Spanish Journal of Agricultural Research (2004) 2 (2), 157-165

Cost-benefit analysis of almond orchard under regulated deficit irrigation (RDI) in SE Spain

J. García, P. Romero, P. Botía* and F. García

Instituto Murciano de Investigación y Desarrollo Agrario y Alimentario (IMIDA). C/ Mayor, s/n. 30150 La Alberca (Murcia). Spain

Abstract

A cost-benefit analysis was performed for a mature, commercial almond plantation [*Prunus dulcis* (Mill.) D.A. Webb] cv. Cartagenera in SE Spain to determine profitability under regulated deficit irrigation (RDI) and an irrigation regimen covering 100% crop evapotranspiration (ETc). The plantation was subjected to two drip irrigation treatments for four years: T1 (control) — irrigation providing 100% ETc coverage throughout the growth cycle, and T2 (RDI treatment)— an irrigation strategy that provided 100% ETc except during the kernel-filling period, when only 20% ETc coverage was provided. A 28% water saving was achieved with this RDI strategy, while almond production was reduced by only 7%. RDI represented an increase in the efficiency of water use, and cost-benefit analysis showed a 10% mean annual reduction in operating costs compared to the control irrigation regimen. This reduction in costs was basically due to the 28% saving in the cost of water and the corresponding saving in electricity. RDI treatment had a greater short-term than long-term benefit per unit cost. The irrigation costs per kg of almond were 0.76 € kg^{-1} and 0.58 € kg^{-1} under RDI and control conditions respectively. The break-even point was lower under RDI; each kilogram cost 0.05 € less to produce than in the control conditions. The results show how RDI, and specifically how this irrigation strategy, may be considered agronomically and economically appropriate in semiarid conditions.

Key words: *Prunus dulcis,* water use efficiency, break-even point.

Resumen

Estudio económico mediante análisis de costes del almendro en riego deficitario controlado (RDC) en el sureste español

Se realizó un estudio económico mediante análisis de costes en una plantación comercial de almendros [*Prunus dulcis* (Mill.) D.A. Webb] cv. Cartagenera en condiciones de riego deficitario controlado (RDC) en el sureste español. Durante 4 años se aplicaron dos tratamientos de riego localizado: T1 (control), regado al 100% de la ETc durante todo el cultivo, y T2 (estrategia de RDC), regado al 100% de la ETc, excepto durante la fase de llenado de grano, donde se aplicó el 20% ETc. El ahorro de agua obtenido en el tratamiento de RDC fue de un 28% respecto al control, aunque la producción de almendra disminuyó tan solo un 7%. Este hecho se reflejó en un incremento de la eficiencia productiva en el uso del agua en RDC. El análisis de costes reflejó una reducción media anual de un 10% en el capital de explotación del tratamiento T2 respecto al control, fundamentalmente debido a una reducción del 28% en los costes del agua de riego y del consumo de energía eléctrica. La estrategia de RDC obtuvo un mayor aumento en el beneficio generado por unidad de capital gastado en el proceso productivo, a corto plazo, respecto a largo plazo. El coste del riego (agua + energía eléctrica) por kg de almendra fue de 0,76 € kg^{-1} frente a 0,58 € kg^{-1} para T1 y T2 respectivamente. Estos resultados muestran que el RDC puede resultar apropiado en ambientes semiáridos, debido al importante ahorro de agua y a la mayor rentabilidad económica que se consigue en estas condiciones de riego.

Palabras clave: *Prunus dulcis,* eficiencia en el uso del agua, umbral de rentabilidad.

Introduction

Spain is the Mediterranean's largest producer of almonds and the second largest producer and exporter in the world: the country produces 17% of the world's almond crop and is responsible for 13% of global almond exports. Its main competitor is the USA, where, although the area given over to almond production is much smaller [165,000 ha (Kester and Ross, 1996) compared to 629,100 in Spain (Anonymous, 1999)], production per hectare is some ten times greater:

* Corresponding author: pablo.botia@carm.es
Received: 24-03-03; Accepted: 17-03-04.

