Multifunctional Impacts of the Olive Farming Practices in Andalusia, Spain: An Analytic Network Approach

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ABSTRACT

Olive agriculture represents one of the most important economic activities in the region of Andalusia, Spain. Additionally to its economic importance the multifunctional character of agriculture and its wide territorial presence entails that it has a high potential incidence in the environmental and social dimensions of the sustainable development of the region. Despite this importance, it is hypothesised and aimed to be contrasted that olive farmers are not implementing the agricultural practices optimal from an economic, environmental and social point of view. Contrasting this hypothesis entails to evaluate with a holistic and systemic approach the multiple impacts of the different technical alternatives to diverse agricultural practices. The use of the Analytic Network Process, a Multiple Criteria Decision Analysis technique, will be illustrated as a useful approach to deal with this kind of problems characterised by complexity, lack of information and risk. The study will focus on the average yield, climatic, environmental, etc., conditions of olive cultivation in Andalusia. The results seem to confirm the initial hypothesis when comparing the current situation with different scenarios of optimal technical alternatives. In particular the technical alternatives implemented nowadays they are far from being environmentally optimal. The multifunctional benefits and the technical costs of a change from the current situation to these optimal scenarios will be analysed.

Keywords: Olive farming practices; Multifunctionality; Analytic Network Process.

1. Introduction

Olive production is a strategic sector for the economy and the social and territorial cohesion of Andalusia, the southern region of Spain. Olive cultivation covers 31% of the agricultural area in the region, and represents 59% of the olive area of Spain, 27% of the EU and 25% of the world (Junta de Andalucía, 2007; MAPA, 2006). In fact, Andalusia is the world-leading region in olive production. Olive growing generates 37% of the Andalusian agricultural gross margin and 30% of the agricultural employment (Junta de Andalucía, 2002; 2007). Factors such as the globalization and liberalisation of markets, the increasing social awareness on food quality, environmental respect, and survival of the rural world are reinforcing a model of European agriculture multifunctional, based on its competitiveness and sustainability (Diputación Provincial de Jaén, 2007). Multifunctionality of agriculture refers to the fact that this human activity has diverse functions or impacts, that is, it produces not just an economic (financial) output, that is, food and fibres, but also diverse environmental and social services usually non remunerated by markets, known as externalities (see, e.g., OECD, 2001; 2003). For a recapitulation of studies about the multifunctionality of agriculture and agro-food systems see Carmona-Torres et al. (2009). Although previous studies have analysed the relationship between the olive farming practices and their economic, environmental and/or social impacts, they are usually partial in the sense that they focus only on a few agricultural practices and impacts. These studies can be classified according to the group of practices analysed and the most recent ones include: soil management (Gómez et al., 2009a, 2009b; Francia et al., 2006; Rodríguez-Lizana et al., 2007; Romero et al., 2007; Castro et al., 2008; Moreno et al., 2009; de Graaff et al., 2010; Bellin et al., 2009); irrigation (Metzidakis et al., 2008); fertilization (Fernández-Escobar et al., 2009; Tabatabaei, 2006; Biel et al., 2008; Erel et al., 2008; Morales-Sillero et al., 2008; Restrepo-Diaz et al., 2008); phytosanitation (Alvarado et al., 2008; Trapero and Blanco, 2008); and pruning (García-Ortiz et al., 2008). Little information is however available from a systemic and holistic perspective that reflects the multifunctional impacts of olive farming and their connection with multiple farming practices.

Multiple Criteria Decision Analysis, MCDA (Figueira et al., 2005), can provide an appropriate framework for analysis in this context of complexity where multiple criteria and elements must be evaluated and where uncertainty -lack of information- and risk -what is at stake- are high (Parra-López et al., 2007). In particular, discrete MCDA methods are appropriate when the nature of alternatives to evaluate is non-continuous such as in the case of different farming practices and their impacts. Within discrete MCDA, the Analytic Network Process, ANP (Saaty and Takizawa, 1986; Saaty, 1996; 2004), is a flexible and powerful method that allows the incorporation of qualitative, subjective and intangible information, for instance in the manner of experts' knowledge, besides quantitative information when available. ANP (and AHP that is a less sophisticated precedent of ANP) stands out because 1) it increases the transparency and objectivity in evaluation processes where there are diverse agents involved since they must explicitly state their preferences; and 2) it allows a continuous learning in the modelling process being possible at any time to feed-back new information into previous phases of the process. All these properties make very useful the ANP in the systemic modelling of the impacts of olive farming practices due to the complexity of relationships and high number of practices and impacts that must be considered, and the lack of quantitative information (hard data) on many topics.

