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Farmer's subjective elicited water response function for intensive olives and compromise programming method for irrigation supply decision

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ABSTRACT: This research analyses the subjective crop yield-water relationship and proposes a method to determine water supply in irrigated olives. The probability density for water response functions (PDF) is elicited from a series of interviews carried out on a wide group of farmers. The elicitation technique is based upon the triangular distribution (highest possible, most frequent and lowest possible) and estimates of yield related to water supply (low, 'normal' and full irrigation). The model presented illustrates the possibility of implementing simple decision models to support farmers to manage water considering the objectives of maximizing profit and minimizing risk.

KEYWORDS: Compromise programming, deficit, irrigation, decision maker judgment, probability density function, water production function.

JEL classification: Q25, D01, C61.

DOI: 10.7201/earn.2015.02.03.

Función subjetiva de respuesta al agua del agricultor en olivar intenso y la programación compromiso para decisiones

RESUMEN: La investigación analiza la función subjetiva de producción de agua (respuesta producción-riego). Se han obtenido funciones de densidad de probabilidad de respuesta al riego basadas en la función triangular (rendimiento 'más probable', 'pesimista' y 'optimista') correspondientes a diferentes dosis de riego ('completo', 'medio' y 'bajo'). A partir de esta información se plantea un modelo de decisión de tipo normativo para determinar la dosis óptima de riego en olivar intensivo que incluye rentabilidad esperada y riesgo entendido como la probabilidad de no alcanzar un umbral prefijado de ingresos.

PALABRAS CLAVE: Función de densidad de probabilidad, función de producción del agua, programación compromiso, riego deficitario, toma de decisiones.

Clasificación JEL: Q25, D01, C61.

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1. Introduction

Agricultural productivity and input use is based on farmer's decision making process, including objectives of the farmer decision making unit and subjective view of constraints and production functions. Farmer's subjective belief and information availability fundamentally affect input application decisions. Therefore local farmer's decisions have an impact on the microeconomics of farming but also on the general economy as the level of fertilizer, quality of seeds, pesticides or water use affects the global economic behaviour of a country. Additionally, from the environmental point of view some inputs have major externalities, with water and chemicals affecting quantitative and qualitative status of ecosystems.

This paper tries to support decision making in an innovative context where objective data are not available. It belongs then to 'normative' approaches rather than 'descriptive or explicative'. The research tries to make a contribution to a new type of farming (intensive olive irrigation) for all farmers, researchers and policy makers by studying the subjective water/crop relationship when field data are not (and will not in the medium term) available. It will also make an exploratory analysis of the microeconomics of deficit irrigation that has changed (in our opinion) the economics of irrigation both at individual level and at basin scale. Nevertheless, the model can be extended to other inputs (fertilizers, chemicals, etc.) without difficulty, but the research in this paper will focus on water management.

Agriculture uses above 80 % of water resource in Mediterranean and arid regions of the world, and frequently is the most constraining factor in many agricultural systems. Consequently, knowledge of decision-making processes regarding water use is crucial to design some techniques and policies to reach a sustainable use of water resources. The importance of irrigation in agriculture is clearly reflected in its contribution to agricultural world production: although only 18 % of the world agricultural land (250 mill. ha) is under irrigation, irrigated agriculture accounts for 80 % of global water consumption (3,000 km^3/year) and produces 43 % of the world's food supply (more than 50 % in value terms), according to official statistics. Therefore, water allocation policies are of decisive importance in terms of economic efficiency, territorial equilibrium and social equity. The availability of water for irrigation allows farmers to obtain higher yields and the possibility of growing a larger amount of crops. Thus, within this productive framework, the farmers' decision-making process in irrigated agriculture is more complex than that in rainfed farming.

The available information regarding input production functions draws mainly on nitrogen application and water doses. The nature of yield versus irrigation water (IR) curves clarify the importance of attaining relatively higher yields with higher water productivity. According to Molden *et al.* (2010), there is considerable scope for improving water productivity of crop, livestock and fisheries from field to basin scales. Practices used to achieve this include water harvesting, supplemental irrigation, deficit irrigation, precision irrigation techniques and soil–water conservation practices. Our research will pay attention to the technique of deficit irrigation and the subjective belief on risk that farmers assign to this technology.

