

Estimating marginal value of water for irrigated olive grove with the production function method

M. A. Mesa-Jurado^{1*}, J. Berbel¹ and F. Orgaz²

¹ Department of Agricultural Economics. University of Cordoba. Campus Rabanales C5. 14014 Córdoba. Spain

² Instituto de Agricultura Sostenible. CSIC. Alameda del Obispo, s/n. P.O. Box 4084. 14004 Córdoba. Spain

Abstract

Economic valuation of irrigation water is done through the use of production functions for the case of the olive grove. In order to do so the integration of an agronomic model (based on the production function) and an economic model linked to the profitability of the crop (the ratio of revenue and operating costs) in the area under study is proposed. The study case encompasses the Guadalbullon River Sub-basin area, belonging to the Guadalquivir River Hydrologic Demarcation (Southern Spain). Within the overall deficit of the Guadalquivir River basin, the Guadalbullon River poses a special problem as it is unregulated and there are important irrigated fields on its banks, most of them olive groves. Net marginal value of water obtained (having deducted the variable costs of production including harvesting and irrigation) is € 0.60 m⁻³ for the allocation of 1,000 m³ ha⁻¹ and € 0.53 m⁻³ for the water right allowance of 1,500 m³ ha⁻¹ (average for period 2005/2008). The results obtained support the recommendation by other authors suggesting the use of deficit irrigation in olive, additionally the high value of water estimated contributes to explain the substantial increase in irrigated olive area in Andalucía.

Additional key words: Guadalquivir River Basin; irrigation; water management; water valuation.

Resumen

Estimación del valor marginal del agua de riego en olivar mediante el método de la función de producción

En esta investigación se realiza una valoración económica del agua de riego mediante el empleo de funciones de producción para el caso del olivar. Para ello se propone la integración de un modelo agronómico (basado en la función de producción) y un modelo económico relacionado con la rentabilidad del cultivo (relación de ingresos y costes de explotación) en la zona objeto de estudio. El caso de estudio engloba la subcuenca del Guadalbullón, perteneciente a la Demarcación Hidrográfica del Guadalquivir en el sur de España. Dentro del déficit global de la cuenca del río Guadalquivir, la del Guadalbullón presenta una especial problemática al ser una subcuenca «no regulada» y asentarse en sus márgenes importantes riegos principalmente de olivar. El valor marginal neto del agua obtenido (una vez deducidos los costes variables de producción incluido recolección y riego) es de 0,60 € m⁻³ para la dotación de 1.000 m³ ha⁻¹ y 0,53 € m⁻³ para la dotación teórica de 1.500 m³ ha⁻¹ (media para el periodo 2005/2008). Los resultados obtenidos respaldan las recomendaciones de otros estudios en los que se sugiere el uso cuidadoso del regadío deficitario y, adicionalmente, el alto valor obtenido para el agua explica el aumento continuado de la superficie de olivar regado en Andalucía.

Palabras clave adicionales: Cuenca del Guadalquivir; gestión del agua; regadío; valoración del agua.

Introduction

In early stages of water management, this natural resource was treated as a renewable one such as wind or solar radiation, as water was regarded as a freely available, non-economical good and therefore free of

charge in many regions of the world. The International Conference on Water and Environment, that took place at Dublin in 1992, admits that the lack of recognition of the economic value of water in the past has led to over-exploitation and inefficient use of this resource with adverse effects on the environment. To acknow-

* Corresponding author: g02mejum@uco.es

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Abbreviations used: CHG (Confederación Hidrográfica Guadalquivir), ET (evapotranspiration), PPI (producer paid index), Q (olives production), RUE (radiation use efficiency), T (transpiration), WFD (Water Framework Directive), Y (yield).

ledge the status of water as an economic good in its management is an important mean to achieve an exploitation that is efficient, equitable and favourable to the preservation and protection of water resources (ICWE, 1992). Similarly, at the Second World Water Forum (held at The Hague in 2000) particular emphasis was placed on the fact that decisions regarding the allocation of water amongst different competitive uses require further analysis of the valuation of this natural resource (SWWF, 2000). A rational management of water requires the knowledge of the value of the resource.

