

Effects of Irrigation-Water Pricing on the Profitability of Mediterranean Woody Crops

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1. Introduction

Tree-crops play a fundamental role in Mediterranean Spanish regions. Irrigated farmlands of citrus and a wide range of fruit-trees are characteristic of the Valencian Community and the Region of Murcia, for instance. These are intensively grown crops whose production is destined for fresh consumption, and are highly competitive due to the large proportion that is exported. However, there are other crops commonly grown in the inland areas which, although not weighty in economic terms, are of major importance. Examples are the irrigated table grapes, olives, almond trees and vines which are grown mostly under dry or rainfed conditions. The latter are paramount in the settlement and permanence of the rural population, especially in regions where agriculture remains the economic mainstay. Furthermore, management is also highly environmentally sustainable, because these crops consume minimum amounts of water. In this chapter these four species have been chosen to represent the Spanish Mediterranean woody crops.

In recent decades, socioeconomic and political changes have led to a clear transformation of the farming communities in the Mediterranean regions. Both the industrial and the service sectors continue putting strong pressure on labour resources, especially among young people, which limits generational take-over and leads to the disappearance of family farms, giving little incentive to continue farming activities.

The climate in these Mediterranean areas is characterized by short, mild winters, hot summers and, in many areas, with an annual precipitation below 300 mm, making water the scarcest and most valuable natural resource in these regions. Thus, the aquifers are subject to excessive extraction, often resulting in poor water quality. Main crop production can only be guaranteed with some type of irrigation. Official markets of irrigation water have not been developed yet, but in producing regions the resource is exchanged; it is especially common that growers administer their allocation and divert it to more profitable plots. This propitiates marginal management, where a plot is maintained during a period with only basic cultural practices.

To encourage a sustainable use of water in agriculture, the recently entered into force European Water Framework Directive (WFD) proposes the full cost recovery related to water services under the polluter pay principle. For this end, a water pricing policy should

be established by Member States and, it is foreseeable that the price of irrigation water will increase in such a way that the final price of irrigation water to be paid by the grower will cover all of the costs (economic and environmental) incurred in delivering it. But the field prices of most agricultural products are increasingly lower, and any increase in production costs may seriously affect its feasibility.

In this context, the objective of this study is to analyze the potential trend of certain Spanish Mediterranean woody crops, on the establishment of tariff policies that differ from those currently implemented. To achieve this goal, the water demand curves obtained for olives, vineyard, almond trees and table grapes have been analyzed. The results will enable policy makers and water resource managers to be informed of the effect that the introduction of a pricing policy would have on Mediterranean agriculture influencing decision making, taking into account the environmental objectives of the WFD while maintaining the social and environmental benefits of traditional farming in the Mediterranean regions.

The remainder of the chapter is organized as follows. In the next section, the economic analysis of irrigated water use is reviewed, as well as the main methodological approach. In sections 3 and 4 two case studies are analyzed. Finally, general conclusions are drawn.

2. Analysis of irrigation water pricing on Mediterranean crops

2.1 Background

Water is becoming an increasingly scarce resource in the world due to population growth, improved quality of life and diminishing resources. Thus, efficient allocation of water becomes increasingly important and must be achieved if we are to reconcile economy and society, because water management is often guided by contradictory aims. Furthermore, to achieve efficient water management, given the competitiveness of demand, it will be necessary to consider the distribution of wealth among different users, and ensure the right to access to water following environmental criteria that enable ecological sustainability. Therefore, those responsible for water management require broad vision, taking into account the results of different water management policies, and also to learn how to select the specific management tools for each situation.

Numerous papers are found in scientific literature that determine the economic effects of the application of different water policies or the adoption of one type of irrigation system or another. Works related with irrigation water management in Mediterranean crops are: Gurovich (2002) studied the energy cost of irrigating the Chilean table grape; Hearne and Easter (1997) analyzed the impact of applying water markets to the cultivation of fresh grapes; Bazzani et al. (2004) investigated the effects of putting into practice the Water Framework Directive in Europe; Jorge et al. (2003) carried out an economic evaluation of the consequences of drought on the Mediterranean crops; and Fernández-Zamudio et al. (2007) obtained irrigation water demand curves for the Spanish table-grape.

The WFD sets out a strategy for general water management and establishes environmental objectives for water bodies in order to achieve a so-called "good ecological status". To achieve these objectives in innovative ways, the WFD prescribes using economic tools and principles, among which is the principle of full cost recovery related to water services. The incorporation of this principle will lead to member states restructuring existing water rates

to allow recovery of full costs of water services, including both the environmental and the resource. In this sense, water pricing policies are viewed by the WFD as a way to internalize the costs so they can educate users about water shortage.

Economic theory sets that farmers would respond to an increase in water prices by reducing their consumption, in accordance with a negative slope demand curve. Thus, the implementation of water pricing measures would create incentives to use water efficiently and, in accordance with the WFD, would contribute to the achievement of environmental objectives. It is believed that the use of suitable water pricing policies would encourage users to limit their water use (Easter and Liu, 2005).

However, the tariff policy applied must consider the specific conditions of each irrigation area, since its effect will be very different depending on their characteristics. Specifically, in south-eastern Spain, where the irrigation water demand curve is usually inelastic, a tariff policy would be valid only from the standpoint of cost recovery, but is not expected to be so from the water savings perspective (Sumpsi et al., 1998; Varela et al., 1998).

Up to our knowledge, the impact of the water pricing policy in Spain was firstly analyzed in three irrigated areas by Berbel & Gómez-Limón (2000). They applied a simple lineal programming model to analyze the impact of using a volumetric water policy instead of an area pricing scheme on agricultural production. They found that demand curve become inelastic and inefficient for a water prices higher than 0.15 €/m³, concluding that volumetric water pricing would have undesirable consequences over the farm income and the employment, reducing also the range of crops available.

Two years later, after WFD entered into force, Gómez-Limón et al. (2002) study both the impact of the cost recovery principle proposed by the WFD and the effect of the common agricultural policy on agricultural irrigation systems using multi-criteria techniques (multi-attribute utility theory). They used an irrigation community, placed in the north-central of Spain (*Bajo Carrión*, Palencia), and they found that the inelasticity of the water demand curve is reached from 0.09 €/m³. From this value it is concluded that an increase of water price would not influence the amount of water demanded. Also, in this irrigation community, Gómez-Limón & Berbel (2000) derive water demand function using weighted goal programming approach obtaining that water pricing policies are not a satisfactory tool for significantly reducing water consumption in agriculture. They argued that water consumption is not reduced significantly until prices reach such a level that farm income and agricultural employment are negatively affected.