Decision models of irrigated agricultural systems are generally normative so they propose the 'best' decision to achieve the objective(s) and only a small number of descriptive models can be found. However, policy instruments should be selected on the basis of inducing farmers' responses on an aggregated level. Descriptive models give better explanations and predictions of farmers' responses to physical and environmental context. Gómez-Limón *et al.* (2007) argue that models developed within a normative paradigm do not match the observed behaviour of producers, which suggests that there is a need for more complex models capable of providing more accurate results and propose the need to use more realistic hypotheses based on the psychology of decision-makers.

The hypothesis underlying the research is that environmental impact of agriculture is dependent on farmers' decision-making that is subject to the available information, which is reflected by crop-input relationships models and multiple objectives. Greiner *et al.* (2009) conclude that better knowledge of farmers' motivations and risk attitudes is required to define some public policies that reach relevant improvements in the environmental performance of agriculture because adoption processes are strongly affected by factors other than the financial benefit of the innovation, particularly values and motivations and personal risk assessments.

The inclusion of risk in decision models under deficit irrigation has been proposed by some authors such as Grové (2006) who used efficient deficit irrigation schedules based on certainty equivalence assuming an exponential utility function, and Upendram *et al.* (2015) who analysed a series of simulations of irrigated crop production in the Kansas High plains aquifer to identify the risk-efficient conditions. Both papers conclude that models on irrigation decision making should include risk into the objectives of the farmer.

We have adopted for the decision model exposed the methodology proposed by Ballestero y Romero (1991; 1996) where classical portfolio selection bi-criteria problems are addressed, implying an utility function where profitability and safety as objectives are solved with a surrogate utility function as an alternative methodology for selecting portfolios.

The structure of the paper is as follows. The next section presents the concept of irrigation total cost. Section 3 gives a brief description of the study area, while section 4 presents the methodology and the assumptions used and section 5 describes the main result of the survey. The full model is described in section 6 and, finally, section 7 outlines the main conclusions of the paper.

2. Background on decision making under uncertainty

The review of decision-making under uncertainty in agricultural economics should mention the seminal work by Anderson *et al.* (1977) who made a complete and classical exposition of decision methods in agriculture with detailed treatment of risk and uncertainty and a recent updated work by Hardaker *et al.* (2004).

Hazell y Norton (1986) made a complete review of mathematical programming models in the farm with a complete analysis on the introduction of risk through variance, semi-variance, MOTAD and target MOTAD parameters, and also treating the introduction of risk through implementation of game programming models. Risk modelling under a multiattribute utility function has been treated by Gómez-Limón *et al.* (2004) and an example of integration of multicriteria methods and risk analysis is the proposal of Ballestero y Romero (1996).

Most of the abovementioned works are based on the use of measured objective data (economic and technical observations) that are conveniently treated to build a bicriteria decision model with risk and return as the relevant objectives or multicriteria where other attributes are also relevant to decision makers.

This paper adopts an alternative approach because the context under analysis lacks of scientifically observed robust data. Our decision maker's model of behaviour will be based on farmers' perception rather than measured information. Therefore, it is a normative model rather than a descriptive or explicative model. Hardaker and Lien (2010) propose that decision making analysis should explore the subjectivist view where the probability of an outcome is defined as the degree of belief in an uncertain proposition against the dominant approach based on the objective probability defined as the limit of a relative frequency ratio.

Previous research has focused on farmers' perceived temporal yield distributions and variability (e.g. Clop-Gallart y Juárez-Rubio, 2007). Rejesus *et al.* (2013) studied the spatial dimension of yield variability and the subjective perception. They found that the farmer's subjective view of within-field yield variability fundamentally affects input application decisions.

Decision theory states that the most relevant information for decision makers that face risk outcomes is the subjective set which encapsulates their beliefs about uncertain states of nature. We are interested in input use (water) as related to farmer subjective beliefs. A precedent was the work by Griffiths *et al.* (1987) that analysed the subjective distributions for the 'average' farmer and concluded that there is evidence of variables that influence perceptions about the response of mean yield to nitrogen. In their research they concluded that farmers' perceptions on nitrogen-yield relationship depend on characteristics of the farms and of the farmers themselves.

The analysis of farmer subjective perception on water-yield relationship has not been studied previously and can be considered the main innovation of this research.

Probably the most widely used relationship between crop yield and water consumed is the approach proposed by Doorenbos y Kassam (1979). This approach is based on one single equation relating the relative yield loss of any crop (either herbaceous or woody species) to the relative reduction of water consumption, i.e. evapotranspiration (ET), by way of a coefficient (K_y), which is specific for any given crop and condition. A complete review of the present knowledge about K_y coefficients and crops' response to water availability can be found in Steduto *et al.* (2012).

