available at www.sciencedirect.com
ScienceDirect
journal homepage: www.elsevier.com/locate/agwat

Optimal dates for regulated deficit irrigation in 'Algerie' loquat (*Eriobotrya japonica* Lindl.) cultivated in Southeast Spain

Julián Cuevas [a,*], María L. Cañete [a], Virginia Pinillos [a], Antonio J. Zapata [b], María D. Fernández [c], Mónica González [c], Juan J. Hueso [c]

[a] Departamento de Producción Vegetal, Universidad de Almería, 04120 Almería, Spain
[b] Departamento de Ingeniería Rural, Universidad de Almería, 04120 Almería, Spain
[c] Estación Experimental de la Fundación Cajamar, 04710 El Ejido, Almería, Spain

ARTICLE INFO

Article history:
Accepted 19 November 2006
Published on line 8 February 2007

Keywords:
Water stress
Blooming
Earliness
Harvest advancement
Flower development
Fruit value

ABSTRACT

To select the optimal period for regulated deficit irrigation (RDI) in 'Algerie' loquat, three RDI treatments incorporating a reduction of 66% (first season) or 75% (second season) of the water requirements either in June, July or August were compared with fully irrigated trees. RDI during June and July advanced flowering in both seasons. RDI during August had negligible effects or delayed bloom date, depending on the season. Earlier blooming led to an earlier harvest, which in turn improved fruit value. All RDI treatments produced greater bloom. RDI during August, especially with larger water savings, impaired flower development. Fruit set, size and yield did not change among treatments, despite the negative effects caused by RDI during August on the size of the flowers. July has been selected for ongoing research as the most promising date for RDI in 'Algerie' loquat due to its greater effects on the advancement of bloom and harvest date and its harmlessness for flower development.

© 2006 Elsevier B.V. All rights reserved.

1. Introduction

Loquat (*Eriobotrya japonica* Lindl.) is an evergreen tree crop indigenous of southeastern China (Lin et al., 1999) that belongs to the family *Rosaceae*, subfamily *Maloideae*. Unknown in the Western world until the 18th century, the easy adaptation of loquat to the Mediterranean climate has permitted its rapid expansion throughout the Mediterranean Basin. China is the world's largest producer of loquat with more than 314,000 tonnes. Despite China's leadership in production, Spain accounts for 84% of exports worldwide (Caballero and Fernández, 2004).

Loquat blooms in autumn on apical panicles formed on current year wood. Fruits develop during winter and mature in early spring, arriving at markets before any other spring fruit. Earliness is therefore paramount in this crop, which reaches its highest prices at the beginning of the season. Loquat blooming date varies over years and locations suggesting a strong environmental influence (Morton, 1987). In tropical and subtropical fruit trees, water stress has been successfully used to promote flowering (Chaikiattiyos et al., 1994). For instance, out of season flowering can be promoted in different species of *Citrus* by a shortage of water. This practice, known as forzatura, consists of the complete suppression of watering during summer until optimum wilting is reached (Barbera et al., 1981; Maranto and Hake, 1985). Trees are then released from water stress to induce a second bloom which sets a more valuable crop next summer (Maranto and Hake, 1985).

* Corresponding author. Tel.: +34 950 015559; fax: +34 950 015939.
E-mail address: jcuevas@ual.es (J. Cuevas).
0378-3774/$ – see front matter © 2006 Elsevier B.V. All rights reserved.
doi:10.1016/j.agwat.2006.11.005

During recent years, we have developed a strategy of regulated deficit irrigation (RDI) that induces earlier flowering in 'Algerie' loquat. Postharvest RDI, from mid-May to the end of August, advances blooming date up to 3 weeks (Hueso and Cuevas, 2004), leading to earlier harvest (Hueso, 2005). However, we have noticed in water stressed trees that the advancement in prior-to-anthesis phenological stages was partially lost at bloom due to a delay during the last steps of flower development. We also found that the size of the flowers diminished due to the long period of water stress and that, in response to the negative effects on flowers, the resulting fruit set was occasionally reduced.