In this line, and using a multiattribute utility theory (MAUT) mathematical programming models, Gómez-Limón & Riesgo (2004a) analyzed the impact of the hypothetical implementation of recovery of costs water pricing proposed by the WFD on three homogeneous groups of farmers in the irrigation community *Virgen del Aviso*, in the north of Spain. They found again that the effect of irrigation water pricing vary significantly depending on the group of farmers being considered, being the demand curve of the group with higher ability to pay for the water inelastic from 0.12 €/m³. The same methodology was also applied in an irrigation community of the *Pisuerga channel*, in the north of Spain by Gómez-Limón & Riesgo (2004b) obtaining similar findings.

In general, the works quoted above analyze irrigation water demand curves in irrigation communities of Spain, and all of them have been applied to irrigated areas with a

predominance of extensive arable crops. These crops, which represent a majority in Spain, have a yearly production cycle and their production margins are very similar. These characteristics contribute to the replacement of one species by another depending on the harvests. However, it is expected that woody crops show different behaviour than extensive crops due to the higher investment costs and the time needed to recover such investment. Recent studies, such as that by Mesa-Jurado et al. (2010), determine the marginal value of irrigation water in a woody crop, like the olive tree, in a sub-basin the Guadalquivir River Basin using production function based on field experiments. Net marginal values of water obtained from the marginal benefit curve (having deducted the variable costs of production including harvesting and irrigation) were 0.60 and 0.53 €/m³ for an allocation of 1,000 and 1,500 m³/ha respectively.

For the whole Guadalquivir River Basin, a wider analysis of the demand of water has been estimated by all irrigated crops, extensive and perennial. This work has been carried out by Berbel et al., (2011) using the Residual Value Method. This technique is based on the idea that a profit-maximizing firm will use water up to the point where the net revenue gained from one additional unit of water is just equal to the marginal cost of obtaining the water. An approximation to the demand curve can be obtained plotting the average residual water values aggregated for all crops by area and the water consumed by this area. In this work, where citrus and olive tree are considered jointly with extensive crops, the residual water value is estimated between 0.01 and 0.68 €/m³. The high residual water values are explained for the existence of woody crops.

Thus, from the analysis of the previous works it is possible to identify that the demand of water for wood crops seems more inelastic than for extensive crops, due to for small allocation the price is highly valuable, being the marginal water prices of woody crops considerable higher. Studies that analyze the establishment of tariff policies on woody crops are still scarce, and more research based on this kind of crops would contribute to fill this gap of knowledge.

2.2 Methodology for analysis of irrigation water pricing

In order to deduce the effects that irrigation water availability and price have on the viability of the main rainfed tree crops grown in Spain as well as table grapes and the woody crops representative of irrigated farmlands in the Mediterranean region, several mathematical calculations have been used in this work. Together with the calculations of shadow prices and irrigation water demand curves, the maximum price that farmers can afford for water resources has been obtained.

The shadow price of irrigation water is the value corresponding to the opportunity cost of having one more cubic meter of water on the farm. The economic impact that is expected from having more water available, for which the approximate value of irrigation water is cited as Euros per cubic meter. This price cannot be considered the actual price that the farmer may pay for the water resource and it must be inferred from the demand curves.

To calculate shadow prices a quantitative analysis has been carried out using the Compromise Programming (CP) technique belonging to the multicriteria paradigm.

Usually, the analyzed objectives in multicriteria models are in conflict with each other, and therefore, to optimize the different objectives simultaneously and achieve an ideal solution

is impossible. However, it is possible to determine the small group of effective points that bring us closest to that ideal, which would be the solution in which all the objectives reach their optimum value (Romero & Reheman, 2003). The mathematical essence of this calculation was established by Zeleny (1973) and Yu (1973), and a number of authors have used this technique in agriculture. For example, Sabuni & Bakshoudeh (2004) used the CP to determine the opportunity cost of water on farms, or Ballestero et al. (2002) who analysed the establishing of water markets.

The CP is one of the most commonly applied multicriteria techniques due to its high operativity (Romero & Reheman, 2003), and it is associated with the concept of distance, though not in the geometric sense, but rather the distance or degree of proximity from the ideal. This distance (d_j) of the objective $f_j(x)$ with respect to the ideal f_j^* , will be written:

$$d_j = |f_j^* - f_j(x)| \quad (1)$$

Normally the objectives have very different absolute values or they are measured in different units, therefore before adding the degree of proximity they could all have, one must carry out a dimensional homogenization, giving:

$$d_j = \frac{|f_j^* - f_j(x)|}{|f_j^* - f_{*j}|} \quad (2)$$

where f_{*j} is the worst value of the objective when it has been optimized separately and called the anti-ideal value.

Likewise, in the calculation, one must also consider the preferences that the decision centre can show for each objective, for this reason a weight w_j is included. All this means that the effective solutions that come closest to the ideal are achieved by resolving the following optimization problem:

$$\text{Min } L_p = \left[\sum_{j=1}^n w_j^p \cdot \left| \frac{f_j^* - f_j(x)}{f_j^* - f_{*j}} \right|^p \right]^{1/p} \quad (3)$$

Subject to $x \in F$, where x are the decision variables, F is the set of restrictions of the model, n is the number of the objectives introduced in the modelization and p the metric (Romero & Rehman, 2003).

The points that fall closest to the ideal (called the compromise set) can be bounded between the metrics one and infinite, in other words L_1 and L_∞ (Yu, 1973), which is considered acceptable, even though there are more than two objectives. The economic significance of these solutions is connected with the traditional optimization based on utility functions and L_1 indicates the value of greatest efficiency, while L_∞ is the solution with greatest equity (Ballestero & Romero 1991).

For the demand curves, the Multiattribute Utility Theory (MAUT) has been widely founded. The work by Keeney & Raiffa (1976) is a starting point of the MAUT. In essence it consists of

being able to establish a mathematical function U , which encompasses the utility resulting from a series of attributes, which are previously considered according to the importance each of them has for the decisor. This theory starts from strict mathematical requirements; however, the works by Edwards (1977) or Huirne & Hardaker (1998) show that, although these are not strictly satisfied, one can obtain utility functions that are extremely close to the true utility.