mean American production is some 1,200-1,800 kg of almond grain ha^{-1} (Tous Martí, 1995) compared to only 150 kg ha^{-1} in Spain. Productivity is lower in Spain because almonds are raised under dry-land cultivation conditions and on marginal land, unlike in California where production is intensive, highly technical, and nearly always under irrigation (up to 10,000 or even 11,000 m^3 ha^{-1} $year^{-1}$ (Fereres, 1978; Goldhamer, 1996a; Goldhamer and Viveros, 2000). Together, these factors greatly increase American productivity. Such quantities of water are justified in California since the irrigation period is about two months longer than in the Mediterranean, but they are still very high compared to the annual water needs of Mediterranean almonds [some 6200 m^3 ha^{-1} $year^{-1}$ (Girona and Marsal, 1995) to 6500 m^3 ha^{-1} $year^{-1}$ (Torrecillas *et al.*, 1989; Girona *et al.*, 1994)]. In semi-arid southeastern Spain, the scarcity of water makes the supply of such quantities for irrigation very difficult, and water becomes the main limiting factor of production. This problem necessitates the rational use of water; its consumption needs to be reduced, and the efficiency of its use improved.

Regulated deficit irrigation (RDI) strategies are among the methods that improve the efficiency of water use in fruit tree cultivation. Numerous studies involving these strategies indicate that certain types of fruit tree, such as pear, peach and citrus, can tolerate moderate water deficit during certain periods of the annual cycle with no important effects on production (Mitchell and Chalmers, 1982; Mitchell *et al.*, 1984 and 1989; Domingo *et al.*, 1996). Some particularly interesting strategies for use with almonds have been described in recent years, among which is the reduction of water provision during kernel-filling through to harvest. Some very satisfactory results have been obtained in this way. The reduction of irrigation water by 40-60%, or even 80%, during this phase —but avoiding water deficit during rapid vegetative and fruit growth (Martín and Kester, 1978; Girona and Marsal, 1995)— has been found generally productive, largely because of the species' reduced sensitivity to water stress during this period (Girona, 1992; Goldhamer, 1996b; Goldhamer and Viveros, 2000; Romero, 2002).

Although almonds can be a profitable crop when irrigation is available, in southeastern Spain, with its structural, exploitational and marketing problems, profits are very small. Nevertheless, given the species' adaptation to water scarcity (Fereres *et al.*, 1981), it is in these semi-arid areas where RDI could offer an alternative as a prototype of sustainable agriculture (Salazar and Melgarejo, 2002). This type of irrigation could increase long-term yields and sustainability.

Few economic studies have been performed on the profitability of RDI strategies (Hargreaves *et al.*, 1984), and although almonds are known to grow well under these irrigation conditions, the economics of this kind of almond production have been little investigated despite the social repercussion this might have in semi-arid areas.

The aim of this work was to determine indicators of economic and productive efficiency of almond cultivation in southeastern Spain, and to determine break-even points (taking into account the price of water and the market price of almonds) for RDI and non-RDI irrigated crops.

Materials and Methods

This study was performed over a period of four years (1997-2000) at a 13 year-old commercial almond (*Prunus dulcis*, Mill. Webb) cv Cartagenera (cv. Ramillete as pollinator) plantation located near the town of Aljorra, Murcia (Spain). The trees were grown on almond rootstocks in a 7 × 5 m spacing pattern. The soil had a fine clay texture down to 1-m, but below this it was a clayey silt. The irrigation water used had an electrical conductivity (EC) of 1.3 dS m^{-1} and a chloride content of 10.5 meq L^{-1}. Two experimental irrigation treatments were maintained for a period of four years: a control regimen (T1) that took care of 100% of the crop's evapotranspiration (ETc) losses over the annual cycle, and an RDI (T2) regimen that covered 100% of ETc over the whole cycle except for the kernel-filling period (beginning of June to beginning of August). During this time, water supply was reduced by 80% of ETc coverage. Irrigation was programmed weekly using ETo data calculated by the Class A pan method (Doorenbos and Pruitt, 1977), from the tank coefficient (Fereres, 1987), and from the crop coefficients (Kc) for almond orchard in the study area. The amount of rain that had fallen in the previous week was also taken into account. The Kc was 0.22 for January, 0.33 for February, 0.42 for March, 0.52 for May, 0.61 for June, July, August and September, 0.54 for October, 0.38 for November and 0.23 for December. The quantities of water used were adjusted weekly according to soil matric potential, using tensiometers in the control treatment. These were located in the drip bulbs at depths of 30, 60 and 90 cm, and the plots irrigated to maintain the matric potential of those at 30 cm between 10 and 30 kPa.