Regardless of the merits and deficiencies of the previous deficit irrigation strategy, an improvement of postharvest RDI in loquat seems possible by an accurate selection of its optimal dates, intensity and duration. Here, we present results regarding the optimal period for RDI in 'Algerie' loquat.

2. Materials and methods

The trial was conducted during two consecutive seasons (2002/2003 and 2003/2004) at the Experimental Station of Foundation Cajamar in El Ejido (Almería, SE Spain; 36°48′N, 2°43′W). Mean annual rainfall in the area is 231 mm, whereas evaporation from an "A" pan (Epan) located in the Experimental Station reaches an average value of 1922 mm $year^{-1}$. A mature orchard of 'Algerie' trees grafted on 'Provence' quince was used for the experiment. The trees were vase-trained and spaced 5 m × 2.5 m the first year. In the second season, every second tree in the row was removed to minimize the shading of the canopy. Two lines of 2.3 L h^{-1} pressure compensating emitters per tree row were used to apply water. Emitters were extruded into the tubing every 0.5 m. The soil is a well-aerated sandy-loam (72.4% sand, 14.6% loam, and 13.0% clay) of pH 7.8. The soil gravimetric moisture content is 13.4% at field capacity, and 5.1% at wilting point.

Four irrigation treatments were applied. Three of them were RDI schedules that incorporated a reduction of 66% (in 2002/2003 season) or 75% (in season 2003/2004) of the monthly water needs in June, July or August (RDIJn, RDIJl and RDIAu, respectively). The rest of the season, the trees received 100% of the water requirements (Fig. 1). The fourth treatment was a control that received about 40% of Epan measured with a Class A pan placed in the orchard (around 7600 m^3 ha^{-1}). Control trees were watered two–three times per week during fall and winter, four times in spring and up to six during summer. During the period of water deficit, the RDI trees received the same volume of water applied to controls in each watering operation, but we reduced proportionally the number of applications per week. The amount of water applied per irrigation oscillated between 3.8 and 5.3 mm. During the experiment no rainfall interfered with the application of the RDI treatments in either year. The evaporative demand was higher the second year (1878 mm versus 2084 mm for 2002 and 2003, respectively), especially during the deficit irrigation period. Monthly accumulated evaporation figures (mm) were: 165.6, 163.9 and 152.1 for June, July and August 2002, respectively. The corresponding values for 2003 were: 188.4, 192.6, and 186.2.

A randomized complete-block design was used with three replications per treatment. Each replication consisted of one row of trees. The rows of trees were hydraulically isolated by placing a plastic film 1 m deep, where most quince roots remain restricted. The central trees of each row were chosen for measurements. The same irrigation treatments were applied to the same tree rows during both years.

