Instituto Nacional de Investigación y Tecnología Agraria y Alimentaria (INIA)
Available online at www.inia.es/sjar

Spanish Journal of Agricultural Research 2010 8(S2), S5-S20
ISSN: 1695-971-X
eISSN: 2171-9292

Review. Deficit irrigation in fruit trees and vines in Spain

M. C. Ruiz-Sanchez[1,2]*, R. Domingo[2,3] and J. R. Castel[4]

[1] *Departamento de Riego. Centro de Edafología y Biología Aplicada del Segura (CEBAS-CSIC). P.O. Box 164. 30100 Espinardo (Murcia). Spain*
[2] *Unidad Asociada al CSIC de Horticultura Sostenible en Zonas Áridas (UPCT-CEBAS). Paseo Alfonso XIII, 48. 30203 Cartagena (Murcia). Spain*
[3] *Departamento de Producción Vegetal. ETSIA. Universidad Politécnica de Cartagena (UPCT). Paseo Alfonso XIII, 48. 30203 Cartagena (Murcia). Spain*
[4] *Departamento de Recursos Naturales. Instituto Valenciano de Investigaciones Agrarias (IVIA). Apartado oficial. 46113 Moncada (Valencia). Spain*

Abstract

Water has become the most precious of natural resources in many areas of Spain and, since agriculture is the major consumer of water, improvements in water use efficiency are increasingly sought. Regulated deficit irrigation (RDI) is an irrigation strategy based on applying only a fraction of the plant water requirements during certain periods of plant development. The paper reviews the available information on RDI strategies, in woody tree crops and vines based on studies by Spanish research groups. Both the promising results obtained and the drawbacks are covered.

Additional key words: fruit quality; vegetative and fruit growth; water deficit; water relations; yield.

Resumen

Revisión. Riego deficitario en frutales y vid en España

El agua se ha convertido en el más preciado de los recursos naturales en muchas zonas de España y, dado que la agricultura es el principal consumidor, es prioritario mejorar la eficiencia de uso del agua en la agricultura de regadío. El riego deficitario controlado (RDC) es una estrategia de riego que se basa en aplicar tan sólo una fracción de los requerimientos hídricos del cultivo durante determinados períodos del ciclo vegetativo. En este trabajo se presenta la información disponible sobre diferentes estrategias de RDC aplicadas en cultivos leñosos y vid, basada en estudios realizados por grupos de investigación españoles. Se discuten las ventajas y desventajas así como los prometedores resultados obtenidos.

Palabras clave adicionales: crecimiento vegetativo y del fruto; déficit hídrico; producción y calidad de la cosecha; relaciones hídricas.

Introduction

Irrigated agriculture (IA) is the major user of water in Spain, and it is estimated that 75% of the water resources allocated to the various users sections is utilized by IA (Libro Blanco del Agua en España, 2000). As water resources become increasingly scarce, due to a combination of increased demands, periodic droughts, and the difficulties involved in developing new supplies, IA is shifting the paradigm of irrigation management from the full to the partial supply of water needs. Water scarcity in irrigation demands the improvement of water productivity (WP) as a critical goal. One of the most promising techniques that would help attain this objective is the use of Regulated Deficit Irrigation (RDI). Past research has revealed the potential of this technique

* Corresponding author: mcruiz@cebas.csic.es
Received: 31-05-10; Accepted: 29-09-10.

Abbreviations used: CN (Clementina de Nules), DI (deficit irrigation), ET (evapotranspiration), IA (irrigated agriculture), NLL (Navel Lane Late), PRDI (partial root drying irrigation), RDI (regulated deficit irrigation), RDIS (regulated deficit irrigation subsurface), SDI (sustained deficit irrigation), SSC (soluble solids content), T (transpiration), TA (titratable acidity), WP (water productivity), WUE (water use efficiency).

as a way of reducing water use in tree crops and vines with little or no impact on yield and fruit quality. RDI is mainly designed to restrict water when the sensitivity of plant to water stress is the minimum. RDI strategies can also be applied when the available water is insufficient to optimize maximum yields.

In this paper the information existing on RDI strategies in tree crops and vines is reviewed, with special emphasis on studies referring to the Spanish Horticulture. First, the concept of deficit irrigation (DI) and related strategies: regulated (RDI), sustained (SDI) and partial root drying (PRD) are defined. Then, the effects of water deficits on the main physiological plant processes (water relations, vegetative and fruit growth, yield and fruit quality) are described. Finally, the research on plant responses to RDI, with special reference to water savings and yield, is reviewed. Both its promising results and drawbacks are covered.

The concept of deficit irrigation

Deficit irrigation (DI) is a watering strategy proposed many years ago to improve water productivity and reduce the irrigation application. In a broad sense, quoting English and Raja (1996), DI consists of the deliberate and systematic under-irrigation of crops. In other words, the amount of water applied is lower than that needed to satisfy the full crop water requirements. It is well known that reductions in the water applied usually lowers evapotranspiration (ET) and crop growth rates by limiting their principal component, transpiration (T) and, as a consequence, carbon assimilation. For this reason, it is of great interest to know the maximal reduction in ET compatible with obtaining benefits similar or even higher to those obtained when crop evapotranspiration (ET_c) is fully satisfied in mature fruit trees. In young plantations, on the other hand, the main objective is to maximise growth so that trees can mature as fast as possible, which implies the avoidance of even mild water deficits. The correct application of DI requires a thorough understanding of the tree responses to water deficits and of the economic impact of reductions in crop value. The potential benefits of DI, therefore, will come from: i) increased water use efficiency (WUE), ii) reduced irrigation and production costs, and iii) the opportunity cost of water.

Nowadays, DI is a common practice in many areas of the world, especially in dry regions. In these regions it can be more profitable for a farmer to maximize crop water productivity than to maximize the harvest per unit land. The saved water can be used for other purposes or to irrigate extra units of land.

Crop water productivity (WP) is a key term in the evaluation of DI strategies and was defined by Geerts and Raes (2009) as the ratio of the mass of marketable yield (Y_a) to the volume of water consumed by the crop (ET_a):

$$WP\ (kg\ m^{-3}) = Y_a/ET_a$$

When the water supply cannot be guaranteed or its onsite availability depends on external factors —random or unpredictable— such as droughts or political decisions taken at local or national level, as occurs in many arid zones of the planet, the DI is referred to as «uncontrolled». But when the water supply is continuous because water is stored in private ponds or collective reservoirs, it is possible to apply one of the following DI strategies: regulated deficit irrigation, RDI (Chalmers *et al.,* 1981); partial root-zone drying, PRD (Dry *et al.,* 1996); or even sustained deficit irrigation, SDI (Goldhamer *et al*., 2006), the latter based on distributing the water deficit uniformly over the whole crop cycle to avoid the occurrence of sever water stress at any particular moment, which might have unfortunate results.

Regulated deficit irrigation

RDI is an irrigation strategy developed in Australia in peach and pear orchards founded on the use of water stress to control growth and vegetative-fruit competition (Chalmers *et al.,* 1981; Mitchell and Chalmers, 1982). This strategy has a more physiological focus than DI. It looks at both the phenology of the crop and its capacity to resist water stress situations. It accepts that detrimental effects of water stress may have greater or lesser consequences as a function of the phenological moment when it is applied, its intensity and duration.

RDI consists of applying water in quantities below those necessary to satisfy ET_c during certain periods of the crop cycle when production and crop quality are hardly affected, and in the application of all the water needed during the rest of the cycle, especially at critical periods of the cycle when the yield and/or quality would be most affected by a lack of water.

RDI is normally applied during stages of the cycle when reproductive growth is relatively slow and when vegetative growth and other plant processes may be affected, such effects frequently being translated into improved fruit quality.

Partial rootzone drying

This technique consists of maintaining approximately half of the root system sufficiently watered while the other part is allowed to dry. For this, both halves are watered alternately every so often (Dry and Loveys, 1998). In several species, it has been observed that when part of the root system is in the process of drying, a root-shoot signaling mechanism is triggered; these signals molecules are transported via the xylem to the leaves, where they are translated into partial stomatal closure (Dodd, 2005; Egea, 2008). Such stomatal regulation reduces water loss through transpiration with little effect on photosynthesis, thus increasing transpiration efficiency, that is the dry matter produced per unit of water transpired (Dry *et al.*, 1996; Stoll *et al.*, 2000). Several studies pointed to the involvement of abscisic acid (ABA) in the control of stomatal conductance when the soil is dry (Dodd, 2005). At the same time, the part of the root system receiving water that represents the equivalent of 50% of the irrigation water requirements maintains a suitable water balance in the areal part of the plant (Dry and Loveys, 1999). Besides increased transpiration efficiency another effect observed with PRD is the limitation of vegetative growth (Egea, 2008). Recent studies seem to confirm the viability of this technique in grapevines in which fruit quality and quantity increased in comparison with RDI (De la Hera *et al.*, 2007; Dos Santos *et al.,* 2007). However, in some fruit species, PRD has given similar results to those obtained with RDI, with no clear advantage of the former when the volumes of water applied in both methods were the same (Egea *et al.*, 2010). Roots left in drying soil under localized irrigation system might be responsible for the reduction on transpiration and there is no need to alternate irrigation for achieving this effect (Fernández *et al.,* 2006).

Physiological and agronomic response to deficit irrigation

Many studies have been carried out to assess the effects of water restriction applied during different phenological stages of tree development. Research on plant responses to DI has identified the periods of highest plant sensitivity to water deficit (critical periods) such as the background information essential for successful RDI application. The outcomes of these studies are summarized in this section.