This paper focuses on the agricultural use of water which accounts for approximately 70% of world extraction and it is considered to be the least profitable. Irrigation represents the largest use of water resources in Southern Spain with an increasing intra-sector competition and a foreseeable rise in consumption and competition with other uses (industrial, urban, etc.) (Martín-Ortega *et al.*, 2008). This paper intends to assess the economic value of water for a specific agricultural use that has been scarcely analyzed as it is the irrigation of olive grove, and to apply the tools in an environment where the resource is extremely scarce as it is the Guadalbullon River Sub-Basin area belonging to the Guadalquivir River Basin, although the tools developed here can be applied to any other area of Spain and the world.

This research conducts an economic assessment of irrigation water for the case of the olive grove. The goal is to contribute to the design of economic assessment tools that will help to evaluate policies for water distribution between sectors (*e.g.* agriculture *versus* industry) and within agriculture (olive orchards *versus* cereals). There are not previous published researches on valuation of water for irrigated olive groves, and this is a case where production function is particularly appropriate because it is a single crop with a flexible and vigorous response to supplementary irrigation.

Material and methods

Using production functions to estimate the value of water in irrigation

Natural resources are susceptible of being valued economically. In the extensive literature existing on the economic assessment of irrigation water the valuation methods encountered differ both in the approach used and in the obtained results. A review of the approaches

to estimate the economic value of water can be found in the work of Young (2005), and more specifically to irrigation water in Tsur and Dinar (1999), Johansson *et al.* (2002) and Tsur *et al.* (2004). This research selects the production function method which is a deductive method that involves the derivation of shadow prices where water is an input into production systems. It belongs to methods based on the marginal productivity of water (such as mathematical programming methods) and is alternative to other approaches such as Residual Value Method (Bate and Dubourg, 1997; Mesa-Jurado *et al.*, 2008), Hedonic Pricing (Berbel and Mesa, 2007), Contingent Valuation (Carson, 2000) or Choice Experiments (Rigby *et al.*, 2010).

Many authors have proposed and adapted water production functions that relate crop yield to evapotranspiration. The simulation of crop production resulting from irrigation doses has been carried out within linear programming with a limited number of «crop-water dose» activities (*e.g.* unirrigated wheat, irrigated wheat 1,000 m³ ha⁻¹, irrigated wheat 2,000 m³ ha⁻¹, etc.). An alternative approach has been the use of dynamic programming and/or quadratic programming where the production function is approximated through second degree polynomial functions; an example of this methodology can be seen in Reca *et al.* (2001).

The inconveniences of using piecewise functions may be solved by employing continuous production functions that will enable a more realistic simulation of the production, and hence of the profitability of the crop, depending on the total amount of water supplied (rainfall + irrigation). This represents a key improvement, since it allows determining the demand of water, and also facilitates the analysis and quantification of the cost of the scarcity of the resource which at times represents substantial economic losses to the farmers who suffer from it.

The rationale behind this methodology is as follows: assuming *ceteris paribus* the remaining quantities of inputs, the marginal increase in the amount of product per unit of increase of irrigation water is defined as the *physical marginal productivity of water*. The marginal value of each additional unit of water used in irrigation is the result of multiplying the product price by the aforesaid productivity.

Many examples of the estimation of the marginal value of water, obtained as the result of multiplying the marginal productivity of the water by the price of the obtained product can be found in the literature (Young, 2005). The methodology has been applied to wheat, cotton, maize and sugar beet by Hexem and

Heady (1978), Vaux and Pruitt (1983), Gibbons (1986) or Llewelyn and Featherstone (1997).

A majority of applications are focused on «commodity» crops (wheat, maize, cotton...), so that when estimating the water value there is a direct relationship between physical and economic productivity since the costs of cultivation are generally considered as fixed costs (except irrigation), in such a way that a greater amount of product translates directly into a higher marginal benefit (the marginal costs of harvesting are ignored). In the case of crops such as olive grove for which the operating costs, especially for harvesting, are significant, it is necessary to transform the agronomic production function into a net margin function, to obtain the economic marginal productivity of water, this is one of the innovations of this paper as the use of marginal value of water is generally applied to commodity and examples of non-commodities of this technique is scarce.