Despite the importance of olive growing in Andalusia and its potential incidence in the economy, society and environment of Andalusia, the hypothesis underlying the present study, and aimed to be contrasted, is that olive farmers are currently not implementing the technical alternatives for the agricultural practices optimal from an economic, environmental and social point of view. In particular, the objectives to be covered are: 1) modelling the economic, social and environmental impacts of olive agricultural practices and their technical alternatives; 2) evaluating the impacts of current olive farming in Andalusia; 3) identifying the optimal technical alternatives for the olive practices and directions of improvement. The study will focus on the average yield, climatic, environmental, etc., conditions of olive cultivation in Andalusia. The approach of the analysis will be a) holistic, since they will be included the main farming practices available to olive growers and their main impacts in the economic, environmental and social dimensions of sustainability, covering the main groups of practices available by applying a systemic perspective; and b) systemic, since all practices and impacts will be considered all together and interactions among them incorporated. The ANP allows this approach and its use will be illustrated. This study would be a first step for the definition of policies and strategies to encourage the use of more rational olive farming practices in Andalusia.

2. Modelling the impacts of olive agricultural practices and their technical alternatives

2.1. Defining the network

A model is schematized in ANP as a network of elements and clusters of elements, where every element can have an influence on itself or some or all the other elements of the system (Niemira and Saaty, 2004; Parra-López et al., 2008).The definition of clusters and elements of the proposed ANP model was basically based on previous literature, usually partial studies as referred in the Introduction, and subsequently validated by a number of experts on olive agriculture (for a characterisation of the experts see next section). The proposed model consists of:

1. The *Cluster of Impacts* (C_I) contains 11 impacts relative to the economic, social and environmental dimensions of sustainability. They will be detailed on Table 2.
2. The *Cluster of Practices* (C_P) consists of 22 olive farming practices. Some practices can be grouped into a similar topic. They will be specified in Section 3.
3. The *Cluster of Alternatives* (C_A) contains the technical alternatives for the farming practices of the previous cluster. They will also be detailed in Section 3.

The sub-matrices of the supermatrix (Table 1.a) represent the relative contribution (incidence) of the alternatives for each practice to each impact ($\mathbf{W_{A,I}}$), and the inner dependences among impacts ($\mathbf{W_{I,I}}$). Inner dependences among impacts reflect the fact that impacts are not perfectly uncorrelated and one impact can influence another impacts. Each column vector of each sub-matrix is normalized, that is, the sum of its elements must be one (Saaty, 2004). Since all the practices do not contribute equally to a given impact, columns vectors of $\mathbf{W_{A,I}}$ must be weighted accordingly. The control matrix, that consists of one sub-matrix, $\mathbf{W_{P,I}}$, reflects these different contributions (Table 1.b).

Table 1. Structure of the supermatrix and control matrix of the olive model

a) Supermatrix

		C_I: Impacts	C_A: Alternatives
C_I: Impacts		$\mathbf{W_{I,I}}$	0
C_A: Alternatives (for practices P)	P1 P2 ... Pp	$\mathbf{W_{A,I}}$	**I**