Water relations

Studies on soil and plant water status in response to water deficits have pointed to a reduction in the soil water content as the first signal that can be used as a stress indicator. Under RDI, DI periods have to be adapted so that the supply of water is reduced at the desired time (phenological stage), and this can be achieved by monitoring the soil water content. For instance, in deep soils, where both development of plant water stress and its recovery after re-irrigation curse slowly, undesirable results may ensue (Girona *et al.,* 1990). For irrigation management, different commercially available devices have been used to monitor the soil water content and identify the actual plant water status: tensiometers (Li *et al.,* 1989), granular matrix sensors (Intrigliolo and Castel, 2006) or capacitance probes (Abrisqueta *et al.,* 2009b).

Leaf (Ψ_{leaf}) or stem (Ψ_{stem}) water potentials have been profusely used as plant water status indicator, because these parameters are among the earliest responses to DI. Apart from a consideration of their diurnal changes and age-dependant dynamics (Ruiz-Sánchez *et al.,* 1997, 2007), they have been used as threshold values for irrigation scheduling in vineyards (Girona *et al.,* 2006a) and peach orchards (Girona *et al.,* 2006b) or to define the level at which both plant growth and yield were negatively affected, *e.g.* predawn $\Psi_{leaf} \approx -0.5$ MPa during the stage III of apricot fruit growth (Pérez-Pastor *et al.,* 2009) or midday $\Psi_{stem} \approx -1.5$ MPa during the summer for Clementina de Nules (González-Altozano and Castel, 1999), among others.

Vegetative *vs.* fruit growth

The vegetative growth of woody trees is recognized as being the most sensitive process to DI. Reductions in shoot elongation and trunk cross sectional area in response to water deficits lead to reductions in tree size and smaller canopies (Girona *et al.,* 2005a,b; Intrigliolo and Castel, 2005; Marsal *et al.,* 2008a; Pérez-Pastor *et al.,* 2009).

Due to the high sensitivity of growth to mild water deficit, many studies have described trunk diameter fluctuations as the most sensitive indicator of water status, since they are among the first physiological indicators of variations in tree water functioning compared with other discrete or continuous measurements, as it has been found in lemon (Ortuño *et al.,* 2006) and peach trees (Conejero *et al.,* 2007). Current knowledge of the use of trunk diameter fluctuations and their derived parameters for irrigation scheduling in woody crops is reviewed in Fernández and Cuevas (2010) and Ortuño *et al.* (2010).

Fruit water accumulation is highly sensitive to the level of water deficit during all fruit developmental stages, whereas dry matter accumulation is relatively insensitive (Girona *et al.,* 2004). When moderate water deficits were applied during early stages of fruit growth, fruit growth was not reduced compared with fully irrigated trees; moreover, fruit growth was even stimulated due to an accelerated rate of growth when irrigation was increased to 100% ET_c during the subsequent stages, as it has been found in apricot (Ruiz-Sánchez *et al*., 2000; Torrecillas *et al*., 2000), citrus (Cohen and Goell, 1988; González-Altozano and Castel, 2000b), pear (Mitchell *et al.,* 1984; Caspari *et al.,* 1994), apple (Ebel *et al*., 1995), although no such observation has been found in other studies (Domingo *et al.,* 1996; Girona *et al.,* 2003).

There is general agreement that different water deficit intensities during final stages of fruit growth (stage III for the double-sigmoid fruits) cause a reduction of fruit diameter, which adversely affects production, and therefore it is considered the most sensitive period for irrigation (Ruiz-Sanchez and Girona, 1995; González-Altozano and Castel, 1999, 2000a,b, 2003; Torrecillas *et al.,* 2000; Girona *et al.,* 2004).

DI management can be a powerful tool to manipulate plant growth for greater fruit-fullness and less vegetative growth. For this reason, a clear separation between the main periods of vegetative and fruit growth is an advantageous characteristic for the successful application of RDI in fruit trees, since water deficit will affect only one of these processes at a time. Nevertheless, as indicated above, if vegetative and fruit growth processes overlap the former will be the more affected.

Yield and fruit quality

In deciduous fruit trees the final yield depends on irrigation and the climatic conditions prevailing in the current harvest year as well as on the flowering behaviour, which is dependent on the previous year's postharvest period. The effect of DI during fruit growth stages has already been discussed. Lower flowering density and fruit set as a result of DI during the previous postharvest period have been recorded in pear (Marsal *et al.,* 2002), apricot (Ruiz-Sánchez *et al.,* 1999) and peach (Girona *et al.,* 2003).

Crop management practices, including thinning and pruning, influence fruit load. The combined effect of DI and crop load must be considered; in general, high fruit load tends to increase the sensitivity of fruit growth to water stress and may also delay the recovery from it (Marsal *et al.,* 2008a).

DI applied during fruit growth stages in peaches and apricots induced a higher soluble solids content (SSC) and SSC/titratable acidity (TA) ratio, which was also correlated with a more reddish coloration in the fruit skin and earlier maturity (Torrecillas *et al.,* 2000; Gelly *et al*., 2004; Pérez-Pastor *et al.,* 2007).

Deciduous fruit trees

Vines

This section will discuss RDI application in grapevines for wine production mainly based in results from the Spanish Viticulture. The use of RDI in table grapes though is also of agronomic and economic importance will not be specifically addressed here.

Irrigation is a common cultural practice in the viticulture of New World countries, while in Spain, irrigation of grapevines for wine production was forbidden by law until 1996. Though its use for wine production has steeply increased in the last decade, in some viticulture areas it is still somewhat restricted or even prohibited based on a common, and often not scientifically proven, consideration that irrigation detrimentally affects wine composition.

Supplying irrigation to ensure the full vine evapotranspiration, *e.g.* using the crop coefficient values recommended by FAO (Allen *et al*., 1998), may maximize vineyard productivity but normally reduces grape and wine quality (Williams and Matthews, 1990), often due to an increase in berry size through irrigation. If other berry characteristics, such as skin thickness, are not affected by irrigation, then larger berries would have a lower skin to pulp ratio. This leads to a dilution of the main berry quality components that are localized in the skin. Irrigation may also indirectly affect berry quality because of increased and prolonged vegetative growth. An excess of shoot vigour may compete for the carbohydrates available for fruit ripening, and might also impair cluster microclimate, particularly fruit light exposure (Smart *et al*., 1985).

Previous research on irrigation in Spanish vineyards has been mostly based on applying a constant amount of water, less than full ET_c during the whole season, which is SDI. Studies have been conducted on most of the main viticultural areas, like La Rioja (García-Escudero *et al.*, 1991, 1997), Castilla-La Mancha (Bravo de Mingo *et al.,* 1998), Ribera del Duero (Rubio *et al.*, 2004; Yuste *et al.*, 2005), Extremadura (Valdés *et al.*, 2004), Tarragona (Nadal and Arola, 1995), Madrid (Esteban *et al.*, 1999), Murcia (De la Hera *et al.*, 2004), Islas Baleares (Escalona *et al.*, 1998), Somontano (Sipiora and Gutiérrez-Granda, 1998) and Utiel-Requena (Intrigliolo and Castel, 2008). Results have shown a general increase in yield, mostly due to increased berry and cluster weight, and in some instances also some beneficial effects of irrigation on fruit ripening, mainly higher acidity and increased berry sugar concentration, but frequently it has been observed a decrease in the concentration of skin anthocyanins and reduced wine colour (Esteban *et al.*, 2001).

For many wine grapevine varieties, control of berry size is of importance, and in many localities the irrigation management, especially during the pre-veraison period can be a very effective way (though not the only one) of achieving this goal. This strategy is more applicable for red-wine varieties rather than white ones for which control of berry size and canopy size is considered less important.

Water deficit during post-veraison, although less effective in controlling berry size, has also been claimed to beneficially influence fruit composition in ways that are, at least in part, independent of berry size (Roby *et al.*, 2004) and it was recently found that water deficit can enhance accumulation of anthocyanins by stimulating the expression of genes encoding their biosynthesis (Castellarin *et al.*, 2007). RDI can then be applied as a strategy to reduce the possible negative impact of irrigation on wine quality, as well as allowing water savings and increasing WUE.

RDI in wine grapevines in Spain has been studied in cvs. 'Bobal' (Salón *et al.*, 2005) and 'Tempranillo' (Intrigliolo and Castel, 2009b; Yeves *et al.*, 2009), where pre- and post-veraison RDI treatments where compared to a fully irrigated control. In 'Tempranillo' in the pre-veraison RDI, irrigation was withheld until midday Ψ_{stem} values reached –1.0 MPa, while RDI post-veraison was irrigated like the control until veraison's end and afterwards at 25-50% of control, increasing or decreasing the reduction trying to avoid that water stress would become too severe (Ψ_{stem}< –1.4 MPa). The results showed that early water deficit allowed for water savings of 40% and gave the best agronomic results, given that yield was practically the same as in the control, but berry size was reduced leading to more concentrated berries in terms of anthocyanins, although other compositional berry parameters (sugar, titratable acid, pH, malic and tartaric acids and total phenols) were similar to fully irrigated vines. Contrarily, the post-veraison water shortage produced water savings of only 17%, did not affect final berry size but impaired berry sugar accumulation and delayed maturation due to detrimental effects of water stress on leaf photosynthetic rate. These results are in agreement with reports on 'Colombard' (Van Zyl, 1984), 'Cabernet Franc' (Matthews and Anderson, 1988), and 'Shiraz' (McCarthy, 1997), where water deficit occurring before veraison also reduced berry size more than during late season. However, they do not confirm the beneficial influences of post-veraison RDI on berry composition of other reports (Roby *et al.*, 2004; Castellarin *et al.*, 2007).