In order to do so an agronomic model (based on the production function) has been integrated to an economic model linked to the profitability of the crop (the ratio of revenue and operating costs).

Data source

Most of the hydrological, climatic and economic data comes from the studies carried out for Water Framework Directive (WFD, 2000) 2000/60/EC implementation in Guadalquivir River Basin. Guadalbullon River sub-basin was selected as a pilot sub-basin to study olive irrigation and water guarantee, as it was considered by Confederación Hidrográfica a good example of the irrigated olive characteristics for Guadalquivir Upper Valley. In the WFD implementation process, there is a specific public participation workshop focused in Guadalbullon that it is used to obtain most of the information needed for this study (CHG, 2009a).

Production cost data is obtained from Agricultural Farm Economic-Technical Reports of the Ministry of Agriculture (MARM, 2005). In these reports an average of four years (2002-2005) was used to obtain the estimation of harvest costs for different crops cultivated in Andalusia. These data has been updated until 2008 for this study case. Additionally, data on olive prices is based upon Statistics Service of Spanish Ministry of Agriculture (MARM, 2006; 2008)

Data corresponding with irrigation costs, water allocations and characteristics of the olive grove is

obtained from primary sources. Personal interviews were realized to Irrigators' Community and experts in the focus area during June 2009.

Description of olive cultivation in Guadalbullon River

This study case covers the Guadalbullon River Sub-Basin area with an average annual flow of $150 \cdot 10^6 \text{ m}^3 \text{ year}^{-1}$, belonging to the Guadalquivir River Hydrologic Basin in Southern Spain. Within the overall deficit of the Guadalquivir River basin, the Guadalbullon River poses a special problem set as it is not regulated and there are important irrigated fields on its banks, most of them olive grove. The Figure 1 shows its location in the Guadalquivir River Basin.

This river has flows in summer that have historically enabled the establishment of irrigated fields, initially located on the stretch near the junction with the Guadalquivir that have subsequently, with the boom of irrigation in olive grove in the province of Jaen, spread throughout the valley. Irrigation is by far the largest use of water resources in Southern Spain with an increasing intra-sector competition and a foreseeable rise in consumption and competition with other uses (industrial, urban, etc.) (Martin-Ortega *et al.*, 2008).

The total area under cultivation in the sub-basin area is 71,374 ha of which 22,177 (31%) are irrigated surface and the rest is rain-fed. In the sub-basin, agriculture uses 70% of the water consumption practically with olive groves as single-crop farming (91% of total irrigated area). It is estimated that total consumption in the basin uses 65% of the renewable resources and that the minimal environmental flow is not reached in a significant number of days.

Farmers face a scenario of uncertainty over the available amount of water each season, so every campaign they confront a situation of instability on the earnings they obtain.

The current policy in Guadalquivir River basin (where Guadalbullon River Sub-basin belongs) is to improve farm irrigation systems (changing from surface to trickle irrigation) and the distribution system (pressurized networks). Each farmer receives an amount of water assigned by the water authority as a «water right» or allocation. Water allocations usually are assigned for a «standard year» at $6,000 \text{ m}^3 \text{ ha}^{-1}$; it should be noted that this amount is an average from the different administrative allocations in Guadalquivir