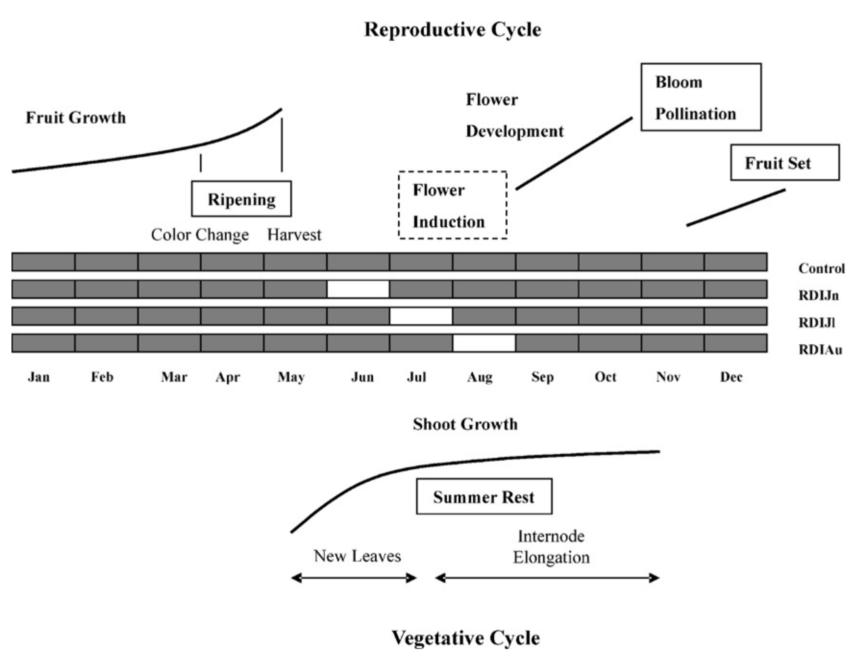

Fig. 1 – Annual cycle of loquat in Almería (Spain) showing RDI treatments which consist of reductions of 66% (season 2002/2003) or 75% (season 2003/2004) of monthly water needs (in June, July or August). The rest of the season RDI trees received the same amount of water as controls (about 40% of Epan).

Plant water status in response to the treatments was monitored by measuring predawn and mid-day leaf water potential (Ψw_{pd}, and Ψw_{md}, respectively), before, during, and after the period of water deficit. Ψw was estimated using a pressure chamber following the procedure of Scholander et al. (1965). Six mature leaves per treatment were sampled from the outer part of the canopy at 1.5–2 m height. The soil water content was estimated using Watermark (Irrometer Co. Inc.) electrical-resistance blocks. The changes in soil moisture were followed using three sets of two sensors, one set per block and treatment, with sensors placed at 30 and 60 cm depth. Watermarks measure in the range of −10 to −200 kPa.

Flowering date, intensity and quality, and the resulting harvest date, yield, fruit quality and value were compared among treatments. Depending on the measured parameter, a variable number of flowers, panicles or fruits were subsampled from each tree. The blooming course was recorded every other day on six trees per treatment and rated based on phenological stages previously described by Cuevas et al. (1997). Bloom intensity was estimated in every treatment by the percentage of main and lateral shoots developing an apical panicle. The number of flowers per panicle formed in the main shoots was counted. Flower quality was estimated by its size and fertility. The size of the flowers was measured by their dry weight collecting at the balloon stage a sub sample of 10 king flowers per tree. The effects of deficit irrigation on flower fertility were evaluated by counting the number of fruits initially enlarged on eight unthinned panicles per tree. The remaining panicles of the trees were hand-thinned at bloom by removing the two upper thirds of the panicle length. The final fruit set was calculated at harvest as the number of fruits per panicle on these thinned inflorescences. Harvest was performed at commercial maturity based on fruit skin color. The average harvest date was considered the day in which 50% of the total yield had been harvested. The amount of precocious yield was calculated by considering the percentage of yield harvested before 15 April (Gariglio et al., 2002). The commercial yield and the number of marketable fruits were obtained from every tagged tree and used to calculate the average fruit weight. Harvested fruits were graded according to commercial fruit size classes. Different maturation parameters were also measured at harvest, namely soluble solids content, acidity and skin color of the fruits.

Finally, fruit value was compared among treatments by considering the prevalent prices in the main Spanish markets at harvest date. The gross revenue considered the fruit value, the yield and the water savings for each treatment. The water fee in the area is established at around 0.20€ per m^3.