A farmer takes decisions on the irrigation water dose (W) that is related to ET by the value of the effective rainfall plus irrigation efficiency. Additionally, irrigation

efficiency depends on the uniformity of application and the relative irrigation supply. In the short term the decision variable that can be managed is the water dose. There is a large body of literature that propose empirical and theoretical yield-irrigation functions as the relationship between irrigation and crops' yield is the basis for optimal management of irrigation.

3. Case study

The Guadalquivir River is the longest river in Southern Spain, with around 650 km. The total added length of the river and its tributaries is around 10,700 km. The basin covers an area of approximately 58,000 km^2 with a population of 4.1 million. The most populated cities are Seville, Cordoba, Granada and Jaen.

Irrigation schedule, techniques and water dose decisions are taken in an uncertainty context as most variables have an stochastic nature such as future water supply (rain and supply guarantee), water demand (climate), yields and prices. Agriculture is a risky business subject to market, climate and natural uncertainties. Expected utility theory is a dominant paradigm in the agricultural decision theory.

The basin has a Mediterranean climate with an uneven rainfall distribution (averaging 630 mm) and an average annual temperature of 16.8 °C. The largest land cover in the basin is forestry (49 %) followed by agriculture (47 %), urban areas (2 %) and wetlands (2 %) (Confederación Hidrográfica del Guadalquivir, 2010). Surface waters have an annual flow of 7,100 million m^3 and groundwater has a flow of 2,576 million m^3. Currently half of these surface waters and groundwater are extracted for use by the various sectors, with agriculture using the most (87 % of the volume). Per capita water consumption in the basin in 2005 was 1,600 m^3. For an analysis of the evolution of the Guadalquivir basin and the role of irrigated olive in the basin trajectory, see Berbel *et al.* (2013).

The case study selected to analyse the farmer subjective water-yield relationship is the irrigated olive in Andalusia (Southern Spain). According MAGRAMA for year 2014 in Spain 740,511 ha of olive were irrigated (20.54 % of total irrigated area). The adoption of irrigated olive has been increasing from the 70's initially by placing into already existing groves (100 trees per hectare), drip irrigation systems, and slowly increasing densities, intensive (around 250) and superintensive (around 800).

Olive orchard has been a traditional crop since Roman times in Andalusia. Irrigation started in the early 80's based on traditional densities around 100 trees per hectare. Olive orchards are mostly irrigated with supplementary irrigation with low doses (generally around 100 to 150 mm) to an area close to 500.000 ha, which represents the largest irrigated crop area in this region. The high value of water for this use explains the expansion of the technique. Berbel *et al.* (2011) analysed the economics of the deficit irrigated olive with traditional tree densities. López- Baldovin *et al.* (2006) developed a multi-period model of irrigated agriculture in Guadalquivir where irrigated olive was forecasted to increase cultivated area.

Recently farmers have been increasing tree density to around 300 trees per hectare (called 'intensive') or up to 800 trees (called 'superintensive'). The water production function for traditional density (100 trees per hectare) is well known and was analysed in Mesa-Jurado *et al.* (2010) but the water production function for higher densities (300 to 800 trees per hectare) is not known yet. The technique is recent and agronomic research at the moment is lagging behind the deployment of innovative farmers plantations, based upon a trial and error approach to olive intensification.

This paper therefore will use the "perceived production function" to make a proposal for irrigation dose decision making. We conducted a survey in Andalusia focused on medium level densities and farmers with medium to large farms. We selected 98 observations, and average values in the survey were: farm area: 40 ha, trees density: 283 per ha, irrigation water rights: 2,614 m^3/ha, olive irrigation doses: 989 m^3/ha. These values are above the average of irrigated olives in Andalusia (Junta de Andalucía, 2002), summarized in Table 1.

TABLE 1

Survey and Andalusian data

Level	Farm size (ha)	Density (trees/ha)
Andalusia irrigated (global)	6.7	175.0
New Intensive/Flat	10.4	246.8
Our Survey	40.3	283.1