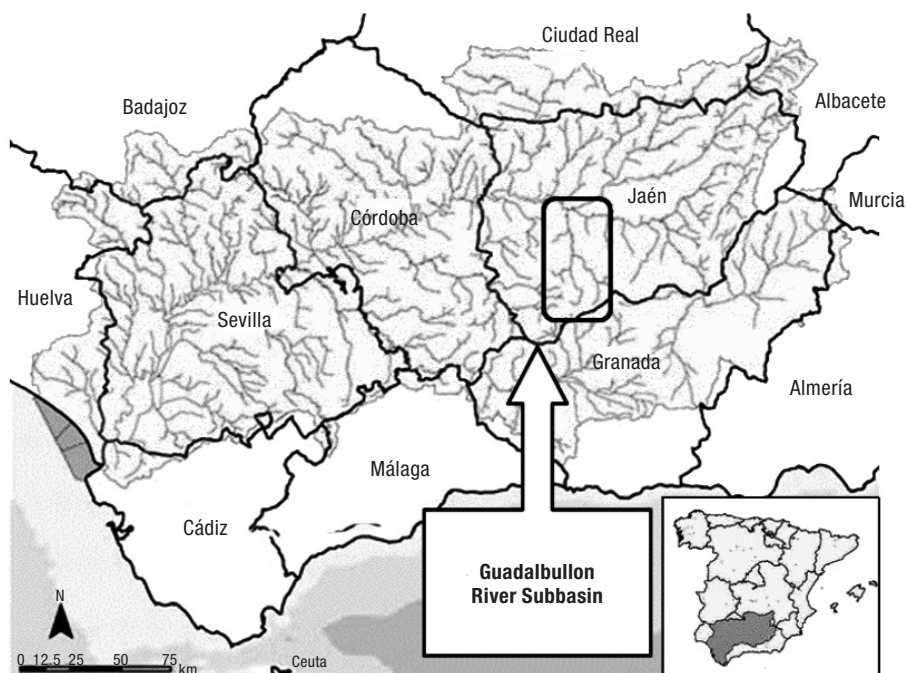


Figure 1. Guadalbullon River Sub-basin's location in Guadalquivir River Basin.
 Source: Confederación Hidrográfica del Guadalquivir (2009b).

River Basin, and it varies according to area and crop type (e.g., rice uses around $12,000 \text{ m}^3 \text{ ha}^{-1}$ whereas some olive cultivation areas receive $1,500 \text{ m}^3 \text{ ha}^{-1}$). However, in the Guadalbullon River basin olive grove farmers rarely receive the full right ($1,500 \text{ m}^3 \text{ ha}^{-1}$) and often the yearly quota is smaller. The average allocation received by the farmers in the last four years was around $1,000 \text{ m}^3 \text{ ha}^{-1}$ (data obtained directly through Irrigators Communities' interviews).

Irrigation of olive grove has entailed a technological revolution in the sector, especially in this region where in 2008 the percentage of olive oil coming from irrigated areas is estimated at 56% of the total. The higher profitability of irrigated olive grove per area and the increased use of family hand labour in small farms are the reasons behind the pressure to increase water consumption in the sector. Taking the Guadalquivir River basin as a whole, the olive grove has prominently become the largest user of water despite its low dose ($1,500 \text{ m}^3 \text{ ha}^{-1}$ versus an average of 6,000 for general irrigation).

Estimating the marginal value of water in olive grove

The production functions methodology described is applied on the specific data of the Guadalbullon River ba-

sin. The estimation of water value is obtained by integrating the following models: a) agronomic model, where yields are a function of applied irrigation; b) economic model, where yields are converted into a profit function.

a) *Agronomic model*

In the literature it is possible to find different examples, some of them carried out in Andalusia, that analyze the relation between yield (Y) and irrigation water dose in olive grove (Lavee *et al.*, 1990; Inglese *et al.*, 1996; Pastor *et al.*, 1999; Moriana *et al.*, 2003, 2007; Perez-Lopez *et al.*, 2007). In these studies, yield responses of different olive orchards to variable water supply are analyzed. Obviously, it is not possible to make generalizations with all these relations since for same water dose, the evapotranspiration (ET) and the yield of the tree vary depending on quantity and distribution of the precipitation and soil depth and water retention. Only in Moriana *et al.* (2003), the relation between yield and ET for a range wider than in other studies for both of these variables is established, for this reason an adapted version of the production function for the olive grove obtained by Moriana *et al.* (2003) in the period 1996-1999 is used. The original production function is showed below:

$Y = -2.78 + 0.011 ET - 0.035 \cdot 10^{-3} ET^2 \quad R^2 = 0.59$ [1]
 where Y = olive oil production, in t ha⁻¹; ET = evapotranspiration, in mm.