b) Control matrix

	C_I: Impacts
C_P: Practices	$\mathbf{W_{P,I}}$

2.2. Assessing the matrices of relationships

To assess the supermatrix and the control matrix, that is, the magnitude of the relationships among elements it can be used hard data, if available, or judgement of experts or stakeholders, it not. The first option is ideal but it is rarely possible to find previous information about exactly the same the elements one is dealing with in an ad-hoc model. In the second case, elements can be evaluated usually on the basis of judgements of experts or stakeholders (1) by relative measurement, through *pairwise comparisons* of the contribution of the elements of one cluster (in rows) to a given element (in columns) (Saaty, 1980; Forman and Selly, 2001), if elements to compare are less than 7±2; (2) by absolute measurement, through 'direct rating' assessment (Larichev et al., 1995; Bottomley and Doyle, 2001; Forman and Selly, 2001), if the number of elements to compare is higher than 7±2. In the proposed model hard data are not available for most of the relationships and the number of elements to compare surpasses there commended limit (19 practices and 11 impacts). Therefore the specification of the relationships was based on experts' knowledge elicitation on the basis of 'direct rating' assessment. The rating scale used to evaluate the relationships ranges from 1 (very weak relationship) to 9 (very strong relationship), reserving 0 for absence of relationship (Parra-López et al., 2008). 15 experts on olive farming systems of Andalusia were individually interviewed (10 belongs to public research centres, 3 to the olive sector, and 2 to public administrations). Each of them filled out individually the supermatrix and the control matrix. They were able to indicate they have not knowledge for some column vectors of the sub-matrices.

2.3. Aggregating and weighting individual matrices

Once the individual supermatrices and control matrices are elicited, the next step is to aggregate them. Each element of the aggregated supermatrix and of the aggregated control matrix is calculated as the arithmetic mean of the corresponding elements of the individual matrices ($w_{i,j(aggr)} = \sum_{\forall i,j} w_{i,j(e)}/E$, where $w_{i,j}$ is an element of a sub-matrix; *e* is the expert e; and *E* is the number of experts). The meaning and mathematical treatment of 'unknown relationships' are different to those of 'non relationships'. Individually unknown relationships are not considered to calculate the mean whereas non relationships are accounted as null elements ($w_{i,j(e)}=0$). Since all the practices do not contribute equally to a given impact, as said before, columns vectors of $\mathbf{W_{A,I}}$ must be weighted by the control matrix $\mathbf{W_{P,I}}$. For instance, the part of the column vector corresponding to the incidence of the alternatives to practice 1 on the impact 1 must be multiplied by $w_{P1,I1}$. Finally each complete column of the supermatrix must be normalized, that is, its columns must add to one, being the aggregated weighted supermatrix stochastic (Niemira and Saaty, 2004). The aggregated weighted supermatrix contains information about the relationships among all the elements and clusters of the model, including inner relations among impacts.

2.4. Quantifying the impacts of farming practices

Defining the impacts of the technical alternatives for the olive farming practices entails to calculate a matrix of interdependent relationships by considering the relationships among the alternatives and their impacts and the inner dependences among impacts ($\mathbf{W_{A,I}}' = \mathbf{W_{A,I}}.\mathbf{W_{I,I}}$) (Saaty and Takizawa, 1986; Lee and Kim, 2000; Karsak et al., 2003; Kahraman et al., 2006; Parra-López et al., 2008). This matrix represents for each alternative the magnitude of its diverse impacts (Table 2). If we define a farming package as a particular combination of technical alternatives to the farming practices, it is possible to quantify for a given farming package its multiple impacts as: $\mathbf{i} = \mathbf{a}.\mathbf{W_{A,I}}'$, where $\boldsymbol{i}$ is a row vector of impacts; and $\boldsymbol{a}$ is a row vector of the alternatives for the farming practices. For a given farming package the magnitude of each of its impacts theoretically ranges from 0 to 1.

Table 2. Matrix of interdependent relationships among alternatives and their impacts ($\mathbf{W_{A,I}}$') (partial view)