Thus, in conditions of scarce water resources, applying moderate water deficits before veraison and irrigating without considerable restriction afterwards, appear as the most convenient irrigation strategy in Tempranillo vineyards.

Although it is known that other factors may also determine grapevines responses to water, particularly the crop level (Bravdo *et al.*, 1985), other reports, in Cabernet Sauvignon in the arid Columbia Valley (Keller *et al.*, 2008) and in Tempranillo in Spain (Intrigliolo and Castel, 2007; Intrigliolo *et al.*, 2007), have shown no interaction between crop load and RDI, except for very high yield levels indicative of unbalanced vines.

Most of the seminal work which originated the PRD practice came from split root experiments with potted grapevine plants (Dry and Loveys, 1999; Stoll *et al.*, 2000; Antolín *et al.*, 2006). These investigations showed that vines with half of the root system always in contact with dry soil had lower stomatal conductance and reduced vegetative growth (responses mediated by root produced abscisic acid), without detrimental effects on yield and improvement in fruit quality, thereby increasing WUE. In vineyards, it has been claimed that PRD helps in controlling excessive vegetative growth and improves grape quality while not reducing fruit production (Loveys *et al.*, 2000).

In the field, instead, there are not only some examples of successful PRD (Dry *et al.*, 2001; Dos Santos *et al.*, 2003, 2007; Du *et al.*, 2008), but also many other cases where PRD did not have any considerable effect on grape performance, when it was compared with the same amount of water applied by conventional drip irrigation (Bravdo *et al.*, 2004; Gu *et al.*, 2004; Pudney and McCarthy, 2004; Marsal *et al.*, 2008b).

Partial rootzone drying applied at two amounts (100% and 50% of the estimated crop evapotranspiration) was compared to conventional drip irrigation, and also to rain fed vines in 'Tempranillo' during two consecutive years in a commercial vineyard with a deep, light-clay soil (Intrigliolo and Castel, 2009a). In both seasons, PRD did not significantly affect physiological parameters, neither growth, yield or fruit and wine quality, when compared to the same amount of water applied by conventional drip irrigation. Overall these results suggest that, under these experimental conditions, it was the irrigation amount rather than the system of application what affected vine performance, indicating the difficulties of successfully employing the PRD type of irrigation with a drip system in heavy and deep soils. This confirms the findings of Marsal *et al.* (2008b) that under heavy deep soils the PRD technique seems to be less effective than under sandy soil (Dos Santos *et al.*, 2003), where wetting and drying cycles can be achieved more easily.

Prunus sp.

In most of the research on plant responses to RDI in *Prunus* sp., water restriction were applied during stages I and II of fruit growth (initial growth and pit hardening, respectively) as well as during the postharvest period, whereas full irrigation was applied during the critical period, namely rapid fruit growth (stage III). The main results on the agronomical response to RDI are summarized below.

The response of peach trees to different RDI strategies has been studied in Lleida province in medium-late maturing cultivars, 'Sudanell' in shallow soils (Girona *et al.,* 2003) and 'Andross' in deep soils (Girona *et al.,* 2005b). Overall, RDI can be used successfully on peach trees. Results indicated that DI at 35% of ET_c during stage II (pit hardening) and/or during the postharvest allowed water saving of up to 22% in shallow soils and 35% in deep soils without affecting yield or final fruit size. However, the carry-over effect of DI affected yield through reductions in tree size after a three-year period. Implications from these studies pointed to that water deficit during the postharvest should be managed carefully in order to avoid reductions in bloom and fruit load (Girona *et al.,* 2003). For this reason, together with climatic conditions, fruit thinning practices must be considered when yield responses to RDI are studied.

Peaches intended for industrial use can be managed under RDI conditions (irrigated at 40% of the control during stage II or at 70% during stage III) without affecting the grower's profit and even increasing the sugar content, as indicated in a long-term trial in a low water holding capacity soil in Lleida (Rufat *et al.,* 2009).

A reduction of up to 25% in irrigation water was obtained when an RDI strategy, based on DI during stage II of peach fruit growth, was applied to a medium maturing peach cultivar 'Babygold' in Murcia, with no differences in final yield (Botía *et al.,* 2004).

In an early-maturing peach cultivar 'Flordastar', an RDI strategy based on irrigation at 100% of ET_c only during stage III of peach fruit growth and 25% during the rest of the growing season led to lower yields compared with full irrigation in mature trees (Abrisqueta *et al.,* 2009a), although it performed well during young stages of tree growth (Alarcón *et al.,* 2006; Ruiz-Sánchez *et al.,* 2006). The results indicated that severe water deficits applied during the postharvest period (longer in the early maturing varieties) limited vegetative growth and the yield of mature peach trees. The experiment was performed in stony, shallow clay-loam textured soil under Mediterranean conditions in Murcia. Fruits from the RDI treatment showed a lower content of vitamin C and carotenoids, while the phenolics content (mainly anthocyanins and procyanidins) increased (Buendía *et al.,* 2008).

PRD (irrigation at 50% of ET_c, alternating irrigation from one half of the tree to the other every 2-3 weeks) has been compared with SDI in the same peach cultivar. No differences in yield between DI treatments were found, although the yield was lower than in fully irrigated trees (Tapia *et al.,* 2009). PRD resulted in a lower reduction in root growth than the obtained with SDI with respect to the full irrigation treatment (Abrisqueta *et al.,* 2008).

The response of mature apricot trees (*Prunus armeniaca* L., cv. 'Búlida') to RDI was studied during four growing seasons in a commercial orchard in Mula valley (Murcia, Spain), with a loamy textured soil under drip irrigation conditions (Ruiz-Sánchez *et al.,* 2000; Pérez-Pastor *et al.,* 2009). The RDI strategy consisted of irrigation at 100% of ET_c during the critical periods (second rapid fruit growth period and two months after harvest), and at 25-40% of ET_c during the rest of the non-critical periods. The longer and more severe deficit periods in the RDI treatment caused a decrease in yield in the two first seasons, when 25% of ET_c was applied; however, under moderate water deficit (up to 40% of ET_c) it was possible to obtain similar yields and fruit quality to those obtained in control trees (irrigated at 100% of ET_c all year). SDI applied throughout the growing season affected productivity and limited vegetative and reproductive growth. RDI can then be considered a practical strategy for apricot plantations in Mediterranean areas suffering permanent limited water resources.

The response of young mid-season Japanese plum trees (*Prunus salicina* cv. 'Black-Gold') to RDI was studied over 4 years in Valencia, Spain (Intrigliolo and Castel, 2005). Water was restricted during phenological stages II and III of fruit growth, or after harvest, replacing 33% or 66% of ET_c, or during both periods at 66% of ET_c. Water deficit during fruit growth reduced average fruit weight, while drought after harvest did not affect flowering, fruit set, fruit growth or yield, in the short-term. However, in the last year of the experiment there was a 10% reduction in yield compared with control trees, due to the smaller trees in post-harvest RDI treatment, as a consequence of the cumulative effects of water deficit on tree growth. Savings in water applications were similar with DI applied after harvest, or before and after harvest. Post-harvest DI, despite its moderate detrimental effect in the long-term, should be considered in commercial orchards not only in cases of water scarcity, but also as a tool to control vegetative growth.

In Spain, almond trees [*Prunus dulcis* (Mill.) D.A. Webb] are mainly cultivated along the Mediterranean coast, an area characterized by scarce rainfall and high temperatures. Traditionally, almond has been considered drought tolerant. Most plantations depend on rainfall and only 6% are irrigated. Although almond is adaptable to a wide range of water availability, yields may be seriously affected when water stress occurs during active vegetative and fruit growth (stages II and III, March-June) and postharvest (stage V, end August-October) periods. However yields are relatively insensitive to mild and moderate water stress during kernel-filling, stage IV, June-August (Girona and Marsal, 1995; Goldhamer, 1996). The strong sink activity of the fruit during this period compared to other plant organs may be the cause of this behavior (Romero *et al.,* 2004). For this reason, phase IV has been considered the most suitable for the application of DI. Nevertheless, avoidance of severe stress in almonds seems highly desirable for a crop where nut size is determined before harvest. Furthermore, it should be noted that processors pay less for smaller fruit (Goldhamer *et al.,* 2006). Girona and Marsal (1995) pointed to a dryland/irrigated crop yield ratio of 1/10, which goes a long way to explaining the increased use of drip irrigation systems in commercial almond tree orchards. The value of this ratio justifies the numerous studies carried out into the response of almonds to RDI.

One of the first groups in Spain to study the response of almond to DI was that of CEBAS-CSIC, Murcia (León *et al.,* 1985; Ruiz-Sánchez *et al.,* 1988; Torrecillas *et al.,* 1989). However, the use of RDI follows the studies carried out by the group at IRTA (Lleida) related with the sensitivity of almond to water deficit as a function of the phenological stage (Girona *et al.,* 1997). Subsequent studies by the same group (Girona *et al.,* 2005a) and others such as those at IMIDA, Murcia (Romero *et al.,* 2004) and UPCT, Cartagena, Murcia (Nortes, 2008; Egea *et al.,* 2009, 2010) have confirmed almond as a crop ideal for applying RDI strategies.