The ET of an olive orchard under localised irrigation has four basic components: a) tree transpiration, b) rainfall intercepted and directly evaporated from the foliage, c) evaporation from the overall soil surface and d) evaporation from the areas wetted by the emitters. Only transpiration (T) has a physiological nature and is related to crop yield. Some examples illustrating the relative importance of the ET components of different olive orchards in Andalucía can be seen in Orgaz *et al.* (2006).

Table 1 shows the characteristics of an average representative olive orchard in the study zone that are used to adapt the Moriana *et al.* (2003) production function.

Maximum transpiration is a function of the fraction of intercepted solar radiation (Orgaz *et al.*, 2006), scaling up with planting density and tree size. Moriana *et al.* (2003) used an olive grove (278 trees ha⁻¹ and around 45% ground cover fraction) different than the one considered in this study case (100 trees ha⁻¹ and 20% of ground cover fraction), therefore production function obtained in the first case is not applicable directly in the second one. It is due to the fraction T/ET varies considerably with tree crown specific volume: while T has a direct relation with the fraction of inter-

cepted solar radiation, and then, with the tree crown volume, ET from the soil surface is not very sensitive to this variable and fundamentally depends on the precipitation frequency and the fraction of the soil wetted by the emitters. It is assumed that for a same ET value, transpiration will be much bigger for an olive grove like the one used in Moriana *et al.* (2003) than the other considered in this study case. For this reason, it is necessary to transform the original function (Y relation with ET) in another one (Y relation with T) in order to apply it in this research.

For this purpose, the models described in Bonachela *et al.* (1999, 2001) have been used to estimate the evaporation in Moriana's research. Mean evaporation has been calculated in 299.7 mm, varying yearly but very little between irrigation schedules. For this reason and because it is based on estimated values, this evaporation amount is subtracted from the original production function ET, instead of subtracting evaporation individual values from each of ET values and adjusting again. The result obtained is the expression presented below:

$$Y = -0.02 + 0.0074 T - 0.006 \cdot 10^{-3} T^2 \quad [2]$$

where T = seasonal transpiration, in mm.

Note that the function relates transpiration and olive oil, but the need to estimate harvesting costs recommends the conversion to olives production (Q) as the cost of harvesting is related to olive production. This can be obtained simply by considering that in the Guadalbullon area the olive yields 22%¹ of oil when harvested, therefore $Q = Y/0.22$.

Finally, to transform the values of irrigation water into seasonal transpiration the following expression is used:

$$T = T_{max} - NIR - W \cdot Ef \quad [3]$$

where:

— T_{max} : average (1983-2002 period) maximum transpiration for irrigated olive orchard in this area ranged from 156 mm for a traditional orchard with a 12% of ground cover fraction, to 708 mm for an intensive grove with a 45% of ground cover fraction. Total ET was 481 mm and 1,087 mm, respectively. To obtain T_{max} the methodology described in Orgaz *et al.* (2006) is applied to an average representative olive orchard in the study area (see Guadalbullon olive grove characteristics in Table 1) resulting in 215.4 mm of maximum transpiration and 568 mm of total ET.

— NIR : taking into account the physiological condition of the crop, soil characteristics, climatic

Table 1. Main physiological condition and soil characteristics of a representative olive orchard in the Guadalbullon River sub basin

Characteristics	
Planting frame ^a	10 × 10 m
Tree crown diameter (D)	5 m
Tree height (H)	3.7 m
Shape tree index (D/H)	1.35
Crown tree volume	48.4 m ³
Ground cover fraction	0.20
Leaf area density	1.72 m ² m ⁻³
Fraction on intercepted solar radiation (Qd)	0.22
Irrigation frequency	Once a week
Fraction of the soil wetted by the emitters	5%
Soil texture	Clay loam
Soil depth	2.00 m

^a This planting frame represents 85% of the olive grove in the area. *Source:* Own data obtained by interviews to experts in the study area.