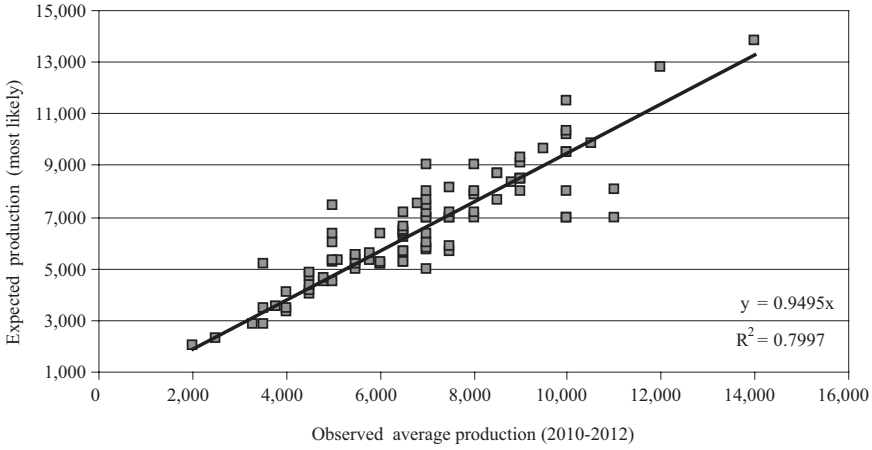
Source: Junta de Andalucía (2002).

Table 1 shows that farm size and density increase simultaneously. The survey was directed to a set of farmers that are early adopters of intensive techniques. The densities are higher than average and also the farm size. Probably there is a bias in the selection as the survey is directed to intensive olives and therefore early adopters are larger farms (in our survey). The ratio "Water use/full irrigation rights (*concesión*)" is 57.5 %. Average production is 6,442 kg/ha with an average percentage of oil about 19.8 %. Olives are 15 year old in average. An explanation for the larger farms size that are in our survey is that we surveyed the 'area under management' rather than administrative property (Official Census information in Table 1).

The analysis of the farmer responses in the survey shows that farmers tend to underestimate water response as illustrate Graph 1.

GRAPH 1

Expected versus observed average oil production (kg/ha)



Source: Own elaboration.

Farmers were inquired about past observations (2011-2013) and also about average expected production, pessimist and optimist expectations for three irrigation doses and rain fed conditions. This is the raw material for designing a decision model that is discussed in next sections. Coefficient of Variation (ratio of the standard deviation to the mean -CV-) is 0.42 at national level and decrease to 0.17 in the sample of 'superintensive', which is due to the homogenization that irrigation and intensification produces on the yield variability. Table 2 shows that production in the sample is 2.27 times over national average.

TABLE 2

Observed yield (kg/ha) olive for oil Spain and sample (2011-2013)

Year	National	%	Sample	%
2011	3,257	113	6,510	100
2012	1,520	53	5,460	84
2013	3,857	134	7,623	117
Mean 11-13	2,878	100	6,531	100
Population CV	0.42		0.17	

Source: MAGRAMA and own elaboration.

Consequently Graph 1 shows a close relation between the observed average production (2011-2013) and expected average production with a coefficient of b = 0.9495 (expected vs. observed average). The fact that it is below unity can have various explanations (pesimism, estrategic behaviour, inter-year variability...) and probably needs further research.

4. Normative decision making for intensive olive farmers

A decision making model assumes that a farmer knows the water-supply response with a certain degree of uncertainty. The distribution function is unknown but may be approximated by a triangular distribution function where three values determine the stochastic distribution, those are: most probable, minimum (pessimistic) and maximum (optimistic) water response.

$$Y = f(W, K) \quad [1]$$

Equation [1] is a technical relationship water-yield where W is the water applied and K is a parameter that integrates the rest of inputs (fertilizer, seed, etc.). Although there may be for some crops and conditions an 'objective' function obtained by agronomic field research, it is frequent that farmers work under uncertainty and they need to rely on a subjective water-supply function that depends on:

- Objective characteristics of farm: soil, climate, harvest technique...
- Subjective characteristics: age, education...

Initially the water production function does no depends on farmers' risk attitude, that may be defined as risk averse, risk neutral or risk seeking depending on the weight that farmer gives to the probability of losses against expected average results. The decision will be based in the maximization of expected utility.

The analysis of utility is always a complex procedure; we will develop here the efficient set 'expected return versus probability of income being below a certain threshold'. This analysis is straightforward and allows the decision maker to analyze the tradeoffs between the profitability, considered as an average or as the most probable profit, and the probability of losses.

This decision model will be based upon the triangular probability function as farmers must give response to the question regarding irrigation doses: (a) no irrigation; (b) deficit irrigation; (c) normal or most probable doses and (d) supersaver or maximum irrigation. Each level will have three possible states of nature: pessimistic, most probable and optimistic. The three approximations give 4 x 3 = 12 points that belong to the three water-crop response functions: optimistic response, normal response and pessimistic response. We will adjust quadratic functions to these curves in order to build the decision model.