3. Results

'Algerie' control trees received 7671 $m^3\ ha^{-1}$ in the first season, and 7428 $m^3\ ha^{-1}$ in the second one. This volume of water kept the soil around the control trees close to its field capacity throughout the year, as Watermark readings showed (Fig. 2). A 66% reduction of the estimated water demands during June and July only resulted in a concomitant slight drop in soil moisture (Fig. 2). Greater effects in the water soil content were noted when the deficit irrigation was implemented in August

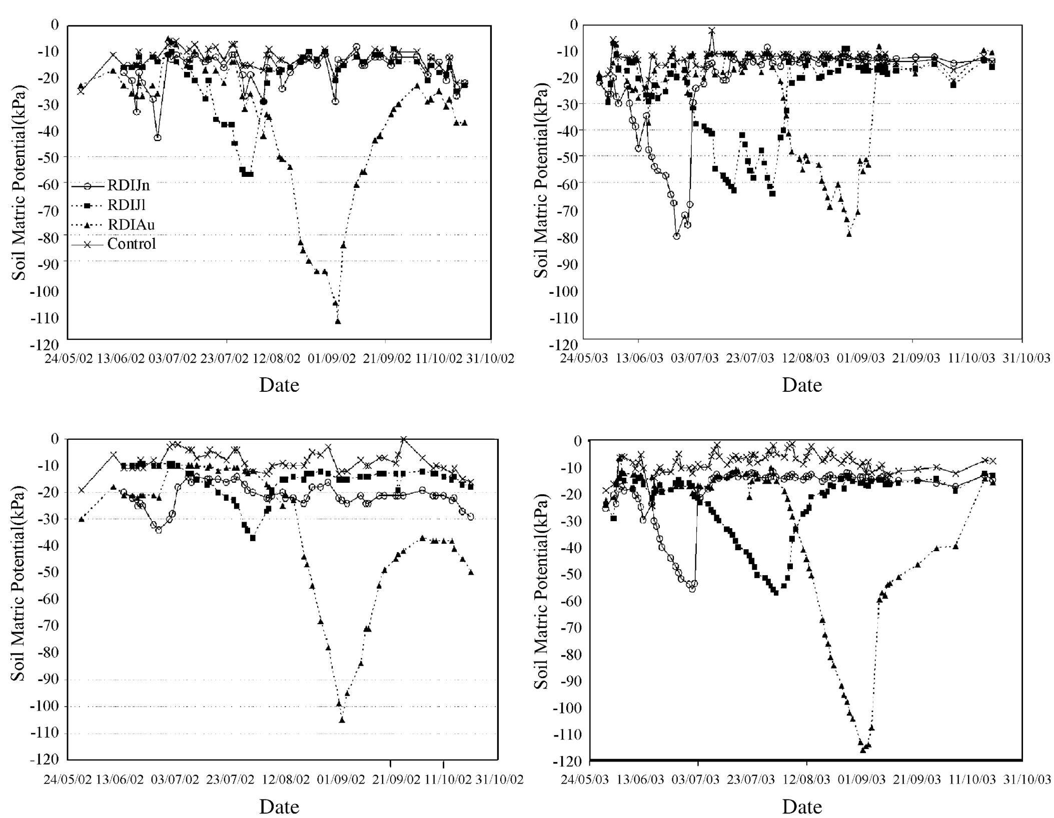

Fig. 2 – Watermark readings before, during, and after regulated deficit irrigation treatments at 30 cm (top) and 60 cm deep (bottom) during 2002/2003 (left) and 2003/2004 (right) seasons.

Table 1 – Leaf water potential at predawn (MPa) in selected dates in response to regulated deficit irrigation treatments and after full restoration of irrigation

Treatment	May (before treatments)		End of June		End of July		End of August		October (after treatments)	
	2002	2003	2002	2003	2002	2003	2002	2003	2002	2003
RDIJn	−0.272 a	–	−0.308 a	−0.505 a	−0.197 a	−0.330 b	−0.182 b	−0.265 ab	−0.092 a	−0.288 a
RDIJl	−0.273 a	–	−0.230 b	−0.308 bc	−0.218 a	−0.615 a	−0.212 b	−0.227 b	−0.118 a	−0.308 a
RDIAu	−0.203 a	–	−0.220 b	−0.232 c	−0.180 a	−0.287 b	−0.307 a	−0.327 a	−0.090 a	−0.305 a
Control	−0.198 a	–	−0.215 b	−0.328 b	−0.185 a	−0.368 b	−0.160 b	−0.210 b	−0.080 a	−0.255 a