¹ Own data source obtained by interviews to experts in the area.

conditions and irrigation method in the area, the net irrigation needs (net required irrigation for maximum production in an average year) are calculated by means of the procedure described in Orgaz *et al.* (2005, 2006) eliciting a value of 125.3 mm.

— W : applied water in mm.

— Ef : irrigation efficiency in the area. It is obtained through the product between *field application efficiency* and *conveyance efficiency*. Using Confederación Hidrográfica del Guadalquivir (2009b) data, the Ef obtained is 0.81.

However, when the maximum transpiration is reached, excess water does not increase production, so the marginal productivity from that point onwards is null. The situation in Guadalbullon is that maximum irrigation is rarely achieved as water resources are below water potential demand therefore the usual situation is to apply deficit irrigation to olives. It results interesting as well to estimate the effect caused by dry years, for this reason the irrigation requirements for 20% of the years covered in the time series analyzed are estimated (the driest years are considered, with average rainfall values close to 352 mm), yielding net irrigation requirements of 221.3 mm. The corresponding irrigation doses for this transpiration is 2,740 m³ ha⁻¹, above which the marginal productivity is null, but average water right is 1,500 m³ ha⁻¹, so that the usual situation is that marginal water value is generally greater than zero (water dose is below maximum transpiration). Therefore, expression [2] is considered valid for irrigation doses smaller than the maximum transpiration, for higher values a linear decrease of the marginal productivity is deduced.

The maximum yield (around 5,900 kg olive ha⁻¹) obtained by the expression [2] is coherent and consistent with data found in the literature. The maximum yield in irrigated olive corresponds to a Radiation Use Efficiency (RUE) of 0.22, similarly to RUE values showed in Villalobos *et al.* (2006) that fluctuate between 0.2 and 0.25 for this olive orchard typology. In the same way, yields estimated for rainfall olive grove (around 2,700 kg of olive ha⁻¹) are considered reasonable taking into account that the average rainfall production in Andalusia is closer to 2,500 kg olive ha⁻¹ (Junta de Andalucía, 2002). In any case, with the studies that are been conducted until nowadays, it is not possible to make a better approximation to estimate irrigation effect in olive production.

b) *Economic model*

The economic model transforms harvest into profit for the farmer measured as net margin (*i.e.* kg olives ha⁻¹ are converted into € ha⁻¹). This profit is obtained by using the following expression:

$$NM = (p - k_h) Q - k_w \cdot W - FC - FIC - AVC \quad [4]$$

where:

— NM : net margin, in € ha⁻¹;

— p : price of the olive, in € kg⁻¹. It has been estimated for the average of the years 2005/2006/2007/2008, eliciting an average price of € 0.52 kg⁻¹ [based on data of Agrarian Yearbooks from Ministry of Agriculture (MARM, 2006, 2008)].

— k_h : coefficient of harvesting cost. The value for the case study is $k_h = 0.0822$ for the average period used as a reference. In this coefficient only *hired labour* is included, as *family labour* represents 70% of total agrarian labour in Jaen province; therefore net margin includes earnings for family labour. Data used in order to obtain harvesting cost coefficient comes from Agricultural Farm Economic-Technical Reports of the Ministry of Agriculture (MARM, 2005). The Producer Paid Index (PPI) has been used to update the cost to 2008.

— k_w : variable cost of irrigation, this cost has been deducted from the field work as representing 85% of the fee paid by farmers to the Irrigators Community to which they belong, covering the cost of electrical energy required for pumping, the remaining cost is the fixed cost detailed below. The irrigation fee paid is expressed in € tree⁻¹. To convert units to € ha⁻¹, a 10 × 10 m planting framework has been considered (100 trees ha⁻¹) which is the most common in the study area. This information related with irrigation costs has been extracted directly by irrigator communities' interviews in the study area.

The total cost of irrigation is broken down into the following items: 85% (electric power used for pumping), 5% (labour hired by the community of irrigators), 4.5% (fertilizer used for fertirrigation), 3% (repairs), 2% (canon of the Hydrographical Confederation of the Guadalquivir) and 0.5% (administration). In this case, the fertilizer costs are not taken in account because these have been considered in the coefficient of olive harvest cost. Last year, there was a significant increase mainly due to the increased cost of electricity. Considering the average of the allocations² they have received

² Own source, obtained by survey in the area.

during the last 4 years ($1,000 \text{ m}^3 \text{ ha}^{-1}$), we have the value of $k_w = \text{€ } 0.26 \text{ m}^{-3}$ for the average of 2005/2008.