In order to estimate the additive utility functions, the framework developed by Sumpsi et al. (1996) and Amador et al. (1998) has been followed, and later applied by Gómez-Limón et al. (2004). First one calculates the pay-off matrix, and then resolves the following system of $n+1$ equations:

$$\sum_{i=1}^n w_i f_{ji} = f_j \quad (4)$$

for $j = 1, 2, \dots, n$ and $\sum_{i=1}^n w_i = 1$

With n being the number of objectives considered, w_i are the weights of the different objectives (and therefore, unknown), f_{ji} are the elements of the payoff matrix, corresponding to the values reached by the objective of column- i when the objective of row- j is optimized. Finally f_j is the value of the j -th objective in accordance with the distribution of the crops observed.

If the above system of equations has a non-negative solution, then w_i indicate the weights of the different objectives, but this is not usually the case, as there is no set of weights that reproduce the farmers preferences with precision. To approximate the said solution as far as possible, one minimizes the sum of m_j and p_j , for which the following lineal program is resolved:

$$\text{Min} \sum_{j=1}^n \frac{m_j + p_j}{f_j} \quad (5)$$

subject to:

$$\sum_{i=1}^n w_i f_{ji} + m_j - p_j = f_j \quad \text{for } j = 1, 2, \dots, n$$

$$\sum_{i=1}^n w_i = 1$$

with m_j the variable of negative deviation and p_j the variable of positive deviation. According to Dyer (1977), the weights obtained previously, coincide with the following expression of the utility function, which is separable, additive and lineal for each attribute $f_i(x)$,

$$U = \sum_{i=1}^n \frac{w_i}{k_i} f_i(x) \quad (6)$$

where k_i is a normalizing factor, for instance the difference between the best or ideal value for each objective, f_i^* , and the worst or anti-ideal, f_{i^*} , which are extracted from the pay-off matrix, with the additive utility function finally being expressed as:

$$U = \sum_{i=1}^n w_i \frac{f_i(x) - f_{i^*}}{f_i^* - f_{i^*}} \quad (7)$$

The utility function it is assumed that the farm owners will maintain their psychological attitude with regard to decision taking for a short to medium term. From this point the study goes on to look at a series of simulations with rising prices of irrigation water, in such a way that, each price is a new scenario in which utility is maximized, and from which a cropping plan is derived with a specific demand for irrigation water.

3. Case 1: Rainfed Mediterranean tree crops (olive, vineyard and almond): Response to variations in irrigation water pricing

Spanish Mediterranean dry-farming is predominant in the large inland extension, and the most traditional and characteristic crops are the olive (*Olea europea*), the vineyard (*Vitis vinifera*) and the almond (*Prunus dulcis*). All of them are shared in the farms in different proportions. These crops have helped in maintaining the countryside, which is one of the marks of the cultural identity of these regions, protect the soil from erosion, and they can also be considered an important promoter of human activity.

In the arid regions of the Mediterranean, agriculture is strongly conditioned by the irregularity of the climate, specially the rains. The most important natural resource is water, which is in short supply and of the greatest value. Consequently, the availability of water for irrigation significantly increases cropping yield, assures a greater regularity in harvest, and decreases the economic risks in farming.

The size of the farm also exerts an influence, but in contrast to the small-holding structure that is characteristic on the coast, in these inland regions the land is not considered as such a restrictive factor, and normally, it is rather the lack of family labour needed to cultivate the farm in optimum conditions that leads to marginal management. "Marginal management" defines non-definitive semi-abandonment, in which these three tree crops survive left to the mercy of the climate. This is often the case in the regions under study and at specific periods of time when, due to the lack of labour or profitability, the farmers do not optimize crop care and limit it to a minimum (Fernández-Zamudio et al., 2006).

3.1 The most outstanding traits of the dry regions

The present study focuses on the Valencian Community, where dry-lands account for 56% of this area. Here the olive, vineyard and almond are the most extensive crops, representing 35% of the worked lands in this region (CAPA, 2011). These three crops can be cultivated in strict dry-farming or with irrigation at very specific moments (irrigated relief), considered as essential to ensure harvest, and in the case of the vineyard and olive conventional drip irrigation is also possible, with greater and more continuous flow.

In order to determine the optimal cropping plans in the Mediterranean cropping dry-land, the following objectives have been chosen: one of economic nature (to maximize profits), another

social (minimization of total annual workforce) and the other environmental (minimization of irrigation water consumption). The mathematical expression of these three objectives is:

$$\text{Max} \sum_{i=1}^n NM_i \cdot X_i \quad (8)$$

$$\text{Min} \sum_{i=1}^n Q_i \cdot X_i \quad (9)$$

$$\text{Min} \sum_{i=1}^n TL_i \cdot X_i \quad (10)$$

Where NM_i is the net margin of the activity i , X_i is the surface area, Q_i is the annual irrigation water supplied and TL_i is total labour employed annually.

3.2 Information and methodology

Family farms predominate in the Mediterranean inland regions; therefore, the analysis is carried out choosing a representative farm, with 32 hectares of land and a full-time family Agricultural Work Unit (AWU). Within the Valencian Community, the study was located in the *l'Alcoià* area, in Alicante province. This is a region with a semi-arid climate, with the risk of frost from November to March, and 474 mm of average rainfall per year. In this region there are two zones that are very different in terms of slope, but the risk of natural erosion is considered moderate. The irrigation water mainly comes from private wells, and a small proportion distributed by the Irrigation Community of the River *Vinalopó*.

The calculations have been applied to two modelization scenarios that are real in these regions, and the differences are exclusively in the degree of mechanization existing on the farm. In the "manual-scenario" low-powered mobile equipment was used together with traditional harvesting and hand-picking, and in the "mechanized-scenario" higher-powered mobile equipment is considered.

In this study the decision variables, or unknowns of optimization, are the surface area in farm for each crop-growing activity. Olive, vineyard and almond, which are most characteristic of the region, have been introduced, being the main difference the amount of irrigation water (Table 1). To calculate the net margin of an activity, the variable costs, which include hired labour and the fixed costs are subtracted from the income earned through selling the production -together with the subsidy if there is one. In calculating the income, the average production for each crop-growing activity was fixed according to the data taken in the region and after validating them with experts. In the production figures, considered inter-annual variability in yield is recorded. For the prices, the average values have been taken as those perceived by the farmers, according to official statistics (CAPA, 2011).

To bring the models closer to the real conditions in the region, a number of restrictions have been taken into account, and have been introduced equally in both scenarios:

- Crop area: A total of 32 hectares are available on the farm.
- At maximum 30% of the available surface area can be subject to marginal management, concept already defined above.

