri, F., Bidel, L.P.R., Bertin, N., 2014. Water shortage and quality of fleshy fruits-making the most of the unavoidable. J. Exp. Bot. 65, 4097–4117.

Rodríguez, M.C., Hueso, J.J., Cuevas, J., 2007. Flowering development in 'Algerie' loquat under scanning electron microscopy. Acta Hortic. 750, 337–342.

Rodríguez, P., Mellisho, C.D., Conejero, W., Cruz, Z.N., Ortuño, M.F., Galindo, A., Torrecillas, A., 2012. Plant water relations of leaves of pomegranate trees under different irrigation conditions. Environ. Exp. Bot. 77, 19–24.

Rodríguez, P., Galindo, A., Collado-González, J., Medina, S., Corell, M., Memmi, H., Girón, I.F., Centeno, A., Martín-Palomo, M.J., Cruz, Z.N., Carbonell-Barrachina, A.A., Hernandez, F., Torrecillas, A., Moriana, A., Pérez-López, D., 2017. Fruit response to water-scarcity scenarios. Water relations and biochemical changes. In: García-Tejero, I.F., Durán, V.H. (Eds.), Water Scarcity and Sustainable Agriculture in Semiarid Environment: Tools, Strategies and Challenges for Woody Crops. Elsevier, (in press).

Ruiz-Sánchez, M.C., Egea, J., Galego, R., Torrecillas, A., 1999. Floral biology of 'Búlida' apricot trees subjected to postharvest drought stress. Ann. Appl. Biol. 135, 523–528.

Saeed, H., Grove, I.G., Kettlewell, P.S., Hall, N.W., 2008. Potential of partial root zone drying as an alternative irrigation technique for potatoes (Solanum tuberosum). Ann. Appl. Bot. 152, 71–80.

Samadi, A., Sepaskhah, A.R., 1984. Effects of alternate furrow irrigation on yield and water use efficiency of dry beans. Iran Agric. Res. 3, 95–115.

Sedaghati, N., Alipour, H., 2006. The effect of different time of irrigation on occurrence of early split (ES) of pistachio nuts. Acta Hortic. 726, 583–586.

Sepaskhah, A.R., Ahmadi, S.H., 2010. A review on partial root-zone drying irrigation. Int. J. Plant Prod. 4, 241–258.

Shackel, K.A., Ahmadi, H., Biasi, W., Buchner, R., Goldhamer, D., Gurusinghe, S., Hasey, J., Kester, D., Krueger, B., Lampinen, B., McGourty, G., Micke, W., Mitcham, E., Olson, B., Pelletrau, K., Philips, H., Ramos, D., Schwankl, L., Sibbett, S., Snyder, R., Soutwick, S., Stevenson, M., Thorpe, M., Weinbaum, S., Yeager, J., 1997. Plant water status as an index of irrigation need in deciduous fruit trees. HortTechnology 7, 23–29.

Sonawane, P.C., Desai, U.T., 1989. Performance of staggered cropping in pomegranate. J. Maharashtra Agric. Univ. 14, 341–342.

Spiegel-Roy, P., Mazigh, D., Evenari, M., 1977. Response of pistachio to low soil moisture conditions. J. Am. Soc. Hortic. Sci. 102, 470–473.

Stellfeldt, A., Cuevas, J., Hueso, J.J., 2011. Gas exchange in 'Algerie' loquat during its annual cycle in the Mediterranean basin. Acta Hortic. 887, 233–237.

Stoll, M., Loveys, B.R., Dry, P., 2000. Hormonal changes induced by partial root zone drying of irrigated grapevine. J. Exp. Bot. 51, 1627–1634.

Testi, L., Goldhamer, D.A., Iniesta, F., Salinas, M., 2008. Crop water stress index is a sensitive water stress indicator in pistachio trees. Irrig. Sci. 26, 395–405.

Toledo, , Burlingame, B., 2006. Biodiversity and nutrition: a common path toward global food security and sustainable development. J. Food Compos. Anal. 19, 477–483.

Torrecillas, A., Domingo, R., Galego, R., Ruiz-Sánchez, M.C., 2000. Apricot tree response to withholding irrigation at different phenological periods. Sci. Hortic. 85, 201–215.

Ünlü, M., Kanber, R., Senyigit, U., Onaran, H., Diker, K., 2006. Trickle and sprinkler irrigation of potato (Solanum tuberosum L.) in the middle Anatolian region in Turkey. Agr. Water Manage. 79, 43–71.

Uriu, K., 1964. Effect of post-harvest soil moisture depletion on subsequent yield of apricot. Proc. Am. Soc. Hortic. Sci. 84, 93–97.

Wakrim, R., Wahbi, S., Tahi, H., Aganchich, B., Serraj, R., 2005. Comparative effects of partial root drying (PRD) and regulated deficit irrigation (RDI) on water relations and water use efficiency in common bean (Phaseolus vulgaris L.). Agric. Ecosys. Environ. 106, 275–287.

Wilkinson, S., Hartung, W., 2009. Food production: reducing water consumption by manipulating long-distance chemical signalling in plants. J. Exp. Bot. 60, 1885–1891.

Zegbe, J.A., Behboudian, M.H., Clothier, B.E., 2006. Responses of 'Petopride' processing tomato to partial rootzone drying at different phenological stages. Irrig. Sci. 24, 203–210.

Zhang, Y., Yao, Q., Li, J., Wang, Y., Liu, X., Hu, Y., Chen, J., 2015. Contributions of an arbuscular mycorrhizal fungus to growth and physiology of loquat (Eriobotrya japonica) plants subjected to drought stress. Mycol. Prog. 14, 84–95.

Zhang, H., 2003. Improving water productivity through deficit irrigation: examples from Syria, the north China Plain and Oregon, USA. In: Kijne, J.W., Barker, R., Molden, D. (Eds.), Water Productivity in Agriculture: Limits and Opportunities for Improvement. CABI publishing, p. 332.