— W : amount of water used, in $\text{m}^3 \text{ ha}^{-1}$.

— Q : olive production, in kg ha^{-1} .

— FC : fixed costs in € ha^{-1} . For this case the average is $\text{€ } 52 \text{ ha}^{-1}$ (MARM, 2005).

— FIC : fixed irrigation cost, in € ha^{-1} (corresponding to the remainder of community of irrigators' fee after deducting variable costs). The resulting values are $\text{€ } 36.75 \text{ ha}^{-1}$ for the period 2005-2008.

— AVC : average of variable costs, in € ha^{-1} . This cost has been estimated for an average yield, this is a simplification as the model considers *ceteris paribus* rest of inputs except harvesting costs. Average costs of all inputs except labour is $\text{€ } 516.17 \text{ ha}^{-1}$.

Results

The combined application of the previous models generates a function of water value (measured as net margin) depending upon water application. Considering Eq. [3] and the unit conversion from olives to income, the net margin for the different doses of irrigation can be elicited. Substituting Q obtained from Eq. [2], Eq. [4] is converted to:

$$\text{NM} = (p - k_h) [-0.02 + 0.0074 (T_{\text{max}} - \text{NIR} - W \cdot E_f) - 6 \cdot 10^{-6} (T_{\text{max}} - \text{NIR} - W \cdot E_f)^2] / 0.22 - k_w \cdot W - FC - FIC - AVC \quad [5]$$

As was mentioned above, the administrative water rights in Guadalbullon granted by the Guadalquivir River Hydrologic Demarcation is $1,500 \text{ m}^3 \text{ ha}^{-1}$, so the previously calculated T_{max} will not be exceeded in this area.

In order to obtain a more realistic scenario, present average water doses in the study area are used which is around $1,000 \text{ m}^3 \text{ ha}^{-1}$ in the last for years. There is a great variability of water supplied because of Guadalbullon is an unregulated river, and then it is difficult to ensure the administrative water rights.

Figure 2 illustrates the marginal value for income and net margin for the period 2005-2008. Plotted marginal income is the derivative of gross income (price by production, without subsidies) respect to water supply; similarly, plotted net margin is the derivative of net margin (estimated by Eq. [5]).

Finally, the estimation of the marginal value of water for the average administrative water rights allowance of $1,500 \text{ m}^3 \text{ ha}^{-1}$ would be $\text{€ } 0.53 \text{ m}^{-3}$ (average prices for period 2005-2008). The value for the actual average

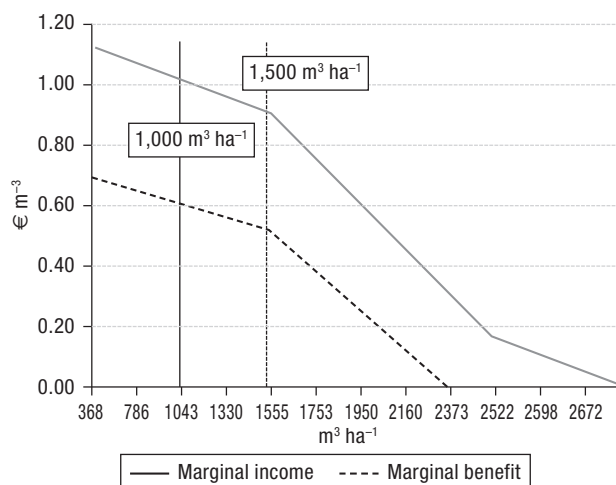


Figure 2. Marginal income and marginal value of water for irrigated olive grove during the period 2005-2008. *Source:* Own elaboration.