			C_I: Impacts										
			I1. Less costs of production	I2. Productivity	I3. Quality of the product	I4. Rural development and employment	I5. Cultural identity and landscape	I6. Less soil erosion	I7. Soil water retention capacity	I8. Soil Fertility	I9. Less water contamination	I10. Less water consumption	I11. Biodiversity
C_A: Alternatives	P1. Olive variety	A1(P1). Picual	0.0050	0.0099	0.0214	0.0082	0.0004	0.0000	0.0000	0.0000	0.0034	0.0089	0.0000
		A2(P1). Hojiblanca	0.0049	0.0083	0.0231	0.0078	0.0004	0.0000	0.0000	0.0000	0.0033	0.0087	0.0000
		A3(P1). Lechín de Sevilla	0.0063	0.0075	0.0204	0.0077	0.0005	0.0000	0.0000	0.0000	0.0043	0.0113	0.0000
		A4(P1). Lechín de Granada	0.0063	0.0077	0.0216	0.0079	0.0005	0.0000	0.0000	0.0000	0.0043	0.0113	0.0000
		A5(P1). Picudo	0.0054	0.0079	0.0237	0.0079	0.0004	0.0000	0.0000	0.0000	0.0037	0.0096	0.0000
	P2. Soil manage-ment	A1(P2). Bare soil, conventional farming (constant tillage)	0.0625	0.0687	0.0000	0.0541	0.0710	0.0786	0.0808	0.0762	0.0743	0.0769	0.0765
		A2(P2). Bare soil, no tillage, weed control with herbicides	0.0749	0.0787	0.0000	0.0531	0.0625	0.0907	0.0907	0.0802	0.0737	0.0859	0.0775
		A3(P2). Bare soil, little tillage or shallow tillage, weed control with herbicides	0.0822	0.0901	0.0000	0.0590	0.0667	0.1026	0.1075	0.0928	0.0848	0.0982	0.0894
		A4(P2). Soil covered by spontaneous or cultivate plants	0.1209	0.1335	0.0000	0.0835	0.0869	0.1584	0.1718	0.1469	0.1327	0.1454	0.1414
	...	...	...	...	...	...	...	...	...	...	...	...	...
	P11. Pruning intensity	A1(P11). Traditional, severe, each 1-2 years	0.0430	0.0313	0.0000	0.0373	0.0337	0.0291	0.0264	0.0206	0.0295	0.0465	0.0208
		A2(P11). Low intensity pruning, every 2-3 years	0.0566	0.0418	0.0000	0.0358	0.0277	0.0370	0.0334	0.0261	0.0333	0.0486	0.0262
		Sum	*1.0000*	*1.0000*	*1.0000*	*1.0000*	*1.0000*	*1.0000*	*1.0000*	*1.0000*	*1.0000*	*1.0000*	*1.0000*

3. Multifunctional impacts of olive agriculture in Andalusia: current situation and directions for improvement

A survey to 200 farmers of the main olive growing zones of Andalusia was carried out from May to November 2010. The objective of the survey is, among other things, to analyse the farming practices implemented by olive farmers. Practices are referred to soil management, irrigation, fertilization, phytosanitation and harvest. This allows us to define the farming package for the current situation in the average conditions of Andalusia. It consists of the modal alternatives, that is, the more used alternatives for each practice. Additionally, it is possible to identify optimal scenarios for the different impacts analysed on the basis of the matrix of interdependent relationships among alternatives and their impacts ($W_{A,I}$', Table 2). For each impact we can determine the optimal technical alternatives that maximise the incidence of each practice on this impact. For instance, for the impact I1 'Less costs of production' the optimal technical alternative for the practice P2 'Soil management' is A4(P2) 'Soil covered by spontaneous or cultivate plants' (contribution 0.1209, Table 2). In this way 11 optimal scenarios could be defined, one for each impact. However due to space limitations only 3 scenarios, apart from the current situation, will be analysed, being representative of the 3 dimensions of sustainability: 1) Economically optimal alternatives, which maximise 'Productivity'; 2) Socially optimal alternatives, maximising 'Rural development and employment'; and 3) Environmentally optimal alternatives, which maximise 'Less soil erosion'. The farming packages associated to these scenarios and the current situation are shown in Table 3.