Mean comparisons in columns by Duncan's test at $P \leq 0.05$.

and in 2003/2004, when the water reduction reached 75% of monthly needs (Fig. 2). The rest of the year the records of Watermark sensors placed at 30 cm depth were between −10 and −25 kPa in all RDI treatments. The savings in water during 2002/2003 ranged between 750 $m^3\,ha^{-1}\,year^{-1}$ for RDIJl and 460 $m^3\,ha^{-1}\,year^{-1}$ for RDIJn. The savings were higher in the second season, and ranged between 796 $m^3\,ha^{-1}\,year^{-1}$ for RDIJl and 621 $m^3\,ha^{-1}\,year^{-1}$ for RDIJn. The water savings during August fell in an intermediate position with 710 and 744 $m^3\,ha^{-1}\,year^{-1}$ for the first and the second season, respectively.

Ψw_{pd} measurements seemed to reflect the plant response to water shortages better than Ψw_{md}, although a similar conclusion can be obtained from both comparisons. From the records of 2002/2003, we may deduce that the 66% reduction in the water applied caused only slight water stress in 'Algerie' trees. The effects were more noticeable during the 2003/2004 season when Ψw_{pd} values reached −0.5 and −0.6 MPa for RDIJn and RDIJl, respectively. These records were significantly higher than those observed in controls and than those from other treatments without water restrictions during these months (Table 1). A similar trend is observed for Ψw_{md} (data not shown). Despite the documented drop in soil moisture, RDI during August 2002 and August 2003 produced only slight stress in the plant as indicated by $\Psi w_{pd} = -0.3$ MPa. This conclusion is confirmed by the lack of differences in Ψw_{md} between RDIAu trees and controls at the end of August of both seasons (data not shown). All trees were recovered from water deficit on October (Table 1).

The RDI treatments strongly modified bloom phenology. Control trees reached full bloom on 7 November in 2002 and on 26 November in 2003. Mean full bloom date for 'Algerie' during the last 7 years in the orchard is established on 21 November. The early bloom of the control trees during the year 2002 was due to a more rapid complementation of the heat requirements from bud break to bloom, and it bore no relation to previous water management. Even so, the treatments of deficit irrigation, when properly timed, enhanced bloom earliness of loquat (Fig. 3). The effects were greater for RDIJl, although RDIJn also caused earlier bloom. On the contrary, RDIAu delayed bloom date in the 2002/2003 season, and had a minor positive effect during 2003/2004 season (Fig. 3).

There were no significant differences among treatments in the percentage of main and lateral shoots developing panicles in any season (data not shown). On the other hand, RDI trees tended to produce more flowers per panicle than controls in both years, although some differences emerged between years. In the first season, the average flower number per panicle was low and the differences among treatments were not significant ($P = 0.69$), while in the second season, when the