The use of RDI in almond, applied during the kernel-filling phase, was evaluated over four consecutive years by Girona *et al.* (2005a). Average fruit yields recorded were relatively high in all the assayed treatments (kernel yield > 1,400 kg ha^{-1}). But it was the treatment irrigated at full ET_c (T_{100}), which obtained the optimal yield response, which was even higher than that obtained in trees receiving 30% more water (T_{130}). In RDI treatments, the one irrigated at the same rate as T_{100} (except during the kernel filling period, when irrigation was 20% of T_{100}), did not decrease kernel dry matter accumulation during the first two experimental years. This suggests that kernel growth during the kernel-filling phase seems to be relatively resistant to water stress. However, and due to carry-over effects, both cropping and kernel growth were reduced during the third and fourth years of the experiment. According to the authors, the explanation for this decrease could be a hypothetical depletion of the carbohydrate reservoir in RDI trees and also the negative soil water balance observed in the T_{70} (a seasonal SDI strategy receiving 30% less water than T_{100}) and in RDI during winter and spring of the last two years. The RDI strategy represented a 60% saving of water compared with T_{100} but only a 20% reduction in yield. RDI was considered more interesting than T_{70}, pointing to the great interest in this irrigation technique both from an economic and water conservation point of view. However, in an experiment realized in California, Goldhamer *et al.* (2006) indicated that, for the same level of applied water, yields were less affected under SDI than under RDI.

A comparative study of several regulated deficit irrigation treatments applied by surface (RDI) and subsurface (RDIS) drip irrigation was realized by Romero *et al.* (2004), who showed that both RDI and RDIS are valid strategies for improving water productivity and economic benefits. For example, RDI using 20% ET_c during the kernel filling period involved a 26% saving of water compared with what would have been necessary to satisfy 100% of the crop water requirements and only an 11% reduction in production (1,412 *vs.* 1,251 kg kernel ha^{-1}). Also, RDIS based on 20% ET_c during the kernel filling period and 50% during post-harvest was more profitable than irrigation at 100% ET_c throughout the season. RDIS produced a greater horizontal distribution of fine roots and stimulated a deeper root development in the soil profile than the surface drip system. This was probably the main reason for the greater WUE reached with the RDIS treatments.

More recently, Egea *et al.* (2010) studied the long-term effects of different DI options on tree growth, yield determinants and water productivity of almond trees cv. Marta grown in a semiarid climate. Three partial root-zone drying (PRD) irrigation treatments (30, 50 and 70% ET_c) and a RDI (at 50% ET_c during kernel-filling) were compared over three consecutive growth seasons with full irrigation (control). The results showed that all DI treatments had a negative impact on trunk growth parameters, the magnitude of which was strongly correlated in a linear fashion with the annual volume of water applied per tree. Except in PRD_{70}, individual kernel weight was significantly reduced in the deficit irrigated treatments. Water productivity increased drastically with the reduction of water application. Meanwhile, the amount of water applied in PRD_{30} represented 28% that of the control, which translates into a 123% relative increase in water productivity. The treatments that received similar annual water volumes under contrasting DI strategies (*i.e.* PRD_{70} and RDI) showed similar tree performance. This suggests that the type of irrigation strategy was probably not a relevant factor in water productivity in almond trees. It may be said that in water deficit conditions, the partitioning of assimilated carbon in almond tree favours fruit growth at the expense of vegetative growth. This characteristic underlines the suitability of almond as a crop of great interest for using RDI or PRD strategies.

The use of RDI with saline waters ($EC_{25°C} = 4.2$ dS m^{-1}) has also been studied in mature Colorada almond trees during four seasons (Nortes, 2008) in the arid conditions of Fuente Alamo (Murcia). The results showed that water savings of 50% can be achieved with RDI without affecting fruit yield components (775 kg kernel ha^{-1} RDI *vs.* 795 kg kernel ha^{-1} control treatment). These yields represent a five-fold increase over those typical of Spanish dryland agriculture (150 kg kernel ha^{-1}). The strategy involving 100% (stages II + III) –30% (stage IV) –70% (stage V) of control levels may make a large contribution to the productive capacity of this sector. Differences of 0.2-0.3 MPa predawn leaf water potential with respect to the control treatment do not affect the yield or physical quality of almonds. However, a tendency to reduced vegetative growth has been observed in RDI trees, which could affect long term production. Irrigation with saline water has a clearly negative effect on the development and production of almond trees, although the yields obtained were above those that might have been expected given the high degree of salinity of both the water and soil. This autochthonous variety seems to show good adaptation to water and salt stress, which should make it possible to use water more efficiently. In the conditions described above, agricultural practices should be aimed at facilitating the leaching of salts from the soil and the maintenance of the soil structure.

Pome fruits

Pear tree response to RDI was studied in a mature commercial orchard (*Pyrus communis* L. cv. 'Blanquilla') in Lleida. DI during both stages I or II of fruit growth affected fruit production by increasing fruit numbers but decreasing fruit size, while over-irrigation strongly reduced fruit numbers. Optimal fruit production occurred between these extremes. In addition, fully irrigated trees achieved the highest accumulated trunk growth and largest fruit size (Marsal *et al.,* 2002). In potted pear trees RDI (15% of the control) also led to a smaller fruit size at harvest than in fully irrigated trees; despite fruit osmotic adjustment and the slightly higher tree water status in RDI, when full irrigation was resumed during stage II fruit development, the fruit growth rate remained lower in RDI trees than in the control trees (Marsal *et al.,* 2000).

RDI was applied to apple tree (*Malus domestica* L.) in a trial in Lleida with DI (50% of the control) applied during the last stage of fruit growth and full irrigation the rest of the growing season. During the three year period, RDI did not reduce fruit size or yield, while SDI during the whole year drastically reduced fruit size. However, although the use of RDI with no reduction in fruit yield seems plausible, a specific study of plant sensitivity to water deficits is needed (Girona *et al.,* 2009).

Perennial fruit trees

Citrus

The application of RDI to citrus has been widely studied. Results in drip-irrigated mature 'Salustiana' citrus trees during seven seasons (Castel and Buj, 1989, 1993) showed that RDI, irrigation at 60% of a fully irrigated control, during spring (April to June) allowed seasonal water savings of about 20% ($\approx$120 mm year^{-1}) respect to the control and reduced yield by 8%, while RDI at the same restriction (60% of control) during the last phases of fruit growth (September to March) produced a water saving of 15% and the yield reduction was only 4%. These small yield losses were due to reduced fruit size, as fruit number was not affected in most years. Fruit internal quality was practically unaffected.

Studies on the application of RDI and DI to drip-irrigated 'Clementina de Nules' (CN) citrus trees over Carrizo citrange (Ginestar and Castel, 1996) showed that flowering and fruit set are periods highly sensitive to water restrictions, as water stress during this stage increases fruit drop and consequently reduces yield substantially. It was also found that the more appropriate phenological period for applying water restrictions was during the summer, soon after the physiological fruit drop.

Further work in the same orchard by González-Altozano and Castel (1999, 2000a,b, 2003) showed the feasibility of applying RDI treatments in CN trees during the summer months (mainly July-August), that allowed water savings of about 10-20% without any detrimental effect on yield or fruit size during several seasons. They also identified threshold values of plant water stress (midday $\Psi_{stem} \approx -1.5$ MPa) which did not affect fruit size, providing that water restrictions would finish sufficiently before harvest, in order to allow for compensation in fruit growth (González-Altozano and Castel, 2000b), a fact that has also been observed in grapefruit (Cohen and Goell, 1988).

Ballester *et al.* (2008, 2009) studied the extrapolation of the previous results and Ψ_{stem} threshold, obtained at the IVIA experimental farm, to commercial orchards planted with 'Clementina de Nules' (CN) and 'Navel Lane Late' (NLL), both over Carrizo citrange. In these experiments, two levels of RDI (restrictions of about 50 to 35% respect to control during July-mid September, for RDI-1 and RDI-2, respectively) have been compared to a control treatment, fully irrigated during the whole season. Results from the 2007 and 2008 seasons show that in CN a reduction of seasonal water application of about 21% (RDI-1) did not affect yield or fruit size with respect to control. However, the higher water restriction (28%, as in RDI-2) produced a significant 15% yield loss, mainly due to reduced fruit size. RDI treatments did not affect number of fruit per tree; neither had they had any residual effect on flowering or fruit-set during the second season. Over all treatments fruit-set percentage in 2008 was 3.7%.

Results in NLL were somewhat different. Thus, yield was significantly reduced in both RDI levels (16% in RDI-1 and 19% in RDI-2) compared to the Control, also mainly due to reduction of average fruit weight in both RDI levels, as fruit number per tree was practically the same for all treatments.

In both cultivars, RDI increased internal fruit quality (*e.g.,* total soluble solids and titratable acidity) respect to control trees, nearly in proportion to the water restriction severity. In CN there was clear evidence of active fruit osmotic adjustment. A fact that has been also found in Valencia oranges on Carrizo citrange and rough lemon rootstocks (Barry *et al.*, 2004). Higher fruit TSS and TA normally increase fruit price in markets where not only external fruit characteristics (*e.g.* size and appearance) are valued.

Another clear effect of RDI treatments was a reduction of trunk growth that in a relative basis (*e.g.* relative growth rate) was reduced with respect to the control by 13% to 16%, and by 24% to 29%, on a seasonal basis in CN and NLL cultivars, respectively. A reduction in tree growth can be considered a positive effect of RDI since it diminishes the competition between vegetative and reproductive growth, increasing tree efficiency and it might also reduce pruning costs.

Recent experiments in a commercial mature Navelina orchard (Gasque *et al.*, 2009) have also confirmed the feasibility of applying RDI during the summer months to this orange cultivar, where water savings of 16 to 23% respect to fully irrigated control trees (516 mm year^{-1}) did not affect yield or fruit quality during the 2007 and 2008 seasons.

In conclusion these results indicate that the previous information on RDI obtained in Clementina can be thoroughly extrapolated to commercial orchards of this variety and to Navelina oranges, while Navel Lane Late seems to be more sensitive to water stress and further studies are still needed to define more precisely the timing and severity of water restrictions adequate for this late season cultivar.