Table 3. Farming packages associated to different scenarios

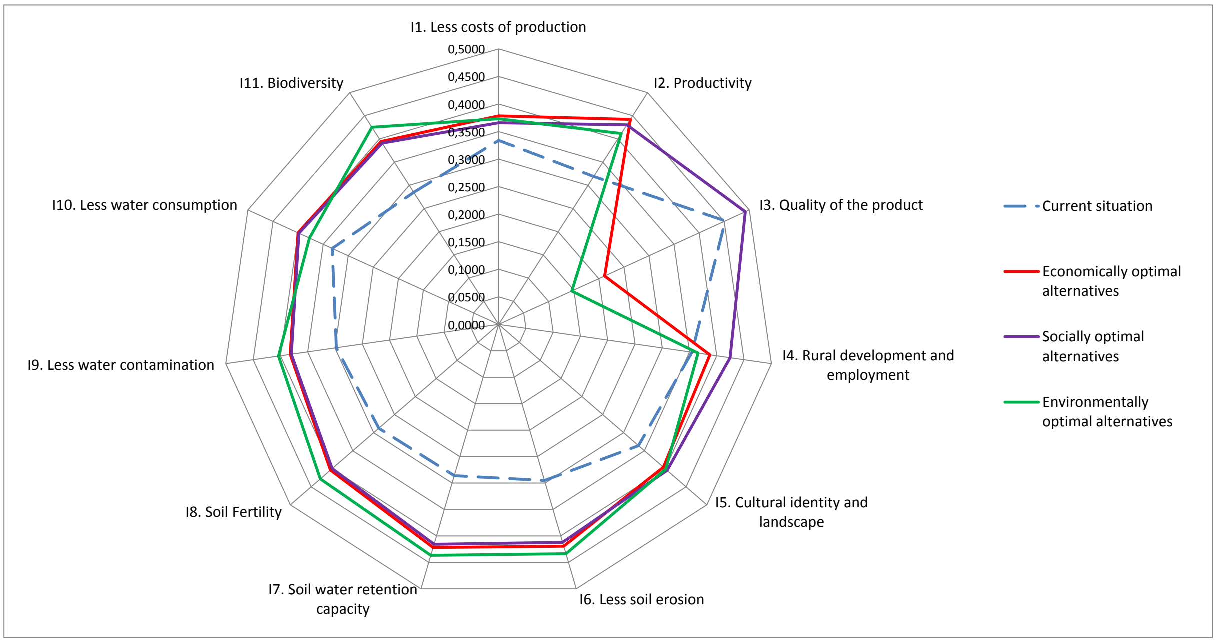
Farming practices	Current situation	Economically optimal alternatives	Socially optimal alternatives	Environmentally optimal alternatives
P1. Olive variety	A1(P1). Picual	A1(P1). Picual	A1(P1). Picual	- Indifferent -
P2. Soil management	A2(P2). Bare soil, no tillage, weed control with herbicides, or A3(P2). Bare soil, little tillage or shallow tillage, weed control with herbicides	A4(P2). Soil covered by spontaneous or cultivate plants	A4(P2). Soil covered by spontaneous or cultivate plants	A4(P2). Soil covered by spontaneous or cultivate plants
P3.1. Irrigation	A2(P3.1). No irrigation	A1(P3.1). Irrigation	A1(P3.1). Irrigation	A1(P3.1). Irrigation
P3.2. Irrigation system	A4(P3.2). No irrigation	A1(P3.2). Trickle irrigation	A1(P3.2). Trickle irrigation	A3(P3.2). Flooding irrigation
P3.3. Timing of irrigation	A3(P3.3). No irrigation	A2(P3.3). Following expert advice (depending on crop needs)	A2(P3.3). Following expert advice (depending on crop needs)	- Indifferent -
P3.4. Analysis of the quality of the irrigation water	A4(P3.4). No irrigation	A1(P3.4). Analysis of water	A1(P3.4). Analysis of water	A1(P3.4). Analysis of water
P4.1. Fertilization	A1(P4.1). Fertilization	A1(P4.1). Fertilization	A1(P4.1). Fertilization	A1(P4.1). Fertilization
P4.2. Method for the application of fertilizers	A3(P4.2). Spray application to the leaves	A2(P4.2). Fertilization through the irrigation water (fertirrigation)	A2(P4.2). Fertilization through the irrigation water (fertirrigation)	A1(P4.2). Direct application to the soil
P4.3. Fertilizers used	A2(P4.3). Inorganic fertilizers	A1(P4.3). Organic fertilizers (including pruning remains, compost, etc.)	A1(P4.3). Organic fertilizers (including pruning remains, compost, etc.)	A1(P4.3). Organic fertilizers (including pruning remains, compost, etc.)
P4.4. Analysis of soil or leaf before fertilization	A1(P4.4). Analysis of soil/leaves	- Indifferent -	A1(P4.4). Analysis of soil/leaves	- Indifferent -
P5.1. Phytosanitation	A1(P5.1). Phytosanitation	A1(P5.1). Phytosanitation	A1(P5.1). Phytosanitation	A2(P5.1). No phytosanitation
P5.2. Treatment of olive fruit fly (Bractroceraoleae)	A3(P5.2). Non-biological insecticide	A3(P5.2). Non-biological insecticide	A2(P5.2). Biological control (Opiusconcolor)	A4(P5.2). No phytosanitation