The level of water used determines the olive oil production and cost. When we assume an expected price (in this case the price is hold constant as we want to focus in the water-crop relationship), we will obtain the level of expected gross margins according to the pessimistic/normal/optimistic response curve. All of them imply that gross margin is equal to the values given by [2].

$$GM = Q\,(W)P - C_w W - C_v Q\,(W) \qquad [2]$$

Where: *GM* is gross margin (EUR/ha), $Q(w)$ is the produced olive oil (kg/ha), *P* is the olive oil price, C_w is the water cost, *W* is the water dose (m^3), and C_v is the variable cost EUR/kg (mainly the harvesting cost). If we also substract the rest of costs that are constant (taxes, depreciation…) or that can be assumed constant (management…), we can obtain the net margin, although in our model is more convenient to operate with the GM. Next section will show the development of this model in some real cases.

The sample gives the results shown in Table 3 for some variables that can be considered as good estimators of sample values.

TABLE 3

Economic variables obtained from sample

		Number	Minimum	Maximum	Average	StDev
Irrigation cost*	EUR/m^3	62	0.03	0.30	0.11	0.08
Fertiliser (soil)	EUR/ha	94	20.00	300.00	77.93	65.64
Fertirrigation	EUR/ha	89	20.00	290.00	196.01	48.89
Pruning	EUR/ha	98	6.00	290.00	162.23	55.58
Machinery	EUR/ha	21	7.00	50.00	19.24	10.48
Pesticides	EUR/ha	98	120.00	380.00	254.54	59.55
Harvest	EUR/kg	97	0.05	0.30	0.13	0.03
Oil yield	%	79	15.00	23.00	19.47	2.13

* Irrigation cost is variable, and comprises the energy plus cost paid to Water User Associations (CCRR).

Source: Survey.

Information displayed at Table 3 is useful for modelling the decision making were the more relevant variables will be variable cost of water (from 0.03 to 0.30 EUR/m^3) and the variable cost of harvesting (from 0.05 to 0.30 EUR/kg). The values of fertilizer, pesticides etc. can be considered fixed costs. Nevertheless, we have not received a significant number of answers to 'fixed cost' (insurance, depreciation...) and, therefore, we used values from MAGRAMA (2014) for an estimation of the fixed or 'quasi fixed' production costs.

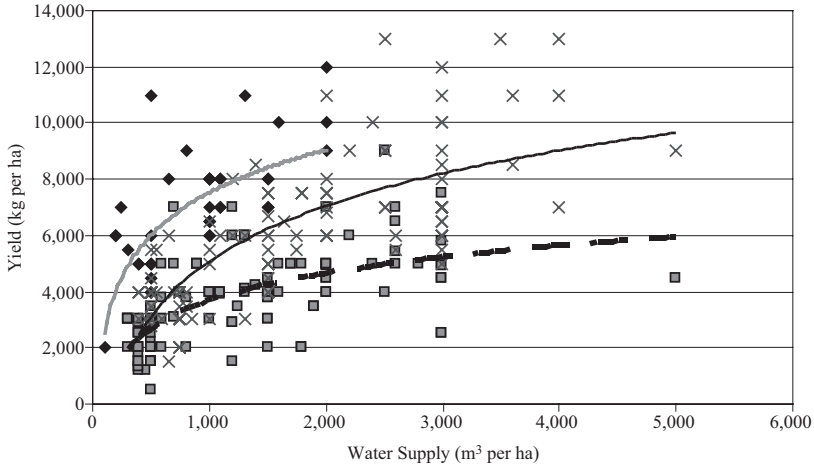
5. Analysis

The survey originally included all farmers (n = 99). The main objective is to find an expected water response curve and a secondary objective is to link the expected water response to farmer subjective and objective characteristics. Regarding the water response we have lost 10 cases because they were defined as outliers or they lack in some critical information (water supply or expected yield), consequently we proceeded with n = 89 farmers to study response curves.

We were unable to find significant relations between variables after applying a battery of methods and finally we produced a cluster analysis to make a classification of responses. Graph 2 illustrates the curves for the three selected clusters.

GRAPH 2

Response to water supply by cluster



*Continuous line (rhombus points): Ln(Y) = 0.37653 * ln(W) + 6.28872.*
*Point line ('X' points): Ln(Y) = 0.50283 * ln(W) + 4.96895.*
*Segments line (square points): Ln(Y) = 0.42895 * ln(W) + 5.13677.*

Source: Own elaboration.