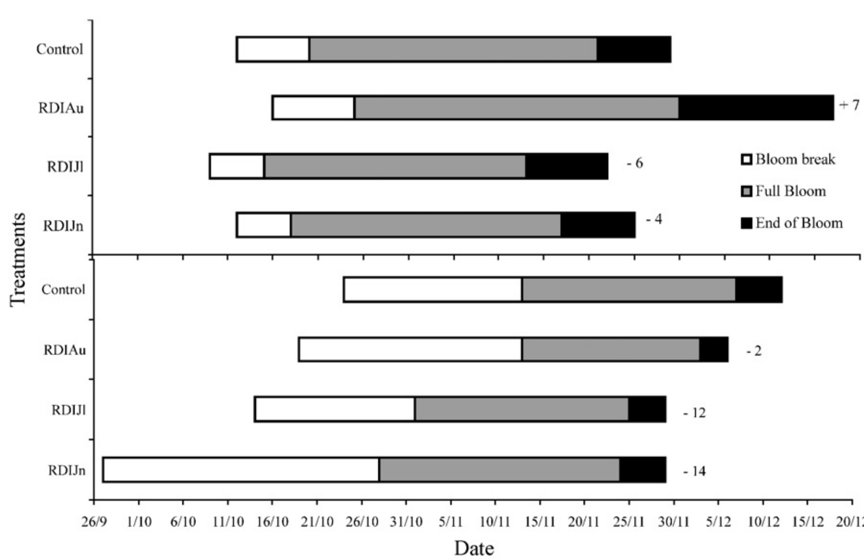

Fig. 3 – Blooming course in 'Algerie' loquat in control trees and after regulated deficit irrigation either in June, July or August. Control trees reached full bloom on 7 November 2002, and on 26 November 2003. Numbers mean displacements in days from full bloom in controls. Top: season 2002/2003. Bottom: season 2003/2004.

Table 2 – Effects of water deficit applied in different months on flower number, size and fertility of 'Algerie' loquat

Treatment	Flower per panicle		Flower dry weight (mg)		Flower fertility (initial set as fruit per panicle)	
	2002/2003	2003/2004	2002/2003	2003/2004	2002/2003	2003/2004
RDIJn	140 a	228 b	45.7 a	54.0 a	7.6 a	15.4 a
RDIJl	123 a	244 a	47.7 a	51.7 ab	7.3 a	16.0 a
RDIAu	140 a	225 b	47.3 a	49.7 b	7.2 a	17.1 a
Control	116 a	179 c	49.0 a	54.3 a	7.3 a	13.4 a

Mean comparisons in columns by Duncan's test at $P \leq 0.05$.

water shortage was increased, the number of flowers per panicle was higher and the differences with respect to controls became significant ($P = 0.0001$) (Table 2). The average number of flower per panicle in control trees in the last 7 years is 187.

The shortages in water had negative consequences on the size of the flower, especially with larger water cuts and in late RDI treatments. In the first season, the differences in the dry weight of the flower were slight and not significant ($P = 0.74$). In the second season, the differences were greater, significant ($P = 0.046$) and gradual, since losses in flower dry weight where higher as flower induction and differentiation progressed from June to August. Control trees produced the heaviest flowers and RDIAu trees the lightest ones (Table 2). The size of the flower did not, however, affect its fertility since the number of fruits initially formed in unthinned panicles was equally high for all treatments in both seasons (Table 2). A seasonal effect on initial fruit set was, on the other hand, patent in response to the higher number of flowers per panicle produced in 2003/2004.

As a consequence of their earlier blooming, harvest occurred sooner in trees that were water stressed during June and July. The average harvest date was advanced, and the precocious yield was enhanced for these treatments (Table 3). On the contrary, late water stressed trees (RDIAu) showed slight or no advancement in harvesting (Table 3). The effects of RDI on precocious yields were less noticeable in 2003/2004 due to a general delay in harvesting this season (compare, for instance, in Table 3 the harvest dates in control trees in 2002/2003 versus 2003/2004). The average fruit value per harvested kilogram reflects better the advantages of some RDI treatments (Table 3). The water restriction during July increased the fruit value between 0.10 and 0.12€ per kg, depending on the season. The fruit value enhancement was also noteworthy for water stressed trees in June. However, this treatment presented a more scattered ripening and needed more harvesting operations reflecting its extended blooming (Fig. 3). As happened with harvest time, the fruit value showed slight or no improvement under RDIAu (Table 3).

Fruit set at harvest did not vary among treatments (data not shown). The amount of yield did not differ among treatments either ranging between 25.6 and 19.0 kg per tree in 2002/2003 and between 49.5 and 33.0 kg per tree in 2003/2004. The general increase in the number of harvested kilograms per tree in 2003/2004 yield reflects a larger tree canopy achieved by removing every second tree after 2002/2003 harvest. Strikingly, the water stress during August, which was proved to be detrimental for flower development, allowed the highest yield in both seasons, followed by RDIJl. Fruit weight was statistically unaffected by water stress ($P = 0.52$), although the distribution of marketable fruits into commercial grades reflects a slight displacement to larger fruit classes under RDIJl and RDIAu, especially in the second season (data not shown). Nevertheless, RDI effects seem less important in this respect. Other fruit quality parameters such as TSS content, acidity, and color did not differ among treatments in either season (data not shown).