P5.3. Treatment of olive moth (Prays oleae)	A2(P5.3). Chemical treatments	A2(P5.3). Chemical treatments	A1(P5.3). Biological control (Bacillus thuringiensis)	A3(P5.3). No phytosanitation
P5.4. Treatment of peacock spots, olive leaf blotch, olive leaf spot (Spilocaeaoleagina, Cycloconiumoleaginum)	A2(P5.4). Copper fungicides	A2(P5.4). Copper fungicides	A1(P5.4). Pruning to clear	A4(P5.4). No phytosanitation
P5.5. Timing of phytosanitary treatments	A1(P5.5). On a fixed calendar basis or with the first symptoms of infestation/infection	A2(P5.5). When the infestation/infection surpasses a threshold or following expert advice	A2(P5.5). When the infestation/infection surpasses a threshold or following expert advice	A3(P5.5). No phytosanitation
P5.6. Localization of phytosanitary treatments	A1(P5.6). The whole plantation	A2(P5.6). Only the infestation source	A1(P5.6). The whole plantation	A3(P5.6). No phytosanitation
P6. Timing of harvest	A1(P6). According to a fruit ripeness index	- Indifferent -	A1(P6). According to a fruit ripeness index	- Indifferent -
P7. Method for picking the fallen olives from the ground	A1(P7). By hand	A1(P7). By hand	A1(P7). By hand	A1(P7). By hand
P8. Method for picking the olives from the trees	A2(P8). Branch or trunk vibrators	A3(P8). Handpicking	A3(P8). Handpicking	A1(P8). Hand–pole beating
P9. Separation of the fallen olives picked from the ground and from the trees	A1(P9). Separation	- Indifferent -	A1(P9). Separation	- Indifferent -
P10. Ways of carrying the olives to the olive mill	A3(P10). In the tractor or lorry trailer	- Indifferent -	A2(P10). Boxes	- Indifferent -
P11. Pruning intensity	A1(P11). Traditional, severe, each 1-2 years	A2(P11). Low intensity pruning, every 2-3 y.	A1(P11). Traditional, severe, each 1-2 years	A2(P11). Low intensity pruning, every 2-3 y.

The technical alternatives implemented are very diverse in the different scenarios. Only for two practices are applied the same alternatives in the four scenarios: for P4.1 ‘Fertilization’, that is used and for P7 ‘Method for picking the fallen olives from the ground’, that is ‘by hand’. Additionally four practices are equally implemented in the optimal scenarios but are different than for the current situation: P2 ‘Soil management’, P3.1 ‘Irrigation’, P3.4 ‘Analysis of the quality of the irrigation water’, and P4.3 ‘Fertilizers used’. Therefore the achievement of any of the optimal scenarios would require at least: 1) keeping the implementation of fertilization and the picking of the ground olives by hand, and 2) changing the management of soil by renouncing to bare soil and using soil covered by plants, 3) introducing the use of irrigation and the analysis of the irrigation water, and 4) using organic fertilizers instead of inorganic ones. In any case, the alternatives currently implemented are closer to those of the socially optimal scenario, since 9 of the 22 practices are equally implemented, and to the economically optimal scenario, with 7 practices in common. The environmentally optimal scenario is more distant from a technical point of view, and just 2 practices are equally done in the current situation. Therefore the achievement of social and economic objectives from the current situation would be technically less costly whereas the environmental ones would be more difficult.