Cluster analysis shows that 'Red cluster' (rhombus points) with higher response have a medium size (40 ha), higher olive tree height (4.3 m), younger groves (13.7 years), and the main varieties are 33 % Picual and 33 % Hojiblanca. 'Green' cluster ('X' points) have smaller size (30 ha), younger groves (14.2 years), lower trees (3.6 m), and the main varieties are 50 % Picual, 25 % Hojiblanca. Members of cluster 'Blue' (Squared points) with the lowest response have a greater size (50 ha), older groves (16.7 years), lower trees height (3.6 m) and the main varieties are 50 % Picual, 25 % Hojiblanca.

The discriminant analysis applied to the three groups did not generate any variable that explains satisfactorily belonging to each group. It has not been possible to relate the expected response to any objective (farm size, density...) or to any subjective farmer's characteristic. We believe that a further analysis of this research question is required.

Nevertheless to illustrate the application of the method, we apply the model for a singular farmer (#78) that can be extended to the cluster groups or individual farmers although that is outside the scope of this paper.

6. Model of irrigation decision for a farmer

As we mention above, farmers were inquired about the expected water-crop response, so that we will study three cases for farmer 78 who is a farmer with 102 ha, 408 trees per ha, average irrigation is 1,400 m^3/ha although he declares a quota of 1,450 m^3/ha and the elicited production function as shows in Table 4 and Graph 3 and 4.

TABLE 4

Farmer #78 subjective water crop response

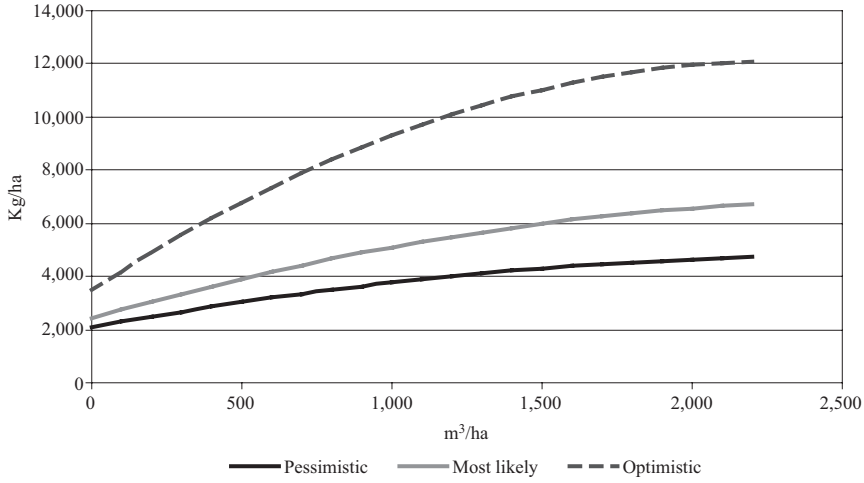
	Water	**Production (kg/ha)**		
	m^3/ha	**Pessimistic**	**Normal**	**Optimistic**
Rain fed	0	2,000	2,500	3,000
Deficit	400	3,000	3,500	4,000
Normal	1,400	4,200	5,800	6,500
Surplus	2,800	5,000	6,500	7,800

Source: Own elaboration.

This production function (kg/ha) can be transformed into a gross margin estimation with the following parameters that can be considered average for the last marketing seasons: olive oil net received price (EUR/kg) $P = 1.80$; oil percentage per kg olive: $r = 20$ %; Cost of water (EUR/m^3) $C_w = 0.28$; Variable cost per kg of olives (EUR/kg), $C_v = 0.12$; Fixed cost (EUR/ha), $FC = 800$. As said before, this farmer declares a 'normal' irrigation quota of 1,450 m^3/ha. With these parameters we generate the three "Gross Margin vs Water" functions (pessimistic, likely and optimistic) that are illustrated in Graph 4.