4. Discussion

The aim of the RDI strategies here compared was not to cause severe water stress to force loquat bloom to occur. On the contrary, the purpose of this comparison was to advance as much as possible natural loquat flowering by a mild water stress which minimizes the damage to flowers and does not reduce fruit set or size. The best RDI for loquat probably relies on moderate water stress limited to non-critical periods. In this sense, the 66% reduction in water applied during June, July or August in 2002 caused a minimal non-significant reduction in the size of the flowers. In the second season, when the water shortage was elevated to 75%, the deficit irrigation reduced flower size when implemented during August, but did not cause any significant loss when implemented in June or July (Table 2).

Water deficit during June and July also turned out to be more convenient than deficit irrigation during August in terms of

Table 3 – Effects of water deficit applied in different months on mean harvest date, the amount of precocious yield and, consequently, on the average fruit value

Treatment	Mean harvest date		Precocious yield (% before 15 April)		Average fruit value (€ kg^{-1})	
	2002/2003	2003/2004	2002/2003	2003/2004	2002/2003	2003/2004
RDIJn	23 April	27 April	22.5	13.6	2.49	2.65
RDIJl	20 April	29 April	20.4	9.8	2.53	2.55
RDIAu	26 April	1 May	14.0	7.2	2.41	2.48
Control	25 April	3 May	17.7	9.1	2.43	2.43

early blooming (Fig. 3). Such flowering advancement may be due to modifications in the plant hormonal balance (due to root signals) which eventually lead to earlier flower induction. However, since loquat blooms terminally, the growth of the shoot must also be completed before the apical bud differentiates. To what extent an earlier cessation of shoot growth and/or hormonal balance changes are responsible for the earlier blooming has yet to be determined. However, the importance of an accurate timing for successful RDI is highlighted by the bloom delay observed in 2002/2003 and the damage to flowers in response to water deficit during August.

Finding non-critical periods is a recurrent aspiration in many RDI studies. In their search many authors focus on postharvest. However, when adopting a strategy of postharvest deficit irrigation, the negative effects that water deficit may have on flowers that are differentiating concomitantly inside the bud must be considered. Early works on apricot by Brown (1953) and Uriu (1964) demonstrated that a reduction in the water applied after harvest has profound implications on flower development and yield in the following season. More recently, Torrecillas et al. (2000), also for apricot, observed a reduced fruit set the following spring after early postharvest RDI due to greater fruitlet abscission. Lamp et al. (2001) cited work by Goldhamer and colleagues, who found that, in almond, water stress during flower development (the previous summer) reduced the next season's crop yield because of reduced flower quality. Scanning Electron Microscopy studies carried out after this experiment date panicle initiation in 'Algerie' loquat at the end of July, therefore confirming that water stress in August may restrain the normal flower development (Rodríguez et al., 2006). Nevertheless, in our study the negative effects on the flowers caused by RDIAu did not reduce flower fertility, yield or fruit size.

By comparing the effects of deficit irrigation on bloom date during 2002/2003 versus 2003/2004, we can say that the greater the water shortage was, the earlier the trees bloomed. However, at some level there must be a compromise between bloom advancement and negative effects on flower fertility, depending also on the phenological stage in which the plant is, and on the velocity of recovery of both soil and plant. When compared with our previous experiments, the advancements in blooming and harvest achieved in this study were modest. Taking into consideration the shorter duration of the water deficit period in this experiment, we had decided to increase monthly water savings from around 45% in our prior experience up to 66% per month, in the first season, and up to 75% per month, in the second one. However, the records from leaf water potential indicate that we were not able to cause similar levels of water stress when we reduced the water deficit period. Despite the fair advancement in harvest date, the profits of farmers increased remarkably when we implemented RDI during July. Water deficit during July augmented profits between 5800 and 17250€ per ha. Although the profits are strongly affected by the high yield obtained under RDIJl in the second season, the improvement in the fruit value is undeniable.