Otherwise the multifunctional impacts of the farming packages for the different scenarios are summarised in Figure 1. It stands out the poorest performance of the practices implemented in the current situation in all the impacts with the exception of the ‘quality of the product’ where it is the second best scenario. The distance between the performances of the current situation and the three optimal scenarios is high in general. However it is not so far for two impacts: less costs of production, and rural development and employment, which are respectively economic and social objectives. Therefore a change to the economic or social optimal scenarios would entail less benefits that a change to the environmentally optimal scenario.

Figure 1. Impacts of the scenario farming packages



Regarding the ‘quality of the product’ impact, the environmentally optimal scenario and, surprisingly, the socially optimal scenario have the lowest performances. For the rest of impacts the three optimal scenarios have not very different performances, and each scenario stands out generally in the impacts relative to the dimension of sustainability they are associated to (e.g. the environmentally optimal scenario achieves the best performance in the environmental impacts).

4. Conclusions

The analysis of the multiple impacts associated to agriculture requires and holistic and systemic approach if all the underlying relationships, direct and indirect, are aimed to be captured. This represents a complex problem, with multiple criteria and elements to be evaluated and where uncertainty -lack of information- and risk -what is at stake- are high. The Analytic Network Process, ANP, proved to be an adequate framework of analysis to deal with this problem since it allowed the simultaneous consideration of multiple criteria and the interactions among them, and the integration of quantitative and qualitative through the incorporation of both hard-data and experts’ knowledge.

The results in the average yield, climatic, environmental, etc., conditions of the olive cultivation in Andalusia confirm our initial hypothesis. In effect the olive farmers seem not being implementing the technical alternatives optimal from an economic, social and environmental point of view. In particular they are far from applying the environmentally optimal alternatives. The results suggest that olive farmers are achieving high quality standards for their product (the olives) while they neglect to some extend the social and, especially, the environmental impacts of their activity. A change toward more environmentally respectful practices would significantly improve the global performance and especially the environmental performance of the olive agriculture in the region. However, the quality of the product would be negatively affected. In any case the technical costs of a change toward more environmentally friendly practices would be the highest, bigger than for the socially and economically optimal scenarios. A further cost/benefit analysis would be required to determine the global sustainability of the alternative scenarios to current practices.

In any case the movement toward any of the optimal scenarios defined would require changing the management of soil from bare to covered soil, introducing the irrigation and the analysis of the irrigation water, and applying organic instead of chemical fertilizers. Finally it is necessary to qualify that these results are preliminary since they are an advance of a wider survey intended to the agro-food olive sector of Andalusia. At least the double number of farmers and experts are aimed to be interviewed in subsequent studies which can alter some of the results and conclusions obtained here.

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REFERENCES

Alvarado, M.; Civantos, M.; Durán, J.M. (2008). Plagas. In: El cultivo del olivo (Ed. Barranco, D. et al.). Madrid, Ediciones Mundi-Prensa y Junta de Andalucía. pp.509-593.

Bellin, N.; van Wesemael, B.; Meerkerk, A.; Vanacker, V.; Barbera, G.G. (2009). Abandonment of soil and water conservation structures in Mediterranean ecosystems. A case study from south east Spain. Catena 76(2): 114-121.

Biel, C.; De Herralde, F.; Savé, R.; Evans, R. (2008). Effects of CO2 atmospheric fertilization on greenhouse production of olive trees (Olea europaea L. 'Arbequina'). European Journal of Horticultural Science 73(5): 227-230.

Bottomley PA.; Doyle, JR. (2001). A comparison of three weight elicitation methods: good, better, and best. Omega-International Journal of Management Science 29: 553-560.

Carmona-Torres, C.; Sayadi, S.; Parra-López, C. (2009). Revisión bibliográfica sobre multifuncionalidad de los sistemas agrarios y agroalimentarios [Bibliographic review on multifunctionality of agricultural and agro-food systems]. Research projects P07-SEJ-03121 (MULTIOLI) and RTA2008-00024-00-00 (ECOINNOLI). Working document. Consejería de Agricultura y Pesca. Junta de Andalucía. Granada, Spain.