GRAPH 3

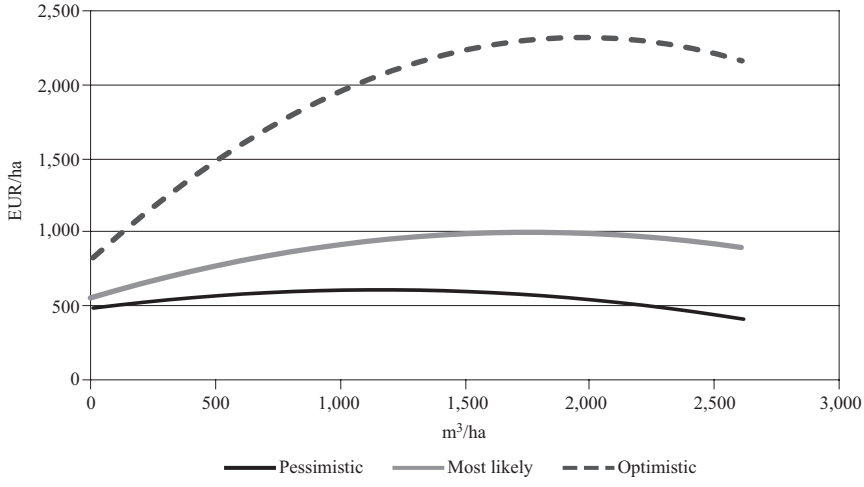
Expected yield/irrigation function (farmer #78)



Source: Own elaboration.

GRAPH 4

Gross Margin as a function of irrigation and subjective perception

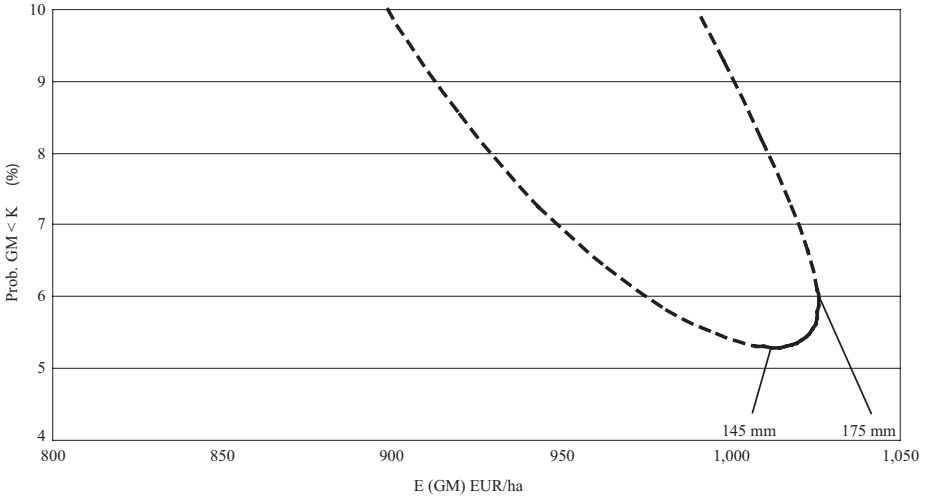


Source: Own elaboration.

Based on this information, the consequent phase is the elicitation of the efficient set and the compromise solution. We used the triangular distribution as proposed by Romero (1977) as an adaptation of Ballestero (1973) for the use in agricultural valuation. This allows using the information contained in the survey response (pessimistic/most-likely/optimistic). Assuming this distribution and assuming also that the fixed cost or desired breakeven margin is K = 800 EUR/ha, the result is the estimation of the efficient curve Expected Margin vs. Risk. We adopt the 'safety first approach' or 'downside risk' paradigm against the mean-variance model where both deviations below the target (losses) and over it (profit) have the same weight in the decision making. A great number of authors favour this concept of risk parameter integrated into decision model (Berbel, 1993). Therefore we draw the probability of not reaching the margin goal (losses) that is shown in Graph 5.

GRAPH 5

Efficient set Gross Margin vs. Risk farmer #78



Source: Own elaboration.

As Graph 5 shows, there is a dominated set below and after the optimal level of irrigation that is summarized in Table 5.

TABLE 5

Pay-off matrix

Irrigation (m^3/ha)	E(GM)	Pr (GM<800)
1,450	1,012	5.29
1,750	1,026	5.89

Note: Farmer's present irrigation is 1,400 m^3/ha, Risk is estimated with a triangular distribution.
Source: Own elaboration.

As we can see the values are close to the farmer's irrigation of 1,400 m^3/ha. The efficient set has a low range of variation for this farmer.

The ideal point is defined in the payoff matrix by E (GM) = 1,026 EUR/ha, and the probability of taking negative profit is equal to 5.29 %. Reaching this point is impossible (see Graph 5), so we have to find the point that, being in the efficient set, is closest to the ideal point. In order to do so, we will calculate distances between every point of the efficient set to the ideal point using different metrics.