During the experimental period, the mean annual evapotranspiration reference value (Class A pan method) was 1,103 mm. Values were very similar every year. Rainfall was variable, depending on the year; the mean was 282 mm per year but 0 mm during the stress period. The mean annual quantity of water supplied by the RDI system for the four years was 436 mm compared to 603 mm by the non-RDI system (Table 1).

The drip irrigation system consisted of one carrier line and four self-compensating emitters (3.5 L h^{-1}) per tree set 1-m apart. Pruning was performed annually. Normal local practice was followed with regard to plant disease treatments and cultivation work. Tree growth variables such as leaf area, trunk diameter and canopy volume were measured periodically. 130 kg ha^{-1} of N, 58 kg ha^{-1} of P_2O_5 and 78 kg ha^{-1} of K_2O were provided as a nitrogenated solution (32% N), ammonium nitrate (33.5% N), phosphoric acid (54% P_2O_5) and potassium nitrate.

The experimental design consisted of four random blocks with one repetition per treatment and block (three trees per repetition). Every year, the production of each tree was monitored independently. The harvest of each tree was separated into hull tight and commercial (full hull split) fractions.

Cost analysis (Mishan, 1982; Mao, 1986; Ballestero, 2000) was used to determine a number of economic indices: *profit/operating cost, profit/investment, incremental cost* and *break-even points* (Blanco-Dopico, 1994; Layard and Glaister, 1994; Cantero Desmartines, 1996). *Profit* is defined as the difference between income and costs. It therefore refers to pre-tax gross profit. The *profit/operating cost* index is the relationship between the profit and the capital circulating in each annual cycle. The *profit/operating cost* index was taken as the ratio between the profit and the capital circulating in each annual cycle (variable cost + fixed running costs). The *profit/investment* ratio shows the relationship between profit and the initial capital invested (long term). The *incremental cost* shows the average variable unit cost as a reflection of the operational efficiency. In this case it refers to the variable cost of a kilogram of almonds, not counting fixed costs (the figures for both treatments in this study were very similar) (Tables 2 and 3). Lastly, the *break-even point* for the average price obtained indicates the price per kilo of almond above which the business begins to generate profit; in other words, it indicates overall technical and economic efficiency.

Table 1. Annual reference of evapotranspiration (Class A pan[1]), rainfall, and water supplied by the two irrigation treatments during the study period

	Year			
	1997	**1998**	**1999**	**2000**
ETc (mm)	1,103	1,136	1,074	1,099
Rainfall (mm)	295	200	243	389
Water supplied (mm)				
Control (T1)	571	602	594	644
RDI (T2)	387	442	441	475

[1] Pan coefficient (Kp) obtained from the expression proposed by Fereres (1987) for evaporometers on grasslands.

To carry out such an analysis, a typical plantation must be established, in which all the normal agricultural practices of the study area are carried out. This meant that the plantation had to have a minimum area of 5 ha (the minimum for the area). Land ownership was considered a fixed asset which did not depreciate (Ballestero, 2000). We studied an average year in the period of full production, using data from the experiment and other data referring to irrigated almond production in the Campo de Cartagena (where the plantation is situated) (Salazar and Melgarejo, 2002).

The acquisition of machinery necessary for cultivation (50-60 hp tractor with appropriate attachments, a 2000 L tank and a tipping trailer) was not taken into account since the repayment of such equipment by the experimental plantation alone would render the business unviable. Machinery was therefore considered as a working cost paid to external contractors.

Any opportunity costs (Samuelson and Nordhaus, 1990) generated were included according to long or short-term availability of the capital (six months or one year). In the calculation of this cost, an interest rate of 5% was estimated in line with the money market values then current. Costs were divided into structural overheads, running costs and variable costs (Ballestero, 1975; Mishan, 1982; Mao, 1986) (see annex). Total income was calculated bearing in mind the mean sale price to the cooperatives of the Murcia region from 1998-2002 (2.90 € kg^{-1}) (Tables 2 and 3). This information was obtained from the statistics department of the Agricultural, Water and Environment Council of the Region of Murcia. All calculations of profitability were based on this mean price.