The use of RDI with saline waters has also been recently studied in mature Fortune mandarines during three seasons (Pagán *et al.*, 2009). Results have shown the very negative effects on tree yield and growth produced by the progressive salt accumulation that occurred in the soil profile as consequence of insufficient leaching; an important concern for any irrigation strategy with saline water.

The application of RDI in mature 'Fino' lemon trees was studied during four consecutive seasons in the arid conditions of Santomera (Murcia) under drip irrigation in a stony, clay-loam of low water holding capacity (Torrecillas *et al.*, 1993; Domingo *et al.*, 1996). Two RDI treatments were compared to a control, which was irrigated at 100% of estimated ET_c during the whole season. RDI-1 was irrigated like the control during the fruit growth period (June to October) and at 25% of control thereafter, while RDI-2 was irrigated at 70% of control during the fruit growth period (June to October).

Results showed that the water saving of 22% achieved in RDI-2, was not economical, as fruit growth was delayed by water stress during this period and consequently the proportion of early fruit (those with higher market prices) was significantly reduced. Then, although total yield in RDI-2 was practically the same as in the control, economic revenue was substantially reduced for this early lemon variety. However, water restrictions later in the season (RDI-1) allowed seasonal water savings of about 25% without any effect on total yield and the proportion of early fruit was also practically unaffected (only in the driest year of the 4 studied there was a reduction). Therefore, this RDI-1 strategy can be recommended in situations of water scarcity, so common in Eastern Spain, for early lemon varieties.

Olive

Olive (*Olea europea* L.) is drought-resistant and has traditionally been cultivated in areas with limited water resources in low density plantations under rainfed conditions. However, it responds positively to irrigation, even with low amounts of water (Fernández *et al.,* 1997; Fernández and Moreno, 1999; Moriana *et al.,* 2003). In most Spanish olive growing areas maximum water requirements cannot be satisfied because of water scarcity. For this reason, the policy of the Guadalquivir River Basin District decided to permit DI over a large area rather than full irrigation over a reduced area (Pastor and Hidalgo, 2005).

Fortunately, RDI has been reported as useful for olive oil production (Alegre *et al.,* 2002; Moriana *et al.,* 2003; Iniesta *et al.,* 2009), and the second phase of fruit development, when pit hardening occurs, seems to be the most resistant period to such water deficit. The above authors reduced or even withheld irrigation from the beginning of massive pit hardening to two weeks before the beginning of ripening (July 1-15 to September 15-20). The fact that the second phase of fruit development coincides with a period of high evaporative demand means that the olive tree can be considered a crop of great interest for the application of RDI.

In Lleida, Alegre *et al.* (2002) studied the response of mature olive trees (cv. Arbequina) to full irrigation (100% ET_c) during four seasons and compared the findings to RDI in which 25, 50, or 75% ET_c were applied during the midsummer period. The results showed that RDI improved water productivity, the organoleptic characteristics of the oil and the behaviour of the fruits in the olive mill. The irrigation treatment at 50% ET_c in midsummer was particularly interesting since it allowed water savings of 35% with no yield losses. In general, RDI accelerated fruit ripening and affected fruit and oil composition during the early stages of ripening; however, at harvest, differences in oil content and yield due to irrigation treatment were minimal (Motilva *et al.,* 2000).

In the same way, Moriana *et al.* (2003) compared the yield response of mature olive trees (cv. Picual) cultivated in Cordoba under SDI and RDI with a control, which was irrigated at 100% of estimated ET_c. The RDI involved 75% of ET_c with a midsummer deficit period without irrigation, while SDI also used 75% of ET_c but evenly distributed throughout the irrigation season. The results illustrated that the average reductions in ET and yield in both DI strategies with respect to control were similar. Although plant water status in SDI was better than in RDI, the difference was not sufficient to justify one strategy as the other since the yield was the same and SDI used greater amount of water. Of note was the fact that the authors found a curvilinear yield-ET_c function, which means that water productivity is highest at low levels of water application and that both irrigation strategies can be considered appropriate in olive trees (Fereres and Soriano, 2007).

The same treatments (full irrigation, SDI and RDI) were tested in an olive orchard (cv. Arbequina) in Cordoba by Iniesta *et al.* (2009). Both DI treatments applied the same seasonal amount of irrigation, about 25% of the control. The results from 2004 to 2006 showed that a reduction of seasonal irrigation application of around 75% caused a decrease in seasonal ET (30-35%) and in radiation use efficiency, leading to moderate (≈15%) reductions in oil yield. WUE for oil in SDI and RDI was higher than in the control, but the oil yield was similar in both deficit treatments. Therefore, both irrigation strategies may be used in olive to save a significant amount of irrigation with moderate reductions in oil yield. In canning olive trees, Goldhamer (1999) found that a reduction in the water applied during midsummer of 15-25% of seasonal application for maximum yield did not have a negative impact on yield.

Many experiments have revealed reductions in vegetative growth induced by DI (Moriana *et al.,* 2003; Iniesta *et al.,* 2009). This effect, which is of great interest for controlling canopy size and for reducing the costs associated with specific agricultural practices, may reduce the number of fruits per tree. Given that most of the above mentioned studies only covered a there year period, a longer study would provide valuable information.

Loquat

The easy adaptation of loquat (*Eriobotrya japonica* Lindl.) to warm-temperate areas has permitted its rapid expansion throughout the Mediterranean basin. Earliness is a determining factor for the marketing and profitability of this crop, which reaches its highest prices at the beginning of the season. Early flowering in loquat in response to DI resembles that observed in other tropical and subtropical fruit crops (Crane, 2004). According to the studies of Cuevas *et al.* (2007), the optimal period for RDI application in 'Algerie' loquat cultivated under subtropical semi-arid climate of Almería in a sandy-claim-loam textured soil, was from mid-June to the end of July (postharvest period). For better fruit value it was found more useful to completely suppress watering rather than to subject to lengthier milder DI (Cuevas *et al.,* 2009). This strategy led to mean soil matric and midday stem water potential values of –160 and –125 kPa at 30 and 60 cm depth, and –2.1 MPa at the end of water deficit period, respectively, inducing a 66% reduction of water needs and was able to advance next blooming up to 3 weeks and harvest date by 8 days (Cuevas *et al.,* 2009). The long-term response confirms the suitability of RDI in loquat and the economic benefits of saving water during the summer (Hueso and Cuevas, 2010).

Concluding remarks

Based on the above mentioned results, the following can be concluded for a well-designed RDI strategy:

— A deep knowledge of the stages of plant sensitivity to water deficit is required so that the deficit is applied at times when the impact on yield and fruit quality is minimized. As a whole, fruit growth is most sensitive to water deficit during cell expansion (stage III) and the least during pit hardening (stage II).

— RDI is based on the concept that DI allows excessive vegetative growth to be controlled, while fruit growth is unaffected or even enhanced. For this reason, the main periods of vegetative and fruit growth must be clearly differentiated for the successful application of RDI in fruit trees.

— A compensatory fruit growth rate constitutes a basis for the successful application of RDI strategies. After the DI period, the full recovery of plant water status must be guaranteed at the beginning of the critical phenological stage.

— The level of water deficit applied during DI periods needs to be adapted to the sensitivity of each tree cultivar. Care must be taken when adapting postharvest water deficit in order to avoid reductions in the fruit load of the return bloom, which might limit subsequent yields.

— Interaction between fruit load and water stress must be taken into account when studying the responses of fruit trees to RDI. Fruit thinning and pruning practices have to be carefully managed under DI conditions.

— Long-term effects of DI, together with climatic conditions and crop techniques variations, must be considered, because the long-term plant responses to RDI may be different from short-term responses.

— WUE, in terms of harvestable fruit per unit of irrigation water applied, was always the highest in RDI conditions as compared to full irrigated or continuous deficit irrigated plants.

For the above reasons, and based on the successful use of RDI in fruit trees and vines reviewed herein, the adoption of RDI strategies in water-limited areas should be encouraged.

Acknowledgements

This research was supported by Spanish Ministry of Science and Innovation MICINN (AGL2006-12914-C02-01; AGL2007-66279-C03-03/AGR; AGL2009-06981), Séneca Foundation, Murcia (08845/PI/08; 08847/PI/08), and Rideco-Consolider CSD2006-00067 grants to the authors.

References

ABRISQUETA J.M., MOUNZER O., ÁLVAREZ S., CONEJERO W., GARCÍA-ORELLANA Y., TAPIA L.M., VERA J., ABRISQUETA I., RUIZ-SÁNCHEZ M.C., 2008. Root dynamics of peach trees submitted to partial rootzone drying and continuous deficit irrigation. Agric Water Manage 95, 959-967.

ABRISQUETA I., TAPIA L.M., CONEJERO W., SÁNCHEZ-TORIBIO M.I., ABRISQUETA J.M., VERA J., RUIZ-SÁNCHEZ M.C., 2009a. Riego deficitario en melocotonero extratemprano. Actas XXVII Congreso Nacional de Riegos, Murcia. pp. 23-24. [In Spanish].

ABRISQUETA I., VERA J., TAPIA L.M., ABRISQUETA J.M., RUIZ-SÁNCHEZ M.C., 2009b. Soil water content variations as water stress indicator in peach trees. Proc VI International Symposium on Irrigation of Horticultural Crops, Viña del Mar, Chile, Nov 2-6, p. 97.

ALARCÓN J.J., TORRECILLAS A., SÁNCHEZ-BLANCO M.J., ABRISQUETA J.M., VERA J., PEDRERO F., MAGAÑA I., GARCÍA-ORELLANA Y., ORTUÑO M.F., NICOLÁS E., CONEJERO W., MOUNZER O., RUIZ-SÁNCHEZ M.C., 2006. Estrategias de riego deficitario en melocotonero temprano. Vida Rural 225, 28-32. [In Spanish].