- Given these are woody crops, and that the models under consideration are static and short-term, the maximum surface area of each species is limited to its present value (32% in olive, 8% in almond and 60% in vineyard). This restriction permits changes in variety within a species, changes in the type of irrigation, or for this to pass to marginal management.
- With respect to the availability of irrigation, due to the dryness of these regions, very strict conditions are introduced, fixing a use equivalent to the levels of habitual consumption, which according to the criteria of the experts consulted, can be maintained medium term (Table 1). Therefore, it is established that only 10% of the available surface area can receive some kind of irrigation, the water supplied cannot exceed 600 m³ monthly for the whole farm, and that the total amount allotted to the farm is of 5,000 m³ annually. The current price of irrigation water is 0.15 €/m³.
- The other restrictions are derived from manual labour. The availability of family labour is fixed at an agricultural work unit (an AWU to be 2,160 hours a year), and hired labour is limited to complement what cannot be covered by family on a three-monthly basis.

The curves obtained will be consequence of the adaptation of the farm to increasing prices for irrigation water in the short term. The simulation models are applied to the manual scenario and to the mechanized scenario and are similar to those used to obtain the shadow prices, with the following considerations:

- The MAUT is obtained for the objectives: maximization of the net margin of the farm and minimization of total workforce.
- From the previously calculated margin (Table 1), the cost of the water (corresponding to the usual price, 0.15 €/m³) is deducted and the value corresponding to each simulation, starting from 0 €/m³, is added.
- The restrictions to the models, and the average volumes of irrigation applied to each variety of crop coincides with those previously described (Table 1).

The utility function characteristic of a representative farm of the region under study has been found, assuming that the farm owners will maintain their psychological attitude with regard to decision-taking for a short to medium term. A series of simulations are made with rising prices of irrigation water, in such a way that, each price is a new scenario in which utility is maximized, and from which we derive a cropping plan with a specific demand for irrigation water. Finally, the set of simulations carried out serves to set out the demand functions and will be a consequence of the adaptation of the farm short-term at increasing prices for irrigation water.

3.3 Results and discussion

Typically, the demand curves of the areas placed inland of the Mediterranean coastal, show large inelasticity; therefore farmers display a strong willingness to pay for each cubic meter of water. The question it should ask, then, is whether these high prices are affordable by Mediterranean farmers. For this reason, it has also obtained the maximum price of irrigation water that guarantees the family farm income.

Table 2 shows the achievement levels for each of the three objectives for the metrics L_1 and L_∞ , the different cropping plans and the requirements of hired manual labour. The results

Species	Varieties, description	Irrigation	Annual water supply (m ³ /ha)	Net margin manual-scenario (€/ha)	Net margin mechaniz.-scenario (€/ha)
Olive	Authochthonous: Grossal	Dry-land	0	315	314
Olive	Authochthonous: Grossal	Irrigated relief	700	662	734
Olive	Authochthonous: Grossal	Irrigated	1500	1314	1511
Olive	New: Arbequina	Dry-land	0	441	300
Olive	New: Arbequina	Irrigated relief	700	933	858
Olive	New: Arbequina	Irrigated	1500	1585	1611
Almond	Authochthonous: Comuna Group	Dry-land	0	236	330
Almond	Authochthonous: Comuna Group	Irrigated relief	700	151	329
Almond	New: var.Late-flowering	Dry-land	0	451	577
Almond	New: var.Late-flowering	Irrigated relief	700	360	568
Vineyard	Monastell in tube	Dry-land	0	550	564
Vineyard	Monastell in tube	Irrigated relief	1100	783	807
Vineyard	Monastell in tube	Irrigated	1900	1458	1492
Vineyard	Monastell in espalier	Dry-land	0	499	655
Vineyard	Monastell in espalier	Irrigated relief	1100	788	955
Vineyard	Monastell in espalier	Irrigated	1900	1409	1602

Source: own calculations

Table 1. Rainfed tree crops, decisional variables: description, net margin for scenarios and annual water supply

show a number of advantages on moving from the manual scenario to the mechanized scenario. With regard to the water requirements, in the most balanced cropping plan (L_{∞}), which is the one that demands most irrigation, it does not exceed 2,227 m³/year on the whole farm in the manual scenario, and 2,418 m³/year for the mechanized scenario. Given the strict conditions used to establish the models, it is possible to think that the proposed plans will be sustainable, even in these arid agricultural conditions. Moreover, in solution L_1 there are plans that do not necessitate irrigation, verifying the continuity of traditional dry-farming on its own.

Having reached this point, it is especially interesting to reflect on the behaviour of the profit maximization objective with respect to minimizing irrigation water. If the compromise sets are calculated just for these two objectives, these points can be represented on a Cartesian

plane and, the slope of the line joining the points L_1 and L_∞ , or trade-off, show us the opportunity cost or the shadow price of the irrigation water, understood in its marginal values. In other words, as the increase in the net margin of the farm if one applies an additional unit of water (Florencio-Cruz et al., 2002).

The lines obtained in both scenarios are represented in Figure 1. The volume of irrigation water required by such a plan is represented on the axis of abscissas, while the axis of ordinates shows the net margin this plan generates. The result is that, the shadow price of the water is 0.76 €/m³ in the manual scenario and 0.87 €/m³ in the mechanized ones. The highest shadow price obtained in both scenarios is very significant, and they are a useful orientation to the value of water in this dry-farming system. However, they have been obtained by exclusively evaluating the impact of irrigation water on the net margin of the farm; therefore, to obtain more rigorous information about how these crops would behave in the event of an increase in water prices, the demand curves will be calculated below.

Metrics:	Manual scenario		Mechanized scenario	
	L_1	L_∞	L_1	L_∞
Value of objectives:				
Net margin (euros)	10,950	14,889	12,520	16,241
Water (m ³)	0	2227	0	2418
Total manual labour (hours)	2,014	2,653	1,200	1,505
Optimisation activities (%):				
Olive. Grossal. Dry-land			2	13.3
Olive. Arbequina. Dry-land	32	27.4		
Olive. Arbequina. Irrigated		4.6		5
Almond. Var.Later flowering. Dry-land	8	8	8	8
Vineyard. Tube. Dry-land	30	42.7	60	60
Farm surface with marginal management	30	17.3	30	13.7
Total hectares properly cultivated (ha)	22.4	26.5	22.4	27.6
Net margin (euros per cultivated hectare)	489	562	559	588
Requirement annual of hired manual labour (hours)	631	1052	0	106

Table 2. Cropping plan and results for the three objectives analysed for compromise solutions in Spanish dry-lands. (Data for a family farm with an agricultural work unit and 32 hectares)

The demand curves obtained are shown in Figure 2. In the event of applying a hypothetical pricing policy, the way the farm behaves will vary according to its degree of mechanization, although we observe that water consumption in the lowest price range is equal in both scenarios. Such inflexible behaviour of the different price ranges should be highlighted, and undoubtedly the great shortage of this resource in these regions. The high productivity of water, even in small amounts, mean that the price the farm can pay for irrigation water can be increased.