Table 2. Annual cost-benefit for a 5 ha commercial almond orchard irrigated to cover 100% of water needs (100% ETc) in Murcia (1997-2000)

Fixed costs							
Cost	**Useful lifetime (years)**	**Initial value (€)**	**Final value (€)**	**Interest (%)**	**Amortization/ circulating capital[1] (€)**	**Opportunity costs (€)**	**Total (€)**
Structural overheads							
Shed for storage of irrigation equipment	20	9,256	1,851	0.05	370	19	389
Irrigation equipment	15	4,231	423	0.05	254	13	267
Irrigation network	15	4,976	498	0.05	299	15	313
Orchard	20	3,947	0	0.05	197	10	207
Various materials	5	270	0	0.05	54	3	57
Regulating water tank	20	10,725	2,145	0.05	429	21	450
Total					1,603	80	1,683
Running costs[1]							
Annual pruning	1	451	0	0.05	451	23	474
Machinery	0.5	1,085	0	0.05	1,085	27	1,112
Crop protection treatments	0.5	215	0	0.05	215	5	220
Fertilizer	0.5	819	0	0.05	819	20	839
Herbicides	0.5	210	0	0.05	210	5	215
Maintenance	0.5	184	0	0.05	184	5	189
Leasing	1	0	0	0.05	0	0	0
Electricity	0.5	228	0	0.05	228	6	234
Fixed personnel	0.5	3,907	0	0.05	3,907	98	4,005
Total					7,099	189	7,288
Variable costs							
				Value ($€\ kg^{-1}$)	**Mean production (kg)[2]**	**Opportunity costs (€)**	**Total (€)**
Harvest				0.131	5,525	36	760
Irrigation				0.689	5,525	95	3,902
Total							4,662
Total income							
					Value ($€\ kg^{-1}$)	**Mean production (kg)**	**Total (€)**
Almonds					2.90	5,525	16,023
Total							16,023

[1] Amortization corresponds to amortizable goods or costs of structural overheads. Running costs are those for the growing cycle.
[2] Production of almond seeds for a 5 ha commercial orchard under the experimental conditions.

Table 3. Annual cost-benefit for a 5 ha commercial almond orchard irrigated with RDI in Murcia (1997-2000)

				Fixed costs			
Cost	**Useful lifetime (years)**	**Initial value (€)**	**Final value (€)**	**Interest (%)**	**Amortization/ circulating capital[1] (€)**	**Opportunity costs (€)**	**Total (€)**
Structural overheads							
Shed for storage of irrigation equipment	20	9,256	1,851	0.05	370	19	389
Irrigation equipment	15	4,231	423	0.05	254	13	267
Irrigation network	15	4,976	498	0.05	299	15	313
Orchard	20	3,947	0	0.05	197	10	207
Various materials	5	270	54	0.05	43	2	45
Regulating water tank	20	10,725	2,145	0.05	429	21	450
Total					1,592	80	1,672
Running costs[1]							
Annual pruning	1	415	0	0.05	415	21	436
Machinery	0.5	1,080	0	0.05	1,080	27	1,107
Crop protection treatments	0.5	210	0	0.05	210	5	215
Fertilizer	0.5	819	0	0.05	819	20	839
Herbicides	0.5	210	0	0.05	210	5	215
Maintenance	0.5	184	0	0.05	184	5	189
Leasing	1	0	0	0.05	0	0	0
Electricity	0.5	165	0	0.05	165	4	169
Fixed personnel	0.5	3,907	0	0.05	3,907	98	4,005
Total					6,990	185	7,175
				Variable costs			
				Value (€ kg⁻¹)	**Mean production (kg)[2]**	**Opportunity costs (€)**	**Total (€)**
Harvest				0.137	5,135	35	739
Irrigation				0.536	5,135	69	2,821
Total							3,560
				Total income			
					Value (€ kg⁻¹)	**Mean production (kg)**	**Total (€)**
Almonds					2.90	5,135	14,892
Total							14,892

[1] Amortization corresponds to amortizable goods or costs of structural overheads. Running costs are those for the growing cycle.
[2] Production of almond seeds for a 5 ha commercial orchard under the experimental conditions.