ALEGRE S., MARSAL J., MATA M., ARBONÉS A., GIRONA J., 2002. Regulated deficit irrigation in olive trees (*Olea europea* L. *cv*. 'Arbequina') for oil production. Acta Hortic 586, 259-262.

ALLEN R.G., PEREIRA L.S., RAES D., SMITH M., 1998. Crop evapotranspiration. Guidelines for computing crop water requirements. FAO Irrigation and Drainage paper No. 56, Rome, Italy.

ANTOLÍN M.C., AYARI M., SÁNCHEZ-DÍAZ M., 2006. Effects of partial rootzone drying on yield, ripening and berry ABA in potted Tempranillo grapevines with split roots. Aust J Grape Wine Res 12, 13-20.

BALLESTER C., CASTEL J., CASTEL J.R., 2008. Effects of regulated deficit irrigation on 'Clementina de Nules' and 'Navel Lane Late' citrus trees: growth, yield and fruit quality. Proc 11th International Citrus Congress, Wuhan, China. Oct 14-17, p. 74.

BALLESTER C., CASTEL J., CASTEL J.R., 2009. Riego deficitario controlado en Clementina de Nules y Navel Lane Late: producción y calidad de la fruta. VI Congreso Ibérico de Ciencias Hortícolas, Logroño. Actas de Horticultura 54, 101-102. [In Spanish].

BARRY G.H., CASTLE W.S., DAVIES F.S., 2004. Rootstocks and plant water relations affect sugar accumulation of citrus fruit via osmotic adjustment. J Amer Soc Hort Sci 129, 881-889.

BOTIA P., ROMERO P., NAVARRO J.M., PÉREZ-PÉREZ J.G., GARCÍA OLLER I., TRINTRAN A.J., 2004. Efecto de diferentes estrategias de riego deficitario controlado sobre la producción y calidad de variedades de media estación de melocotonero (*Prunus persica* L. Batsch). Proc VII Simposium Hispano-Portugués de Relaciones Hídricas en las Plantas, Faro, Portugal. Sept 27-29, pp. 53-56. [In Spanish].

BRAVDO B., HEPNER Y., LOINGER S., COHEN S., TABACMAN H., 1985. Effect of irrigation and crop level on growth, yield and wine quality of Cabernet Sauvignon. Amer J Enol Vitic 36, 132-139.

BRAVDO B., NAOR A., ZAHAVI T., GAL Y., 2004. The effect of water stress applied alternately to part of the wetting zone along the season (PRD-partial rootzone drying) on wine quality, yield and water relations of red wine grapes. Acta Hortic 664, 101-109.

BRAVO DE MINGO J., DUQUE MARTÍNEZ M.C., YÁÑEZ BARRAU F., 1998. Riego localizado en viñedo. Vitic Enol Prof 56, 30-41. [In Spanish].

BUENDÍA B., ALLENDE A., NICOLÁS E., ALARCÓN J.J., GIL M.I., 2008. Effect of regulated deficit irrigation and crop load on the antioxidant compounds of peaches. J Agric Food Chem 56, 3601-3608.

CASPARI H.W., BEHBOUDIAN M.H., CHALMERS D.J., 1994. Water use, growth, and fruit yield of Hosui Asian pears under deficit irrigation. J Amer Soc Hort Sci 119, 383-388.

CASTEL J.R., BUJ A., 1989. Response of mature 'Salustiana' oranges to high frequency deficit irrigation. Irrig Sci 11, 121-127.

CASTEL J.R., BUJ A., 1993. Riego por goteo deficitario en naranjos adultos 'Salustiana' durante 7 años. Invest Agrar: Prod Prot Veg 8(2), 191-204. [In Spanish].

CASTELLARIN S.D., MATTHEWS M.A., DI GASPERO G., GAMBETTA G.A., 2007. Water deficits accelerate ripening and induce change expression regulating flavonoid biosynthesis in grape. Planta 227, 101-112.

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.

COHEN A., GOELL A., 1988. Fruit growth and dry matter accumulation in grapefruit during periods of water withholding and after reirrigation. Aust J Plant Physiol 15, 633-639.

CONEJERO W., ALARCÓN J.J., GARCÍA-ORELLANA Y., ABRISQUETA J.M., TORRECILLAS A., 2007. Daily sap flow and maximum daily trunk shrinkage measurements for diagnosing water stress in early maturing peach trees during the post-harvest period. Tree Physiol 27, 81-88.

CRANE J.H., 2004. Selected cultural techniques to improve production of some subtropical and tropical fruit crops. Acta Hortic 632, 179-187.

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 cultivated in Southeast Spain (*Eriobotrya japonica* Lindl.). Agric Water Manage 89, 131-136.

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.

DE LA HERA M., MARTÍNEZ-CUTILLAS A., LÓPEZ-ROCA J.M., GÓMEZ-PLAZA E., 2004. Effects of moderate irrigation on vegetative growth and productive parameters of Monastrell vines grown in semiarid conditions. Span J Agric Res 2, 273-281.

DE LA HERA M.L., ROMERO P., GÓMEZ-PLAZA E., MARTÍNEZ A., 2007. Is partial root-zone drying an effective irrigation technique to improve water use efficiency and fruit quality in field-grown wine grapes under semiarid conditions? Agric Water Manage 87, 261-274.

DODD I.C., 2005. Root-to-shoot signaling: assessing the roles of «up» in the up and down world of long-distance signalling in plants. Plant Soil 274, 251-270.

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.

DOS SANTOS T.P., LOPES C.M., RODRIGUES M.L., DE SOUZA C.R., MAROCO J.P., PEREIRA J.S., SILVA J.R., CHAVES M.M., 2003. Partial rootzone drying, effects on growth and fruit quality of field-grown grapevines (*Vitis vinifera*). Funct Plant Biol 30, 663-671.

DOS SANTOS T.P., LOPES C.M., RODRIGUES M.L., DE SOUZA C.R., SILVA J. R., MAROCO J.P., PEREIRA J.S., CHAVES M.M., 2007. Effects of deficit irrigation strategies on cluster microclimate for improving fruit composition of Moscatel field-grown grapevines. Sci Hort 112, 321-330.

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., 1999. Grapevine shoot growth and stomatal conductance are reduced when part of the root system is dried. Vitis 38, 151-156.

DRY P.R., LOVEYS B.R., DÜRING H., BOTTING B.G., 1996. Effects of partial root-zone drying on grapevine vigour, yield composition of fruit and use of water. Proc 9th Aust Wine Industry Technical Conference. pp. 128-131.

DRY P.R., LOVEYS B.R., McCARTHY M.G., STOLL M., 2001. Strategic irrigation management in Australian vineyards. J Int Sci Vigne Vin 35, 129-139.

DU T., KANG S., ZHANG J., LI F., YAN B., 2008. Water use efficiency and fruit quality of table grape under alternate partial root-zone drip irrigation. Agric Water Manage 95, 659-668.

EBEL R.C., PROEBSTING E.L., EVANS R.G., 1995. Deficit irrigation to control vegetative growth in apple and monitoring fruit growth to schedule irrigation. HortScience 30, 1229-1232.

EGEA G., 2008. Characterization and modelling of the agronomic and physiologic responses of almond trees to water deficit. PhD thesis (shortened version). Universidad Politécnica de Cartagena, Spain. 90 pp.

EGEA G., GONZÁLEZ-REAL M.M., BAILLE A., NORTES P.A., SÁNCHEZ-BEL P., DOMINGO R., 2009. The effects of contrasted deficit irrigation strategies on the fruit growth and kernel quality of mature almond trees. Agric Water Manage 96, 1605-1614.

EGEA G., NORTES P.A., GONZÁLEZ-REAL M.M., BAILLE A., DOMINGO R., 2010. Agronomic response and water productivity of almond trees under contrasted deficit irrigation regimes. Agric Water Manage 97, 171-181.

ENGLISH M., RAJA S.N., 1996. Perspectives on deficit irrigation. Agric Water Manage 32, 1-14.

ESCALONA J.M., FLEXAS J., MEDRANO H., 1998. Contribution of the different levels of plant canopy to total carbon assimilation and intrinsic water use efficiency in Manto Negro and Tempranillo grapevines. Acta Hortic 493, 141-148.

ESTEBAN M.A., VILLANUEVA M.J., LISSARRAGUE J., 1999. Effect of irrigation on changes in berry composition of Tempranillo during maturation. Sugars, organic acids, and mineral elements. Amer J Enol Vitic 50, 418-434.

ESTEBAN M.A., VILLANUEVA M.J., LISSARRAGUE J., 2001. Effect of irrigation on changes in the anthocyanin composition of the skin of cv. Tempranillo (*Vitis vinifera* L.) grape berries during ripening. J Sci Food Agric 81, 409-420.

FERERES E., SORIANO M.A., 2007. Deficit irrigation for reducing agricultural water use. J Exp Bot 58, 147-159.

FERNÁNDEZ J.E., CUEVAS M.V., 2010. Irrigation scheduling from stem diameter variations: a review. Agric Forest Meteorol 150, 135-151.

FERNÁNDEZ J.E., MORENO F., GIRÓN I.F., BLÁZQUEZ O.M., 1997. Stomatal control of water use in olive tree leaves. Plant Soil 190, 179-192.

FERNÁNDEZ J.E., MORENO F., 1999. Water use by olive tree. J Crop Prod 2, 101-162.