In the manual scenario, there is a first range of maximum demand, between 0 and 0.51 €/m³; it continues with a drop to half the demand for tariffs of 0.52 to 0.55 €/m³ and ends up with cropping plans in completely dry-farming when the water costs over 0.56 €/m³. In the mechanized scenario the demand is constantly at maximum until it reaches 0.91 €/m³, at which point the chosen cropping plan changes to one that is strictly dry-farming. The different response must be looked at in the different degree of mechanization. Technology improves management and enables farms to face more effectively the greater labour requirements that arise from irrigated crops. This limitation is accentuated if the labour (especially harvesting) is carried out manually, and for this reason the mechanized farms are better able to pay higher water prices.

The price of water has repercussions on the cropping plan resulting from each simulation. When the prices are low, water is demanded for irrigation and this is destined solely to the olive, specifically to the olive Arbequina irrigated, but for both the almond and the vineyard dry-farming is always chosen. In the manual scenario the dry farmed olive is the Arbequina, while in the mechanized scenario is the autochthonous variety Grossal. With respect to the vineyard, in the manual scenario it is trained in tube, while in the mechanized it is trained in espalier (which is more productive but requires a greater initial investment). The almond chosen is a late-flowering variety in both scenarios. The cropping plans in the mechanized scenario are more economically viable, which means that, with prices of over 0.51 €/m³, they can demand greater quantities of water than in the manual one.

The main conclusions are:

- The different sections of the demand curves demonstrate very inflexible behaviour, which is justified by the fact that the olive, vineyard and almond are woody species that use small amounts of irrigation water very effectively.
- The effect of the price of water on the farm's income make a higher degree of mechanization necessary in order to face high irrigation-water prices. The current price of water is 0.15 €/m³, and although it could increase, to ensure a minimum income for the farm of 21,500 € annually, water cannot exceed more than 0.24 €/m³ in a manually worked farm, or more than 0.44 €/m³ if it is mechanized.
- To increase mechanization may be the most straightforward strategy to ensure the survival of the farms in the Spanish dry-lands, short to medium term, and likewise strengthen their sustainability. As all the results have been obtained considering the operations that demand the most expensive machinery to be hired, it can be deduced that it is a strategy that can be assumed by all the farms. Thus, it will be essential to increase the degree of mechanization in order to guarantee the viability of this agriculture if the current trend of increasing irrigation-water prices is consolidated.

4. Case 2: Irrigated woody crops (table-grapes): Response to variations in irrigation water pricing

4.1 The most outstanding traits of the table-grape regions

Spain, with 15.2% of the vine-planted surface area in the world, is the leader in terms of the extension this crop covers. Although only 5% of this production is destined to fresh-fruit consumption, cultivation of the table-grape (*Vitis vinifera* L.) is important given its long tradition. Spain is the fifth table-grape producer world-wide in the northern hemisphere,

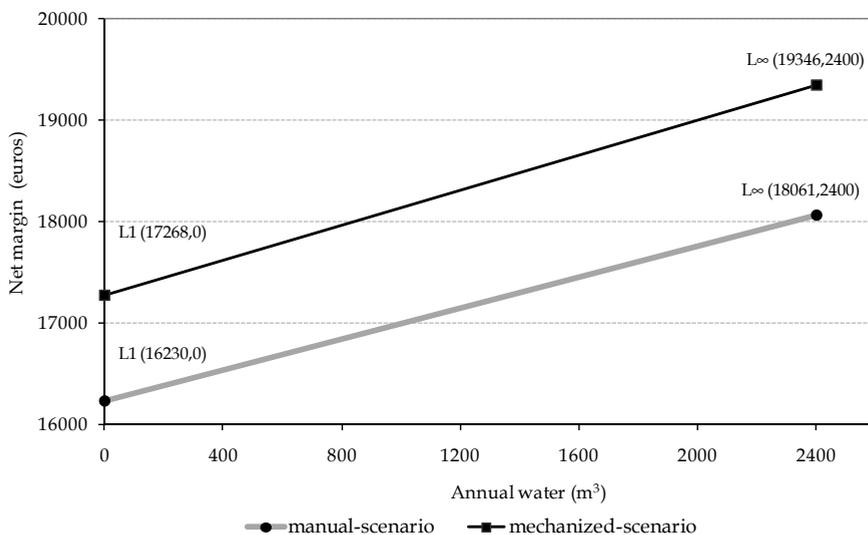


Fig. 1. Shadow price of irrigation water for two scenarios in Spanish dry-lands (Data for family farm with 1 AWH and 32 hectares)

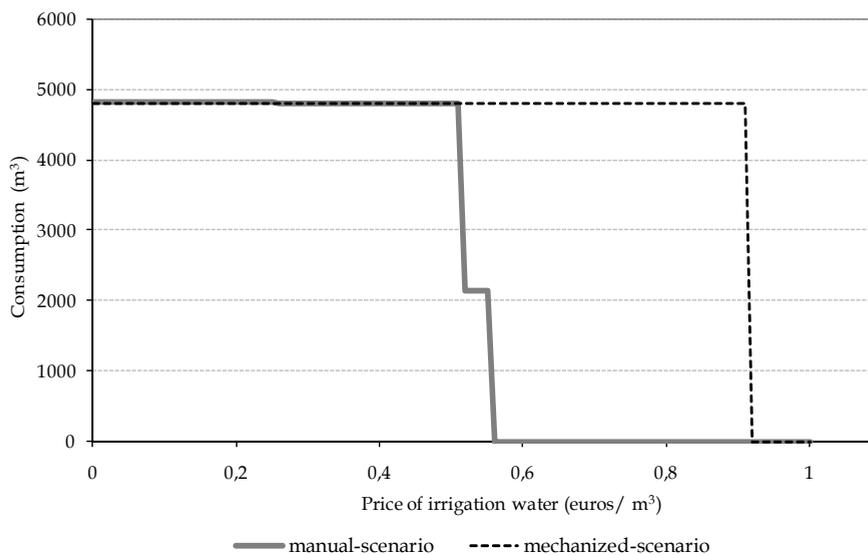


Fig. 2. Demand functions for irrigation water for the two scenarios in Spanish dry-lands

and the second in Europe, surpassed only by Italy. It is the sixth exporter in the world, coming after Chile, Italy, USA, South Africa and Mexico. In 2009, Spain exported 117,143 Tn of fresh grapes, of which 99% were destined to European countries. Table grape is a very typical Mediterranean crop, accounting for 79.3% of the area and 88.8% of the production between the Regions of Murcia and the Valencian Community (MARM, 2011). Both these regions are situated next to the Mediterranean, have a warm climate, but are greatly lacking in rainfall, with average precipitation of below 300 mm annually. Water is the scarcest and most valuable natural resource, given the over-exploitation of aquifers or its low quality, and is the main reason why this crop is partially abandoned. The temporal marginal management are common in table-grape, that is to say, they are left to basic care for a certain amount of time, which habitually consist of maintenance pruning and minimum tillage. If the circumstances that have favoured this situation (scarcity of irrigation water, lack of personal and economic incentive of the agricultural producers, etc.) are longer lasting, then this abandonment becomes definitive. Rejecting optimum crop management is a common practice in these regions of production, and faced with the lack of irrigation water, the choice is to destine the one available to the most economically viable plots.