Table 4. Annual cost-benefit for almonds under the two experimental regimens, 1997-2000

Treatment	Profit (€)	Profit/ operating costs	Profit/ investment	Marginal cost (€ kg^{-1})	Threshold price water (€ m^{-3})	Production costs (€ kg^{-1})
T1 (control)	2,390	0.20	0.0721	0.84	0.20	2.47
T2 (RDI)	2,485	0.23	0.0750	0.69	0.24	2.42

Results and Discussion

Reducing the water supply by 80% during kernel-filling (T2; RDI irrigation) led to a 3.97% higher *profit* compared to providing 100% ETc coverage throughout the crop cycle (T1; non-RDI) (Table 4). The *profit/operating costs* index was also 15.75% greater for T2 (Table 4). The increase in this index was due to lower variable and running costs. In turn, this was mainly due to a reduction in annual pruning costs (8%) and the lower consumption of crop health products as a result of the lower level of vegetative growth of the RDI trees (Table 5), plus a 28% reduction in total water costs and electricity consumption compared to T1 (Tables 2 and 3). This led to a 10% mean annual reduction in the working capital (variable and fixed running costs) in T2 compared to T1. The *profit/investment* index was greater for T2 than T1, but only by 4.02% (Table 4). These indices show the remarkable differences in profit generated per unit of capital spent, i.e., the profits generated compared to the capital invested in the short-term. The long-term profits generated were, however, notably lower.

The *incremental cost* was 18% lower in T2 than in T1, showing the T2 system to be economically more advantageous (Table 4). This was mainly due to the cost of irrigation (water plus electricity costs) per kilogram of almonds produced being notably lower (Tables 2 and 3): T2 irrigation costs were 0.58 € kg^{-1} compared to 0.76 € kg^{-1} for T1.

Table 5. Pruning weight, leaf area and canopy volume of trees under the two experimental regimens

Treatment	Mean leaf area (m^2 m^{-3})	Canopy volume (m^3)	Pruning weight (kg $tree^{-1}$)
Control	11.10	42.52	5.86
RDI	9.86	41.50	5.19
ANOVA	*	ns	**

ns: not significant. * $P < 0.05$. ** $P < 0.01$. Values followed by different letters are significantly different according to Duncan's multiple range test (95% CI).

Bearing in mind the 28% water saving obtained in T2, plus the fact that almond production only fell by 7% compared to T1 (Table 6), the productive efficiency of water use increased notably in this treatment: 0.24 kg of almonds were produced per cubic meter of water provided compared to only 0.18 kg in T1. This is reflected in the greater profits per cubic meter of water in the T2 treatment (Table 6). Girona *et al.* (1994) used the same RDI strategy in the north of Spain and obtained a circa 20% reduction in production but at even greater reductions in the water supply. They thus achieved high productivity efficiency (0.66 kg m^{-3}). However, it is difficult to compare these results with those of the present study since the productivity of the varieties studied, the soil and the climatic conditions of these areas (especially with respect to rainfall; 550 mm in NE Spain and 350 mm in Murcia) are quite different.

In California, studies with different RDI strategies coinciding with kernel-filling have reported slightly higher efficiencies of between 0.25 and 0.30 kg m^{-3}. However, the quantities of water provided were much greater (700 and 860 mm respectively) (Goldhamer, 1996a).

The maximum price for 1-m^3 of irrigation water was calculated, as was the minimum market price of almonds, in order to establish break-even points, i.e., the maximum and minimum prices (respectively) compatible with profitability (profit = 0). For T1, the maximum water price for the chosen almond market price (2.90 € kg^{-1}) was 0.20 € m^{-3}, while the minimum price of the product (i.e., equal to production costs) was 2.47 € kg^{-1} (Table 4). For T2, the maximum water cost was 0.24 € m^{-3} while the minimum almond price was 2.42 € kg^{-1}. These results show that RDI treatment

Table 6. Annual water supply, almond production, water use efficiency (WUE) and profit per m^3 of water consumed

Treatment	Water supplied (m^3 ha^{-1})	Almond production (kg ha^{-1})	WUE (kg m^{-3})	Profit (€ m^{-3})
T1 (control)	6,030	1,105	0.18	0.40
T2 (RDI)	4,360	1,027	0.24	0.57

produces almonds 0.05 € kg^{-1} cheaper than the control treatment, and that higher water costs can be borne (up to 0.04 € m^{-3} more).