The distance is defined by [3]:

$$L_p(X,w) = \left[\sum_{i=1}^{m} w_{ip}\left|\frac{Z_i^* - f_i(X)}{Z_i^* - Z_{i*}}\right|^p\right]^{1/p} \quad [3]$$

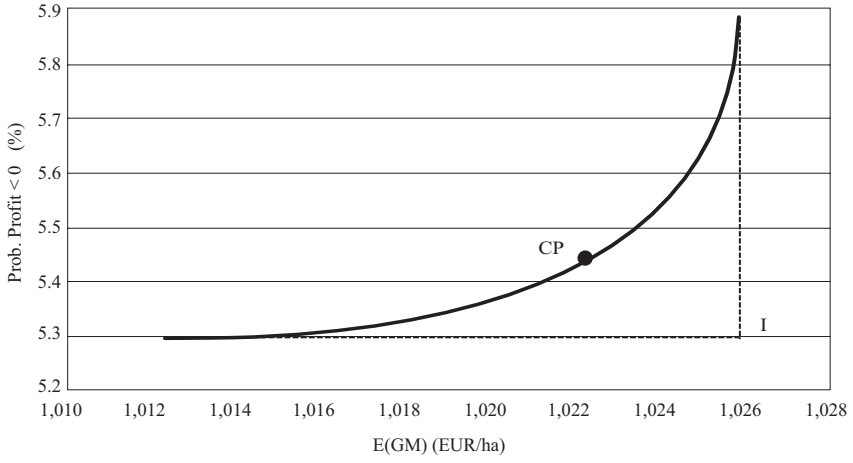
The distance was previously normalized by dividing each criteria by the ideal (Z_i^*) minus anti-ideal (Z_{i*}) (best and worst value for each dimension), and therefore, all distances moved between 0 and 1. We can combine each criterion with different weights (W_i). The compromise programming problem is then to find the minimum distance according to the metric that is included in feasible set *Fd.*

$$C_p(w_p)\begin{cases}\min L_p(X,w)\\ s.t. X \in Fd\end{cases} \quad [4]$$

As Ballestero y Romero (1991) explain, compromise set is the set formed by the optimal solutions of all the compromise programming problems , for p = 1, 2, ..., ∞ where we apply the Yu's theorem (Yu, 1973): "*for a problem with two objectives, the limits of the compromise set are the optimal solutions of C1(w) and C∞(w)*". Ballestero y Romero (1991) proved that for a wide class of utility functions, their maximum value is reached in the compromise set. Graph 6 illustrates the efficient and the compromise set.

GRAPH 6

Efficient set Gross Margin vs Risk and ideal point



I = Ideal solution, CP = Compromise Set.
Source: Own elaboration.

In Graph 6 it can be seen that the ideal solution is (1,026; 5.29 %) and that the compromise set when $w_1 = w_2$ is bounded by solutions C1 (1,022; 5.43 %) for irrigation 1,600 m^3/ha and C∞ (1,022; 5.44 %) for irrigation 1,602 m^3/ha.

7. Concluding remarks

Compromise programming has been used to analyse a farmer's decision regarding an intensive irrigated olive under deficit irrigation regime. As there is not available empirically determined water production function, we use a farmer's elicited subjective production function in order to support decision-making. The results show that the compromise solution is in the range 1,450 to 1,750 m^3/ha, and it is relevant to notice that the farmer's present water use is 1,400 m^3/ha while maximum yield is expected to be achieved with 2,800 m^3/ha. Therefore for intensive olives economic optimum is reached with almost 50 % of maximum irrigation needs (maximum production), this is relevant for policy makers and farmers in order to allocate water rationally.

Regarding the multi-criteria analysis the result for this farmer implies that that present irrigation (1,400 m^3/ha) doses are close to the compromise set (1,602 m^3/ha). The farmer's quota was 1,450 m^3/ha and, therefore, the compromise solution is unfeasible unless farmer could increase his water rights.

We believe that the use of the multi-criteria paradigm and compromise programming will improve decision making in the field of water management. Policy makers should consider the use of realistic models of farmers' behaviour in order to better estimate the impact of water and agricultural policies.

The present research will continue by exploring decision making in irrigation management applied to irrigated olives. The present paper focused on a farmer's decision model based upon a real case in Guadalquivir basin. The model and the small survey presented here may serve as an introduction to improve the knowledge about water use and risk behaviour in farmers that grow irrigated olives, which is presently the most important crop according to water use and irrigated area in Andalusia. Authors can supply the database to any researcher in order to enlarge the discussion and research on this important issue.

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