FERNÁNDEZ J.E., DÍAZ-ESPEJO A., INFANTE J.M., DURÁN P., PALOMO M.J., CHAMORRO V., GIRÓN I.F., VILLAGARCÍA L., 2006. Water relations and gas exchange in olive trees under regulated deficit irrigation and partial rootzone drying. Plant Soil 274, 273-291.

GARCÍA-ESCUDERO E., SANTAMARÍA P., LÓPEZ R., PALACIOS L., 1991. Aplicación de dosis moderadas de agua en el proceso de maduración del cv. Tempranillo en Rioja. Vitivinicultura 2(1), 30-34. [In Spanish].

GARCÍA-ESCUDERO E., LÓPEZ R., SANTAMARÍA P., ZABALLA O., 1997. Ensayos de riego localizado en viñedos productivos de cv. 'Tempranillo'. Vitic Enol Prof 50, 35-47. [In Spanish].

GASQUE M., GRANERO B., ALÓS M., TURÉGANO J.V., GONZÁLEZ-ALTOZANO P., 2009. Resultados de la aplicación de riego deficitario controlado en cítricos de la variedad Navelina en 2007 y 2008. Actas XXVII Congreso Nacional de Riegos, Murcia. pp. 47-48. [In Spanish].

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.

GELLY M., RECASENS I., GIRONA J., MATA M., ARBONES A., RUFAT J., MARSAL J., 2004. Effects of stage II and postharvest deficit irrigation on peach quality during maturation and after cold storage. J Sci Food Agric 84, 561-568.

GINESTAR C., CASTEL J.R., 1996. Response of young 'Clementine' in citrus trees to water stress during different phenological periods. J Hort Sci 71(4), 551-559.

GIRONA, J., MARSAL, J., 1995. Estrategias de RDC en almendro. In: Riego deficitario controlado (Zapata M., Segura P., eds). Colección Cuadernos VALUE I, Mundi-Prensa/Unión Europea. pp. 97-118 [In Spanish].

GIRONA J., RUIZ-SÁNCHEZ M.C., GOLDHAMER D.A., JOHNSON S., DEJONG T., 1990. Late maturing peach response to controlled deficit irrigation: seasonal and diurnal pattern of fruit growth, plant and soil water status, CO_2 uptake and yield. Two year results. XXIII International Horticultural Congress, Florencia, Italia. p. 284.

GIRONA J., MARSAL J., MATA M., ARBONÉS A., MIRAVETE C., 1997. Evaluation of almond (*Amygdalus communis* L.) seasonal sensitivity to water stress. Physiological and yield responses. Acta Hortic 449, 489-496.

GIRONA J., MATA M., ARBONÉS A., ALEGRE S., RUFAT J., MARSAL J., 2003. Peach tree response to single and combined regulated deficit irrigation regimes under shallow soils. J Amer Soc Hort Sci 128, 432-440.

GIRONA J., MARSAL J., MATA M., ARBONÉS A., DE JONG T., 2004. A comparison of the combined effect of water stress and crop load on fruit growth during different phenological stages in young peach trees. J Hort Sci Biotech 79, 308-315.

GIRONA J., MATA M., MARSAL J., 2005a. Regulated deficit irrigation during the kernel-filling period and optimal irrigation rates in almond. Agric Water Manage 75, 152-167.

GIRONA J., GELLY M., MATA M., ARBONÉS A., RUFAT J., MARSAL J., 2005b. Peach tree response to single and combined deficit irrigation regimes in deep soils. Agric Water Manage 72, 97-108.

GIRONA J., MATA M., DEL CAMPO J., ARBONÉS A., BARTRA E., MARSAL J., 2006a. The use of midday leaf water potential for scheduling deficit irrigation in vineyards. Irrig Sci 24, 115-127.

GIRONA J., MARSAL J., LÓPEZ G., 2006b. Establishment of stem water potential thresholds for the response of 'O'Henry' peach fruit frowth to water stress during stage III of fruit growth. Acta Hortic 713, 197-201.

GIRONA J., DEL CAMPO J., BONASTRE N., PARIS C., MATA M., ARBONÉS A., MARSAL J., 2009. Evaluation of different irrigation strategies on apple (*Malus domestica*). Physiological and productive results. Proc VI International Symposium on Irrigation of Horticultural Crops, Viña del Mar, Chile. p. 54.

GOLDHAMER D.A., 1996. Irrigation scheduling. In: Almond production manual (Micke W.C., ed). University of California, Division of Agriculture and Natural Resources. pp. 171-178.

GOLDHAMER, D.A., 1999. Regulated deficit irrigation for California canning olives. Acta Hortic 474, 369-372.

GOLDHAMER D.A., VIVEROS M., SALINAS M., 2006. Regulated deficit irrigation in almonds: effects of variations in applied water and stress timing on yield and yield components. Irrig Sci 24, 101-114.

GONZÁLEZ-ALTOZANO P., CASTEL J.R., 1999. Regulated deficit irrigation in 'Clementina de Nules' citrus trees. I: Yield and fruit quality effects. J Hort Sci Biotech 74, 706-713.

GONZÁLEZ-ALTOZANO P., CASTEL J.R., 2000a. Regulated deficit irrigation in 'Clementina de Nules' citrus trees. II: Vegetative Growth. J Hort Sci Biotech 75, 388-392.

GONZÁLEZ-ALTOZANO P., CASTEL J.R., 2000b. Effects of regulated deficit irrigation on 'Clementina de Nules' citrus trees growth, yield and fruit quality. Acta Hortic 537, 749-758.

GONZÁLEZ-ALTOZANO P., CASTEL J.R., 2003. Riego deficitario controlado en 'Clementina de Nules'. I. Efectos sobre la producción y la calidad de la fruta durante cuatro años. Span J Agric Res 1(2), 81- 92. [In Spanish].

GU S., DU G., ZOLDOSKE D., HAKIM A., COCHRAN R., FUGELSANG K., JORGENSEN G., 2004. Effects of irrigation amount on water relations, vegetative growth, yield and fruit composition of Sauvignon Blanc grapevines under partial root-zone drying and conventional irrigation in the San Joaquin Valley of California, USA. J Hort Sci Biotech 79, 26-33.

HUESO J.J., CUEVAS J., 2010. Ten consecutive years of regulated deficit irrigation probe the sustainability and profitability of this water saving strategy in loquat. Agric Water Manage 97, 645-650.

INIESTA F., TESTI L., ORGAZ F., VILLALOBOS F.J., 2009. The effects of regulated and continuous deficit irrigation on the water use, growth and yield of olive trees. Eur J Agron 30, 258-265.

INTRIGLIOLO D.S., CASTEL J.R., 2005 Effects of regulated deficit irrigation on growth and yield of young Japanese plum trees. J Hort Sci Biotech 80, 177-182.

INTRIGLIOLO D.S., CASTEL J.R., 2006. Performance of various water stress indicators for prediction of fruit size response to deficit irrigation in plum. Agric Water Manage 83, 173-180.

INTRIGLIOLO D.S., CASTEL J.R., 2007. Crop level and irrigation effects on 'Tempranillo' grapevines in Requena, Spain. Proc Congreso Internacional sobre Clima y Viticultura (CONCLIVIT), Zaragoza, Spain. Apr 10-14, pp. 360-365.

INTRIGLIOLO D.S., CASTEL J.R., 2008. Effects of irrigation on the performance of grapevine cv. Tempranillo in Requena, Spain. Amer J Enol Vitic 44, 30-38.

INTRIGLIOLO D.S., CASTEL J.R., 2009a. Response of *Vitis vinifera* cv. 'Tempranillo' to partial rootzone drying in the field: water relations, growth, yield and fruit and wine quality. Agric Water Manage 96, 282-292.

INTRIGLIOLO D.S., CASTEL J.R., 2009b. Response of grapevine cv. 'Tempranillo' to timing and amount of irrigation: water relations, vine growth, yield and berry and wine composition. Irrig Sci 28, 113-125.

INTRIGLIOLO D.S., CHIRIVELLA C., CASTEL J.R., 2007. Response of grapevine cv. 'Tempranillo' to irrigation amount and partial rootzone drying under contrasting crop load levels. Acta Hortic 754, 309-316.

KELLER M., SMITHYMAN R.S., MILLS L.J., 2008. Interactive effects of deficit irrigation and crop load on Cabernet Sauvignon in an arid climate. Amer J Enol Vitic 59, 221-234.

LEÓN A., DEL AMOR F., TORRECILLAS A., RUIZ-SÁNCHEZ M.C., 1985. L'irrigation goutte à goute de jeunes plantations d'amandiers. Fruits 40, 659-663. [In French].

LI S.H., HUGUET J.G., BUSSI C., 1989. Irrigation scheduling in a mature peach orchard using tensiometers and dendrometers. Irrig Drain Syst 3, 1-12.

LIBRO BLANCO DEL AGUA EN ESPAÑA, 2000. Secretaría de Estado de Aguas y Costas, Dirección General de Obras Hidráulicas y Calidad de las Aguas, Ministerio de Medio Ambiente, Madrid. 637 pp. [In Spanish].

LOVEYS B.R., DRY P.R., STOLL M., McCARTHY M.G., 2000. Using plant physiology to improve the water use efficiency of horticultural crops. Acta Hortic 537, 187-197.

MARSAL J., RAPOPORT H.F., MANRIQUE T., GIRONA J., 2000. Pear fruit growth under regulated deficit irrigation in container-grown trees Sci Hortic 85, 243-259.

MARSAL J., MATA M., ARBONÉS A., RUFAT J., GIRONA J., 2002. Regulated deficit irrigation and rectification scheduling in young pear trees: an evaluation based on vegetative and productive response. Eur J Agron 17, 111-122.