These costs were not very different to those obtained in other edaphoclimatic conditions in the San Joaquin Valley in California in 1992, where total costs were around 2.2 \$ kg^{-1} of almonds produced (Klonsky and Blank, 1996) compared to 2.47-2.42 € kg^{-1} in the RDI conditions of this study. These results indicate that the greater profits obtained in the American system are not due to a reduction in production costs, but to a spectacular increase in almond production because of the amount of water supplied (water is not a limiting factor in California and it is much cheaper than in the SE of Spain) and to factors such as the type of soil (deeper and more fertile), the more productive varieties used, and the large areas under production. These factors can reduce costs and therefore the price of the almonds produced, and provide greater profits.

It is noteworthy that irrigation water prices in Murcia —and in particular those of the Campo de Cartagena area— are very variable. Subterranean water is being used to help make up the deficits in water supply from the transfer scheme between the Tagus and Segura basins. The water price used in this study was the lowest possible (0.126 € m^{-3}, corresponding to the price in the Cartagena area; see annex). The price of water from other sources in the area was 0.18-0.24 €; such prices would make almond cultivation unviable since at 0.126 € m^{-3} the *profit/investment* index was only 11.14%.

In semi-arid areas with reduced water supplies, RDI for almond cultivation seems to be an efficient alternative, both in agricultural and economic terms, although it is limited by low economic indices. From these data, we conclude that in semi-arid zones with strictly limited water supplies, RDI is an efficient alternative for almond cultivation. Expensive subterranean water would, however, reduce these indices. The use of poor quality salty water would be an additional risk. Nonetheless, RDI would appear to be an alternative that might become necessary given the water deficit of Spain's southeast.

Acknowledgements

The authors thank the *Fundación Instituto Euromediterráneo de Hidrotecnia* (Murcia region) for the grant provided to Pascual Romero.

References

ANONYMOUS, 1999. Anuario de Estadística Agraria. Ministerio de Agricultura, Pesca y Alimentación, Madrid, 565 pp.

BALLESTERO E., 1975. Principios de economía de la empresa. Alianza Editorial, Madrid, pp. 209-216.

BALLESTERO E., 2000. Economía de la empresa agraria y alimentaria. Ed. Mundi-Prensa, Madrid, 416 pp.

BLANCO DOPICO M.I., 1994. Contabilidad de costes: análisis y control. Ed. Pirámide, Madrid, 436 pp.

CANTERO DESMARTINES P., 1996. El análisis coste-beneficio en el sector agrario. Consejería de Agricultura y Pesca. Junta de Andalucía, Sevilla, 252 pp.

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. Irrigation Sci 16, 115-123.

DOORENBOS J., PRUITT W.O., 1977. Requerimientos hídricos de los cultivos. FAO, Rome, 194 pp.

FERERES E., 1978. Irrigation of almonds. In: Almond orchard management (Micke W., Kester D., eds.). Division of Agricultural Sciences, UCA, Berkeley, CA, Publ. 4092, pp. 71-76.

FERERES E., 1987. Necesidades hídricas de los cultivos. Eficiencia de los métodos de aplicación y consumos totales de agua a nivel de parcela. Proc of the Symposium: Necesidades hídricas de los cultivos y su abastecimiento. Madrid, 3-4 November.

FERERES E., ALDRICH T. M., SCHULBACH H., MARTINICH D.A., 1981. Responses of young almond trees to late season drought. California Agriculture 35, 11-12.

GIRONA J., 1992. Estrategias de riego deficitario en el cultivo del almendro. Fruticultura Profesional 47, 38-45.

GIRONA J., MARSAL J., 1995. Estrategias de RDC en almendro. In: Riego Deficitario Controlado. Fundamentos y aplicaciones (Zapata M. and Segura P., eds.). Ed. Mundiprensa, Madrid, pp. 99-118.

GIRONA J., MATA M., MARSAL J., MIRAVETE C., 1994. Efectos acumulados de 3 años de riego deficitario controlado en almendro (*Prunus dulcis* L.). Proc of the XII Jornadas Técnicas sobre Riegos, 15-17 September, Pamplona, Spain, Annex I, pp. 1-8.

GOLDHAMER D.A., 1996a. Irrigation scheduling. In: Almond Production Manual (Micke W.C., ed.). Division of Agriculture and Natural Resources, UCA, pp. 1-2.