4.2 Information and methodology

The Spanish table-grape farms are very small in size, 72% of those in Alicante (Valencian Community) and 66% of those in Murcia are smaller than 5 ha (INE, 2011). In this study, a 5 ha family farm has been used as reference. The two cropped areas are *Valle del Vinalopó* (Alicante) and *Valle del Guadalentín* (Murcia), geographically closed but technically and managerially different.

Thus, in the *Valle del Vinalopó* there are 9,500 ha of grape (MARM, 2011), forming a well-defined agrarian system that has remained very stable over time. Its most defining feature is its "bagging", by which the bunches of grapes are covered by a paper bag, from just before veraison up until harvesting. Technology is found at an acceptable level, but it is possible to improve the mechanization of the labour. The varietal composition has undergone scarce variation over time, and is fundamentally based on the Italia and Aledo varieties, although important changes are foreseeable in the coming years, and seedless varieties will be introduced, which are still in minor representation. The situation is different in the Region of Murcia, where the surface area dedicated to grape has increased in recent years, reaching 5,159 hectares in 2010 (CARM, 2011) and where new production zones have appeared, with large business producers and a strong bid for seedless varieties. In general terms one can also talk about family farms, but the important investment in capital and technology mean that noticeable differences exist between Murcia and Alicante. There is intense activity concerning the introduction of new plant material, the traditional varieties like Italia and Ohanes have diminished, and instead there has been an increase in the surface area planted with Dominga, Napoleon and, above all, the seedless or early varieties (Superior, Crimson and Red Globe for example).

Currently, in both regions, the growing operation being perfected concerns particularly irrigation, which is bringing about massive implementation of drip irrigation. This type of irrigation covers 50% of the surface area at present, and it is foreseeable that it will reach

90% soon. The shortage of irrigation water in these zones, the irregularity of the supplies and the deficiencies in the quality also encourage the grape-growers to construct accumulation reservoirs, which is more widespread in the Murcia region.

Therefore, the technological improvements that are being adopted more quickly in Spanish table-grape cultivation are: an increase in the average power of the machinery to carry out the labour and the phyto-sanitary treatments, use of tying machines for the summer pruning, use of pre-pruners (in espaliers), generalized use of shredders for the pruning remains and substitution of the traditional irrigation systems for programmed drip irrigation. Moreover, they are improvements that are beginning to spread to the new staking structures (higher espalier in Y in Alicante), and the use of mesh or plastic covering, which are common in Murcia (Fernández-Zamudio et al., 2008).

Maximizing profits (equation 8) is the primary objective of Spanish grape growers, but given the strict water conditions of the regions studied, they must also minimize consumption of irrigation water (equation 9) The decisional variables will be the surface areas occupied by the different growing activities. Table 3 describes the modeled variables, together with their annual water allotment and the net margins in the two technological scenarios analyzed. Scenario-1 represents the traditional production conditions for table-grape in the two zones. From these, one moves to another productive context, in which a series of technological improvements have been adopted, towards a scenario where the two zones would appear to be moving towards according to regional agricultural technicians (scenario-2). The restrictions of the models are a maximum monthly and yearly irrigation allotments, maximum area of cultivation that will be subject to adoption of drip irrigation, change to Y trellises and covering with net screening, as well as those restrictions derived from the market (new varieties introduction).

For analyzing the two objectives together and obtain water shadow prices, compromise programming has been used, while to obtain the demand curves a lineal mathematical programming has been applied, being the objective:

$$\text{Max} \sum_{i=1}^n NM_i \cdot X_i - Q_i \cdot X_i \cdot p_q \quad (11)$$

Where NM_i is the net margin of the activity i , X_i is the cultivated area, Q_i its yearly quota of irrigation water. Also, p_q is the price of irrigation water for each parameter (from zero to 4 Euros per cubic meter). This is the real price that the grower pays for each cubic meter of water; this price includes administrative costs of delivery, maintenance of the infrastructure, energy for pumping, and other taxes or charges. The restrictions of the model are the same as in compromise programming.

4.3 Results and discussion

From the optimal cropping plans obtained (Table 4), it is possible to deduce that technological improvements will broaden economic expectations of grape growers. Net profits will increase by a mean of 15% in Alicante and 97% in Murcia, figures that concord with technological changes introduced in each region.

(1) Variable description	Irrigation type	Scenario	Q _i (m ³ /ha) (2)	Net Margin (3)	
				Scen.-1 (€/ha)	Scen.-2 (€/ha)
A Aledo. Traditional espalier. Bagged	Flood	1& 2	3900	7311	7430
A Aledo. Traditional espalier. Bagged	Drip	1& 2	4000	8156	8015
A Aledo. Y espalier. Bagged	Drip	1& 2	4000	8999	8836
A Italia. Traditional espalier. Bagged	Flood	1& 2	3900	5000	4917
A Italia. Traditional espalier. No bagged	Flood	1& 2	3900	5233	5150
A Italia. Traditional espalier. Bagged	Drip	1& 2	4000	4916	4872
A Italia. Traditional espalier. No Bagged	Drip	1& 2	4000	5638	5582
A Italia. Trellis. Bagged	Flood	1& 2	3900	5199	5247
A Italia. Trellis. Bagged	Drip	1& 2	4000	6160	6223
A Italia. Y espalier. Bagged.	Drip	1& 2	4000	5934	5771
A Victoria. Y espalier. No bagged	Drip	2	3500		7931
A Superior. Y espalier. No bagged	Drip	2	3500		10866
A Marginal management		1& 2	0	-720	-720
M Napoleon. Wood trellis	Flood	1& 2	5100	4433	4509
M Superior. Wood trellis	Flood	1& 2	5100	7224	7014
M Italia. Wood trellis	Flood	1& 2	5100	3675	3679
M Dominga. Wood trellis	Flood	1& 2	5100	6995	6959
M Red Globe. Wood trellis	Drip	1	4620	7112	
M Superior. Wood trellis	Drip	1	3990	8754	
M Superior. Galvan.-iron trellis	Drip	2	3990		7939
M Red Globe. Galvan.-iron trellis. Mesh cover	Drip	2	4620		6163
M Superior. Galvan.-iron trellis. Mesh cover	Drip	2	3990		13573
M Superior. Galvan.-iron trellis. Mesh & plastic	Drip	2	4550		15635
M Crimson. Galvan. -iron-trellis. Mesh cover	Drip	2	4860		17590
M Marginal management		1& 2	0	-787	-787