In short, RDI has been proven a suitable and a more profitable strategy to produce loquat. Our results point out to July as the optimal date for RDI in 'Algerie' loquat due to its greater effects on bloom and harvest dates, its better economical results, and its harmlessness for flower development. Moreover, preliminary results from current research indicate that a deficit irrigation of 75% water requirements over 6 weeks from mid-June to the end of July advances 'Algerie' full bloom by an astonishing 27 days.

Acknowledgements

This research was partially supported by the UE FEDER funds through projects AGL 2002-01108 and AGL2005-03972 of the Spanish Ministry of Education and Science. Cajamar kindly provided support for orchard management. Guillermo Zaragoza improved the readability and grammatical correctness of an earlier draft.

REFERENCES

Barbera, G., Fatta del Bosco, G., Occorso, G., Lo Cascio, B., 1981. Some aspects on water stress physiology on forced lemon (*C. limon* Burm.) trees. Proc. Int. Soc. Citric. Cong. (Tokyo) 2, 522–523.

Brown, D.S., 1953. The effects of irrigation on flower bud development and fruiting in the apricot. Proc. Am. Soc. Hort. Sci. 61, 119–124.

Caballero, P., Fernández, M.A., 2004. Loquat, production and market. Options Méditerrannéennes Serie A 58, 11–20.

Chaikiattiyos, B.S., Menzel, C.M., Rasmussen, T.S., 1994. Floral induction in tropical fruit trees: effects of temperature and water supply. J. Hort. Sci. 69, 397–415.

Cuevas, J., Gavilán, J., Lorente, N., 1997. Fenología del níspero japonés (Cv 'Algerie') en la Costa de Almería. Actas de Hort. 16, 490–495.

Gariglio, N., Castillo, A., Juan, M., Almela, V., Agustí, M., 2002. El níspero japonés. Técnicas para mejorar la calidad del fruto. Sèrie Divulgació Técnica no 52. Consellería de Agricultura, Pesca y Alimentación de la Generalitat Valenciana, Valencia.

Hueso, J.J., 2005. Riego deficitario controlado en níspero japonés. Thesis. University of Almería.

Hueso, J.J., Cuevas, J., 2004. Deficit irrigation effects on flowering of loquat. Options Méditerranéennes Serie A 58, 105–108.

Lamp, B.M., Connell, J.H., Duncan, R.A., Viveros, M., Polito, V.S., 2001. Almond flower development: floral initiation and organogenesis. J. Am. Soc. Hort. Sci. 126, 689–696.

Lin, S., Sharpe, R.H., Janick, J., 1999. Loquat: botany and horticulture. Hort. Rev. 23, 233–276.

Maranto, J., Hake, K.D., 1985. Verdelli summer lemons, a new option for California growers. Cal. Agric. 39, 4.

Morton, J., 1987. Loquat. In: Julia, F., Morton (Ed.), Fruits of warm climates, Miami, Fla. distributed by Creative Resource Systems, Winterville, N.C., pp. 103–108.

Rodríguez, M.C., Hueso, J.J., Cuevas, J., 2006. Flower development in 'Algerie' loquat under Scanning Electron Microscopy. In: II Intern. Symp. on Loquat, Guangzhou, China.

Scholander, P.F., Hammel, H.T., Bradstreet, E.D., Hemmingsen, E.A., 1965. Sap pressure in vascular plants. Science 148, 339–346.

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

Uriu, K., 1964. Effect of postharvest soil moisture depletion on subsequent yield of apricots. Proc. Am. Soc. Hort. Sci. 84, 93–97.