GOLDHAMER D.A., 1996b. Regulated deficit irrigation of fruit and nut trees. Proc of 7th International Conference on Water and Irrigation, Tel Aviv, 13-16 May, pp. 152-167.

GOLDHAMER D.A., VIVEROS M., 2000, Effects of preharvest irrigation cutoff durations and post-harvest water deprivation on almond tree performance. Irrigation Sci 19, 125-131.

HARGREAVES G.H., ASCE, F., SAMANI Z.A. 1984. Economic considerations of deficit irrigation. J Irrig Drain Eng 110, 343-358.

KESTER D.E., ROSS N.W., 1996. History. In: Almond production manual (Micke W.C., ed.) Division of Agriculture

and Natural Resources, UCA, Publ.3364, Oakland, pp.171-178.
KLONSKY K., BLANK S.C., 1996. Economic considerations. In: Almond orchard management (Micke W.C., ed.), Division of Agricultural Sciences, UCA, Publ. 4092, Berkeley, CA, pp. 71-76.
LAYARD R., GLAISTER S., 1994. Cost-benefit analysis. Cambridge University Press, 497 pp.
MAO J.C.T., 1986. Análisis financiero. El Ateneo, Buenos Aires, 558 pp.
MARTIN G.C., KESTER D., 1978. Almond growth and development. In: Almond orchard management (Micke W.C., Kester D., eds). Division of Agricultural Sciences, Univ. California, Berkeley, pp. 46-51.
MISHAN E.J., 1982. Cost-benefit analysis. Georges Allen & Onwin Ltd., London, 447 pp.
MITCHELL P.D., CHALMERS D.J.,1982. The effect of reduced water supply on peach tree growth and yields. J Am Soc Hortic Sci 64, 541-552.
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 Am Soc Hortic Sci 109, 604-606.
MITCHELL P.D., VAN DEN ENDE B., JERIE P.H., CHALMERS D.J.,1989. Responses of 'Barlett' pear to withholding irrigation, regulated deficit irrigation and tree spacing. J Am Soc Hortic Sci 114, 15-19.
ROMERO P., 2002. Respuesta del almendro al riego deficitario controlado (RDC) en condiciones de riego localizado subterráneo. Doctoral thesis. Univ. Murcia, 288 pp.
SALAZAR D.M., MELGAREJO P., 2002. Cultivos leñosos: frutales de zonas áridas. El cultivo del almendro. Ed. Mundi-Prensa, Madrid, 307 pp.
SAMUELSON P.A., NORDHAUS W.D., 1990, Economía. Ed. Mcgraw-Hill, Madrid, 1193 pp.
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 Hortic Sci 64,1-7.
TOUS MARTÍ J., 1995. Frutales mediterráneos cultivados en California. Agricultura, 680-684.

Annex

Structural overheads

1. ***Buildings.*** Shed for storage and irrigation equipment

— Area: 70 m^2
— Useful life (UL): 20 years
— Current value (CV): 132.23 € m^{-2}
— Residual value (RV): 20%

2. ***Irrigation equipment***. 3" sand filter, filter mesh, water pump with a flow of 20 $m^3 h^{-1}$ and 24 m Hm, dispenser and fertiliser tank, automatic control for 9 sectors, 10 atm PVC tubing and valve.

— UL: 15 years
— CV: 4,231 €
— RV: 10%

3. ***Irrigation network.*** PEBD tubing: main ∅ 63 mm, primary ∅ 50 mm and drip carriers of 16 mm; self-compensating 4 l h^{-1} in line emitters, four per tree.

— UL: 15 years
— CV: 4,976 €
— RV: 10%

4. **Plantation.** Characteristic spacing of the study area (7 × 5 or 6 × 6 m) with 256 trees ha^{-1} and the following preparation: subsoiling to 80 cm (1h ha^{-1}), surface work to 25 cm (1.5 h ha^{-1}), harrowing and levelling (0.4 h ha^{-1}), planting and first replantation watering (3 min $tree^{-1}$), grafting, basic fertilisation (calcium superphosphate 400 kg ha^{-1}, and potassium phosphate 200 kg ha^{-1}), organic fertiliser (3 kg $tree^{-1}$).