(1) Areas: Alicante (A), Murcia (M). (2) Q_i is annual water supply for i activity. (3) Net margins excluding manual labour cost. Source: Own elaboration

Table 3. Decisional variables of Spanish table-grape: description, net margin for scenarios and annual water supply

Water shadow prices are higher in Alicante, where smaller water allocations than in Murcia are allowed, and water is an even more valuable resource; thus, productivity of each cubic meter is higher even when technology is adopted. In any case, the resulting values are very high and caution is recommended when considering them. To determine what the real affordable price is, demand functions were calculated in such a way that the cost of the required water is subtracted from each resulting cropping plan. The cost of water is concordant with the price included in each parameterization. The results of this calculation

are Figure 3, where it is observed that the production units in Murcia demand more water than those of Alicante, up to 0.60 €/m³, a price at which Murcia would begin to reduce consumption. The curves of scenario-2 show a higher demand than those of scenario-1 since, if the grower has technology, other limitations, such as labour, can be compensated, and more productive varieties will be planted, but these consume more water.

Since the demand for water only begins to decrease when prices are very high, availability of the resource is an even greater limitation than its price. Analyzing the repercussion of the price of water on net profit (Figure 4), it can be observed that with prices above 1.5 €/m³ only a very low profit is obtained, or there may even be losses. If a reference income is set at 18,000 euros to compensate the yearly work of the entrepreneur, the maximum price that small grape growers in Alicante can afford is 0.25 €/m³ in scenario-1 and 0.60 €/m³ in scenario-2. In Murcia, this reference income is achieved when prices are lower than 0.15 Euros per cubic meter in scenario-1, while the current price of water is 0.18 €/m³, meaning that only those growers with more technology are achieving profits. In the case of implementing the improvements of scenario-2, in Murcia it is possible to surpass the reference income when the price of water is not more than 1.1 €/m³.

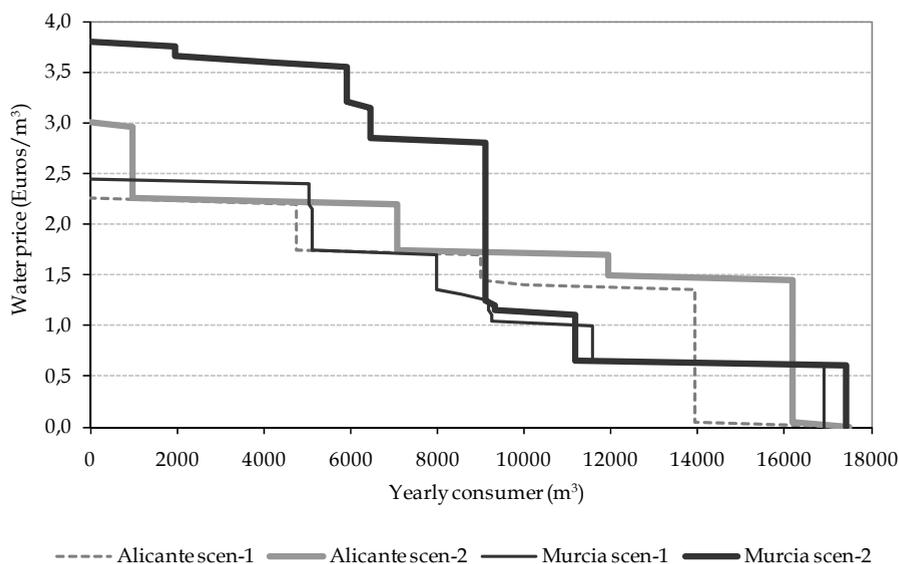


Fig. 3. Irrigation water demand curves in Spanish grape-table (Data for 5 ha production unit)

The main conclusions are:

- To guarantee the continuity of the Spanish table-grape farms (most of them being small and family-run), the adoption of technological improvements seems to be essential. An essential improvement (being massively applied in both areas) is the increase of surfaces with drip-irrigation. This technique enables choice of the watering times for the plots, achieving an optimization of the allotments awarded in the plantation, these usually being lower than the theoretical needs of the crops.

- The scarce response of the demand, because of rising water prices, and therefore, of implementation of a pricing policy, denotes that the problem of these producing regions is its availability rather than its price. This conclusion is only valid if the growers have an acceptable profitability, which cannot be assured in the medium or long-term with the current market situation. To achieve the minimum profit fixed in this study, the price of water should not exceed 0.15 €/m³ in Murcia and 0.25 €/m³ in Alicante. These prices could be considerably higher if growers improve their level of technology. Therefore, the adoption of technology will be the most direct strategy for increasing expectations of continuing production of the growers, who, in general, do not feel capable of overcoming the iron rules of the markets.

Proportion of activities (in %) ¹	Irrigation Type	Scenario-1		Scenario-2	
		L ₁	L _∞	L ₁	L _∞
ALICANTE (VINALOPO):					
Aledo. Traditional espalier. Bagged	Flood			16.8	
Aledo. Traditional espalier. Bagged	Drip	40.5	40.5	23.7	40.5
Aledo. Y espalier. Bagged	Drip	4.5	4.5	4.5	4.5
Italia. Traditional espalier. No bagged	Flood	20.3	20.2		
Italia. Traditional espalier. No Bagged	Drip	4.7	4.8	10	12.5
Victoria. Y espalier. No bagged	Drip			10*	10*
Superior. Y espalier. No bagged	Drip			5*	5*
Proportion with marginal management		30*	30*	30*	27.5
Total Net Margin (€)		21,175	21,177	23,785	24,874
Total manual labour (h)		1,345	1,345	1,210	1,254
Total water consumption (m³)		13,898.5	13,899	13,841	14,428
Shadow irrigation prices (€/m³)		4		1,9	
MURCIA :					
Napoleón. Wood trellis	Flood	25	27	5	5
Dominga. Wood trellis	Flood	5	5	10	10
Superior. Wood trellis	Flood	10	8		
Superior. Wood trellis	Drip	30	32		
Superior. Galvan. iron trellis. Mesh cover	Drip			45*	45*
Crimson. Galvan. iron trellis. Mesh cover	Drip			10*	10*
Proportion with marginal management		30*	28	30*	30*
Total Net Margin (€)		17,511	18,034	35,070	35,103
Total manual labour (h)		1,835	1,873	2,154	2,158
Total water consumption (m³)		16,185	16,607	15,233	15,285
Shadow irrigation prices (€/m³)		1,24		0,63	

1) Respect total surface (5 ha). * Limit coincident with the restrictions of the models.