(2005-2008) of $1,000 \text{ m}^3 \text{ ha}^{-1}$ applied water implies that marginal value of water would be $\text{€ } 0.60 \text{ m}^{-3}$. Unfortunately for farmers, a small percentage of the years (around 25%) the actual water used is equal to water rights allowance, most of the years is below the administrative quota and the actual average obtained by survey illustrates this deficit of guarantee due to the need of water infrastructure (reservoirs) in the basin, presently a large bank-side reservoirs is under construction. The present research might used for valuation of the profitability of the projected hydraulic infrastructure.

Discussion

The results of this work can be used to analyze the value of water for the irrigation of olive grove. The combined application of agronomic and economic models gives relevant results for analysis of water demand in the Guadalbullon River basin.

The Guadalbullon Basin has been used as an example of the impact of this method in hydrological resources; after developing an agronomic model that relates irrigation and olive production, and another economic model that relates olive production with revenue and farming costs. The combination of both models generates a function of the marginal water water in the area. During the period 2005-2008, a water value of $\text{€ } 0.53 \text{ m}^{-3}$ for the water allocation of $1,500 \text{ m}^3 \text{ ha}^{-1}$ is estimated; and $\text{€ } 0.60 \text{ m}^{-3}$ for an allotment of $1,000 \text{ m}^3 \text{ ha}^{-1}$. These allocations are chosen due to they are the most frequent ones in the area.

Ward and Michelsen (2002) emphasised that the use of marginal values enables policy analysts to anticipate and evaluate the impacts of future policy proposals. These authors also stated that average values, while being attractive for its ease of calculation and simplicity, might be misleading since they are typically much larger than marginal ones and value only the existing uses tending to over-estimate the impacts of changing the current uses. The values found in this research are higher than ones in previously reported studies such as in Berbel and Mesa (2007) who estimated capitalized value of water for irrigated olive in Jaen at € 3.46 m⁻³ implying a value of € 0.21 m⁻³ when it is discounted at 6% of interest rate (data for 2005) using quasi-hedonic method, and in Mesa-Jurado *et al.* (2008) who reported a value of € 0.47 m⁻³ for irrigated olive in the Guadalquivir River basin based on the residual value method.

The alternative values mentioned, yield an average value of the water while the production function used in this research estimates a marginal value. The fact that average values of water given in alternative studies for irrigated olive in Guadalquivir are lower than marginal ones estimated in this work is explained by the different doses employed in computations. While the values showed in this paper have been calculated for deficit irrigation allotments (in the range 1,000 to 1,500 m³ ha⁻¹), the alternative studies use higher doses (in the range 2,250 to 2,500 m³ ha⁻¹) so that the decreasing marginal productivity explains lower values. Obviously, the production function method gives a continuous curve with decreasing values for water where it can be observed that finally, it goes to zero at water allocations related with maximum transpiration.

Pastor *et al.* (2002) recommend that due to the high cost of water pumping and the existence of shortages of the supply in the Jaen area, the irrigated doses should be around 1,500 m³ ha⁻¹; this recommendation is also adopted by Water Agency (CHG) and widely used by the farmers. The results obtained support this recommendation because the values of water for allotments close to this quantity are sufficiently profitable in irrigated olive grove.

According to Calatrava-Leyva and Garrido (2002), uncertainty about water availability can be represented by a probability distribution of water allocations, which translates into a probability distribution of profits. Due to decreasing marginal productivity of water, profit reductions in dry years are bigger than profit increases in years in which water availability is above average.

So with a greater variability the cost for producers is raised. For this purpose, the production function designed in this paper will be used in a further research for the assessment of water management in the context of water supply uncertainty.

In conclusion, this methodology might be of great interest to support decision making both at farm level and policy makers as the increase in olive irrigation is presently the main pressure on water resources in the Guadalquivir River Basin. The study scope is limited (spatially and temporally) and further development under process. Next steps in this research will be: i) to enlarge analysis to other areas of irrigated olive, ii) to include variability in water supply and to evaluate water guarantee. Nevertheless, the Guadalquivir is one of the most representative Jaen olive cultivation areas and the conclusions of the presented case of study might be used as an indicator for water value in Upper Guadalquivir Basin.

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