MARSAL J., LÓPEZ G., GIRONA J., 2008a. Recent advances in regulated deficit irrigation (RDI) in woody perennials and future perspectives. Acta Hortic 792, 429-439.

MARSAL J., MATA M., DEL CAMPO J., ARBONÉS A., VALLVERDÚ X., GIRONA J., OLIVO N., 2008b. Evaluation of partial root-zone drying for potential field use as a deficit irrigation technique in commercial vineyards according to two different pipeline layouts. Irrig Sci 26, 347-356.

MATTHEWS M.A., ANDERSON M.M., 1988. Fruit ripening in *Vitis vinifera* L.: responses to seasonal water deficits. Amer J Enol Vitic 39, 313-320.

McCARTHY M.G., 1997. The effect of transient water deficit on berry development of cv. Shiraz (*Vitis vinifera* L.). Aust J Grape Wine Res 3, 102-108.

MITCHELL P.D., CHALMERS D.J., 1982. The effects of reduced water supply on peach tree growth and yields. J Amer Soc Hort Sci 107, 853-856.

MITCHELL P.D., JERIE P.H., CHALMERS D.J., 1984. Effects of regulated water deficits on pear tree growth, flowering, fruit growth and yield. J Amer Soc Hort Sci 109, 604-606.

MORIANA A., ORGAZ F., PASTOR M., FERERES E., 2003. Yield responses of a mature olive orchard to water deficits. J Amer Soc Hort Sci 128, 425–431.

MOTILVA M.J., TOVAR M.J., ROMERO M.P., ALEGRE S., GIRONA J., 2000. Influence of regulated deficit irrigation strategies applied to olive trees (Arbequina cultivar) on oil yield and oil composition during the fruit ripening period. J Sci Food Agric 80, 2037-2043.

NADAL M., AROLA L., 1995. Effects of limited irrigation on the composition of must and wine of Cabernet-Sauvignon under semi-arid conditions. Vitis 34, 151-154.

NORTES P.A., 2008. Respuesta agronómica y fisiológica del almendro al riego deficitario. Indicadores de estrés hídrico. Doctoral thesis. Universidad Politécnica de Cartagena, Spain. 194 pp. [In Spanish].

ORTUÑO M.F., GARCÍA-ORELLANA Y., CONEJERO W., RUIZ-SÁNCHEZ M.C., ALARCÓN J.J., TORRECILLAS A., 2006. Stem and leaf water potentials, gas exchange, sap flow and trunk diameter fluctuations for detecting water stress in lemon trees. Trees Struct Funct 20, 1-8.

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.

PAGÁN E., PÉREZ-PASTOR A., MOSCA M., ROBLES J.M., DOMINGO R., 2009. Efectos del riego deficitario controlado durante la fase II del crecimiento del fruto en mandarino. Actas XXVII Congreso Nacional de Riegos, Murcia. Jun 16-18, pp. 41-42. [In Spanish].

PASTOR M., HIDALGO J., 2005. Programación del riego en olivar con cantidades deficitarias de agua. Vida Rural 208, 42-47. [In Spanish].

PÉREZ-PASTOR A., RUIZ-SÁNCHEZ M.C., MARTÍNEZ J.A., NORTES P.A., ARTÉS F., DOMINGO R., 2007. Effect of deficit irrigation on apricot fruit quality at harvest and during storage. J Sci Food Agric 87, 2409-2415.

PÉREZ-PASTOR A., DOMINGO R., TORRECILLAS A., RUIZ-SÁNCHEZ M.C., 2009. Response of apricot trees to deficit irrigation strategies. Irrig Sci 27, 231-242.

PUDNEY S., McCARTHY M.G., 2004. Water use efficiency of field grown Chardonnay grapevines subjected to partial rootzone drying and deficit irrigation. Acta Hortic 664, 567-573.

ROBY G., HARBERTSON J.F., ADAMS D.A., MATTHEWS M.A., 2004. Berry size and vine water deficits as factors in wine grape composition: anthocyanins and tannins. Aust J Grape Wine Res 10, 100-107.

ROMERO P., BOTÍA P., GARCÍA F., 2004. Effects of regulated deficit irrigation under subsurface drip irrigation conditions on vegetative development and yield of mature almond trees. Plant Soil 260, 169-181.

RUBIO J.A., ALBURQUERQUE M.V., YUSTE J., 2004. Influence of water stress and crop load on the physiology and the productivity of Tempranillo under semiarid conditions. Acta Hortic 640, 99-106.

RUFAT J., DOMINGO X., PASCUAL M., VILLAR J.M., 2009. Water productivity of peach for processing in a soil with low available water holding capacity. Proc VI International Symposium on Irrigation of Horticultural Crops, Viña del Mar, Chile. Nov 2-6, p. 63.

RUIZ-SÁNCHEZ M.C., GIRONA J., 1995. Investigaciones sobre riego deficitario controlado en melocotonero. In: Riego deficitario controlado (Zapata M., Segura P., eds). Colección Cuadernos VALUE I, Mundi-Prensa/Unión Europea. pp. 69-95. [In Spanish].

RUIZ-SÁNCHEZ M.C., TORRECILLAS A., DEL AMOR F., LEÓN A., ABRISQUETA J.M., 1988. Leaf water potential and leaf conductance during the growing season in almond trees under different irrigation regimes. Biol Plant 30, 327-332.

RUIZ-SÁNCHEZ M.C., DOMINGO R., SAVÉ R., BIEL C., TORRECILLAS A. 1997. Effects of water stress and rewatering on leaf water relations of lemon plants. Biol Plant 39, 623-631.

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.

RUIZ-SÁNCHEZ M.C., TORRECILLAS A., PÉREZ-PASTOR A., DOMINGO R., 2000. Regulated deficit irrigation in apricot trees. Acta Hortic 537, 759-766.

RUIZ-SÁNCHEZ M.C., TORRECILLAS A., SÁNCHEZ-BLANCO M.J., ABRISQUETA J.M., VERA J., PEDRERO F., MAGAÑA I., GARCÍA-ORELLANA Y., ORTUÑO M.F., PLANA V., NICOLÁS E., CONEJERO W., MOUNZER O., ALARCÓN J.J., 2006. Respuesta fisiológica del melocotonero temprano al riego por desecación parcial de raíces. Proc VIII Simposium Hispano-Portugués de Relaciones Hídricas en las Plantas, Tenerife. pp. 117-121. [In Spanish].

RUIZ-SÁNCHEZ M.C., DOMINGO R., PÉREZ-PASTOR A., 2007. Daily variations in water relations of apricot trees under different irrigation regimes. Biol Plant 51, 735-740.

SALÓN J.L., CHIRIVELLA C., CASTEL J.R., 2005. Response of *Vitis vinifera* cv. Bobal to deficit irrigation in Requena, Spain. Water relations, yield and wine quality. Amer J Enol Vitic 56, 1-18.

SIPIORA M.J., GUTIÉRREZ-GRANDA M.J., 1998. Effect of pre-veraison irrigation cutoff and skin contact time on the composition, color and phenolic content of young Cabernet Sauvignon wines in Spain. Amer J Enol Vitic 49, 152-162.

SMART R.E., ROBINSON J.B., DUE G.R., BRIEN C.J., 1985. Canopy microclimate modification for the cultivar Shiraz II. Effects on must and wine composition. Vitis 24, 119-128.

STOLL M., LOVEYS B., DRY P., 2000. Hormonal changes induced by partial rootzone drying of irrigated grapevine. J Exp Bot 51, 1627-1634.

TAPIA L.M., LARIOS A., ABRISQUETA I., MOUNZER O., VERA J., ABRISQUETA J.M., RUIZ-SÁNCHEZ M.C., 2009. Peach deficit irrigation. Fruit yield and water use efficiency analysis. Rev Fitotec Mex 33(4), 1-5.

TORRECILLAS A., RUIZ-SÁNCHEZ M.C., LEÓN A., DEL AMOR F., 1989. The response of young almond trees to different drip-irrigated conditions. Development and yield. J Hort Sci 64, 1-7.

TORRECILLAS A., RUIZ-SÁNCHEZ M.C., DOMINGO R., HERNÁNDEZ-BORROTO J., 1993. Regulated deficit irrigation on 'Fino' lemon trees. Acta Hortic 335, 205-212.

TORRECILLAS A., DOMINGO R., GALEGO R., RUIZ-SÁNCHEZ M.C., 2000. Apricot tree response to irrigation withholding at different phenological periods. Sci Hortic 85, 201-215.

VALDÉS E., PRIETO M.H., URIARTE D., MARTÍN D., 2004. Madurez de la uva según dosis y épocas de riego. Agricultura 858, 28-32. [In Spanish].

VAN ZYL J.L., 1984. Response of Colombar grapevines to irrigation as regards quality aspects and growth. S Afr J Enol Vitic 5, 19-28.

WILLIAMS L.E., MATTHEWS M.A., 1990. Grapevine. In: Irrigation of agricultural crops (Stewart B.A., Nielsen D.R., eds). ASA Madison, WI, USA. Agronomy Monograph No. 30, pp. 1019-1055.

YEVES A., PÉREZ D., RISCO D., INTRIGLIOLO D.S., CASTEL J.R., 2009. Estrés hídrico pre-envero *versus* post-envero en la vid cv. 'Tempranillo' en Requena. Respuesta agronómica, fisiológica y calidad de la uva. VI Congreso Ibérico de Ciencias Hortícolas, Logroño. Actas de Horticultura 54, 387-388. [In Spanish].

YUSTE J., ASENJO J.L., ALBURQUERQUE M.V., RUBIO J.A., 2005. Relationships among physiology, growth and production as affected by water regime and vine spacing of 'Tempranillo' grapevines. Acta Hortic 689, 343-348.