Source: Own calculation

Table 4. Cropping plan and results for two scenarios in Spanish table-grape

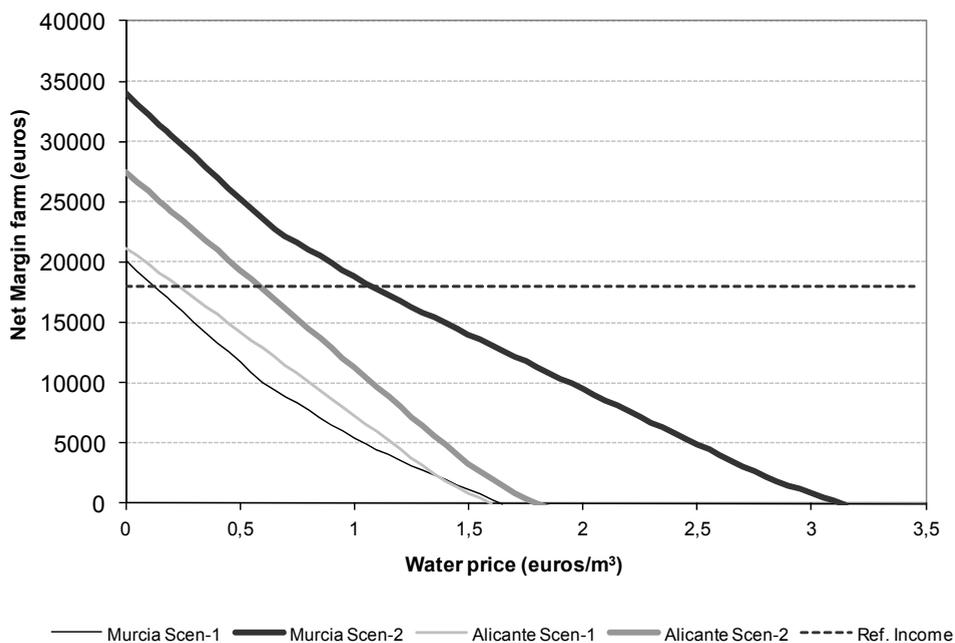


Fig. 4. Repercussion of the price of water on net profit in Spanish grape-table (Data for 5 ha production unit)

5. Conclusion

Water demand curves have been used to analyze the trends of the most important Mediterranean woody crops when up against tariff policies that differ from the current ones. These calculations have been applied to olives, almonds and vineyards grown in the inland regions of the Valencian Community, and table grapes in the two main production areas in the southeast Spanish Mediterranean region. The main conclusions derived from the two case studies are:

- The shadow price of water is very high for all crops under study, increasing in those scenarios with a low technological level. Technology can offset other agronomic technical limitations of the farm-holding, optimizing the production process, and therefore the shadow price of water is reduced. Usually farmers believe that technology is their best strategy to improve farm viability, although, on the other hand, technological improvements allow more productive varieties to be grown, which typically require more water, and as a result the more technologically developed scenarios are also more demanding of water resources.
- Irrigated crops with moderate irrigation requirements, such as table grapes, show highly inelastic demand curves, at least in the first price phases. As this resource becomes more expensive, demand falls while the surface area with marginal management increases, which may be the step prior to future crop abandonment. For the typical rainfed crops, the demand curves display strong inelasticity, demonstrating the huge value of having an extra cubic meter of water, this to be applied at specific

moments and in low doses. In general, Mediterranean crops make very efficient use of the water supplied, even at doses below agronomic irrigation needs. Allocations should be supplied at the point in time most crucial to the crop, which often coincides with reduced water availability on the farm, and in this moment availability becomes a more limiting factor than the price. This does not mean water high prices can be paid, since the real affordable price is much lower.

- Water prices to be paid can theoretically be very high, as with respect to woody species their survival depends on timely supply, which does not indicate that sustained high prices are to be met. In fact, the first step taken by farmers is to increase the surface area with marginal management (prior step to abandonment) and concentrate investment in the more profitable fields or varieties. Therefore, it is foreseeable that a tariff policy implementing high prices would result in the gradual abandonment of Mediterranean crop cultivation and thereby reduce the economic activity in large tracts of land, especially in the inland regions.

Further research based on woody crops in areas where these are implemented would be desirable for the achievement of a sustainable and efficient use of water. The effects of a water pricing policy in other highly extended woody Mediterranean crops, such as citrus, almond, pomegranate or peach, is still unknown. This research would inform farmers and policy makers about reliability of water pricing policies in this kind of crops, avoiding undesirable effects on farmers and environment, and enforcing the reliability of the measures proposed by the WFD.

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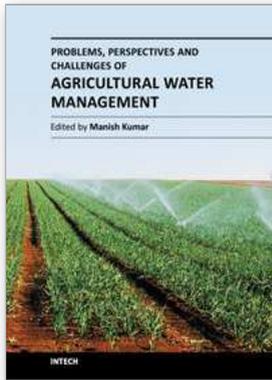
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Problems, Perspectives and Challenges of Agricultural Water Management

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Food security emerged as an issue in the first decade of the 21st Century, questioning the sustainability of the human race, which is inevitably related directly to the agricultural water management that has multifaceted dimensions and requires interdisciplinary expertise in order to be dealt with. The purpose of this book is to bring together and integrate the subject matter that deals with the equity, profitability and irrigation water pricing; modelling, monitoring and assessment techniques; sustainable irrigation development and management, and strategies for irrigation water supply and conservation in a single text. The book is divided into four sections and is intended to be a comprehensive reference for students, professionals and researchers working on various aspects of agricultural water management. The book seeks its impact from the diverse nature of content revealing situations from different continents (Australia, USA, Asia, Europe and Africa). Various case studies have been discussed in the chapters to present a general scenario of the problem, perspective and challenges of irrigation water use.

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