— Subsoiler: 36.06 € h^{-1}
— Grafting: 1.8 € per tree
— Tractor 60 hp: 18.03 € h^{-1}
— Leveller: 21.04 € h^{-1}
— Labour costs: 9.01 € h^{-1}
— 10,000 l vat: 24,04 € h^{-1}
— Calcium superphosphate: 0,12 € h^{-1}
— Potassium sulphate: 0,28 € h^{-1}
— Organic fertilizer: 0,048 € h^{-1}
— UL: 20 years
— CV: 3947 €
— RV: 0

5. ***Various materials.*** Different materials used in cultivation: hedge shears, double blade saw, mattocks, baskets, etc.

— UL: 5 years
— CV: 270 €
— RV: 0

6. ***Regulating water tank.*** To supply 5 hectares with irrigation water (sole supply) for two weeks at the time of maximum need.

— UL: 20 years
— CV: 10.725 €
— RV: 20%

Fixed running costs

1. ***Annual pruning.*** Maintenance and production pruning for adult trees.
   - Availability of capital: 1 year
   - Manpower. Trained worker in charge: 9.92 € h^{-1}
   - Manpower. Labourer: 8.72 € h^{-1}
2. ***Machinery.*** Agricultural tasks using external equipment: surface preparation (3 times per year) between rows to 15-20 cm, phytosanitary treatments (4 times) using 50 hp tractor and 2000 L tank (1.5 h ha^{-1}), herbicide treatments (3 times) with same tractor and tank (0.45 h ha^{-1}), collection of pruned wood with same tractor and trailer (1 h ha^{-1}).
   - Availability of capital: 1/2 year
   - 50 hp tractor + machinery 18.03 € h^{-1}
3. ***Phytosanitary treatments.*** Winter, post-flowering, spring and summer treatments with active materials including oil and several pest control substances (acephate, Phenitrotion etc., approximately 400-500 L ha^{-1}).
   - Availability of capital: 1/2 year
   - Acephate, methomyl, dimethoate: 6.01 € L^{-1}
   - Mineral oil: 0.90 € L^{-1}
   - Copper: 2.50 € L^{-1}
   - Mancozeb: 4.20 € L^{-1}
4. ***Fertilisers.*** The same fertilisation programme was followed in both treatments: 108.80 kg ha^{-1} nitrogenated solution, 152.32 kg ha^{-1} potassium nitrate, 185.60 kg ha^{-1} ammonium nitrate, 96.00 kg ha^{-1} phosphoric acid and 10 kg ha^{-1} nitric acid.
   - Availability of capital: 1/2 year
   - Nitrogenated solution: 0.19 € kg^{-1}
   - Potassium nitrate: 0.43 € L^{-1}
   - Ammonium nitrate: 0.19 € L^{-1}
   - Phosphoric acid: 0.42 € L^{-1}
   - Nitric acid: 0.18 € L^{-1}
5. ***Herbicides.*** Treatment per year along the rows with glyphosate + MCPA.
   - Availability of capital: 1/2 year
   - Glyphosate + MCPA: 7 € L^{-1}
6. ***Maintenance.*** Maintenance costs were taken as 2% of the original cost of the irrigation equipment and network.
   - Availability of capital: 1/2 year
7. ***Ownership.*** Ownership of the land with no opportunity costs.
8. ***Electricity.*** Energy for the pump calculated with respect to number of hours of irrigation, using agricultural electricity tariff of the local supplier, and consumption at a mean between peak and low-point daily price rates; standing charges included.
   - Availability of capital: 1/2 year
   - Load loss: 20 mwc (metres of water column)
   - Flow: 20 m^3 h^{-1}
   - Pump motor performance: 0.7
   - Price kwh: 0.09 €
9. **Staff.** Part-time foreman to carry out agricultural tasks, help with collecting pruned wood, applying herbicides, buying and applying fertilisers etc.
   - Capital availability: half year
   - Cost of part-time labour: 3,907 €
   - Availability of capital: 1/2 year
   - Part time manpower costs: 3,907 € (per year)

Variable costs

1. ***Harvesting.*** Using outside machinery (tree shaker and trailer) (3.5 h ha^{-1}).
   - Tree shaker and trailer: 3606 € h^{-1}
2. ***Irrigation.*** The price used for irrigation water is that for water transferred to the study area and includes management and general distribution costs.
   - Price: 0.126 € m^{-3}