Castro, J.; Fernández-Ondoño, E.; Rodríguez, C.; Lallena, A.M.; Sierra, M.; Aguilar, J. (2008). Effects of different olive-grove management systems on the organic carbon and nitrogen content of the soil in Jaén (Spain). Soil and Tillage Research 98(1): 56-67.

de Graaff, J.; Duarte, F.; Fleskens, L.; de Figueiredo, T. (2010). The future of olive groves on sloping land and ex-ante assessment of cross compliance for erosion control. Land Use Policy 27(1): 33-41.

Diputación Provincial de Jaén (2007). Diagnóstico sobre el sector de la olivicultura en la provincia de Jaén. Proyecto Olivar Sostenible. Novotec Consultores. Publicaciones de la Excma. Diputación Provincial.

Erel, R.; Dag, A.; Ben-Gal, A.; Schwartz, A.; Yermiyahu, U. (2008). Flowering and fruit set of olive trees in response to nitrogen, phosphorus, and potassium. Journal of the American Society for Horticultural Science 133(5): 639-647.

Fernández-Escobar, R.; Marin, L.; Sánchez-Zamora, M.A.; García-Novelo, J.M.; Molina-Soria, C.; Parra, M.A. (2009). Long-term effects of N fertilization on cropping and growth of olive trees and on N accumulation in soil profile. European Journal of Agronomy 31(4): 223-232.

Figueira, J.; Greco, S.; Ehrgott, M. (Eds.) (2005). Multiple Criteria Decision Analysis: State of the Art Surveys. International Series in Operations Research & Management Science. Springer.

Forman, E.; Selly, M.A. (2001). Decisions by objectives. Expert Choice Inc. Available at: http://www.expertchoice.com.

Francia, J.R.; Durán Zuazo, V.H.; Martínez-Raya, A. (2006). Environmental impact from mountainous olive orchards under different soil-management systems (SE Spain). Science of the Total Environment 358(1-3): 46-60.

García-Ortiz, A.; Humanes, J.; Pastor, M.; Morales, J.; Fernández, A. (2008). Poda. In: El cultivo del olivo (Ed. Barranco, D. et al.). Madrid, Ediciones Mundi-Prensa y Junta de Andalucía. pp.389-433.

Gómez, J.A.; Guzmán, M.G.; Giráldez, J.V.; Fereres, E. (2009b). The influence of cover crops and tillage on water and sediment yield, and on nutrient, and organic matter losses in an olive orchard on a sandy loam soil. Soil and Tillage Research 106(1): 137-144.

Gómez, J.A.; Sobrinho, T.A.; Giráldez, J.V.; Fereres, E. (2009a). Soil management effects on runoff, erosion and soil properties in an olive grove of Southern Spain. Soil and Tillage Research 102(1): 5-13.

Junta de Andalucía (2002). El olivar andaluz. Unidad de Prospectiva de la Consejería de Agricultura y Pesca de la Junta de Andalucía y Empresa Pública de Desarrollo Agrario y Pesquero de Andalucía. Available at: http://www.cap.junta-andalucia.es/agriculturaypesca/prospectiva/Olivar4_doc_sinAnexo.pdf. Annexes at: http://www.cap.junta-andalucia.es/agriculturaypesca/prospectiva/Olivar4_doc_Anexo.pdf

Junta de Andalucía (2007). Programa de Desarrollo Rural de Andalucía 2007-2013. Available at:http://www.mapa.es/desarrollo/pags/programacion/programas/Andalucia/PDR_ANDALUCIA_v3_04dic09.pdf

Kahraman, C.; Ertay, T.; Buyukozkan, G. (2006). A fuzzy optimization model for QFD planning process using analytic network approach. European Journal of Operational Research 171(2): 390-411.

Karsak, E.E.; Sozer, S.; Alptekin, S.E. (2003). Product planning in quality function deployment using a combined analytic network process and goal programming approach. Computers & Industrial Engineering 44: 171–190.

Larichev, O. I.; Olson, D.L.; Moshkovich, H.M.; Mechitov, A.J. (1995). Numerical Vs Cardinal Measurements in Multiattribute Decision-Making - How Exact Is Enough. Organizational Behavior and Human Decision Processes 64(1): 9-21.

Lee, J.W.; Kim, S.H. (2000). Using analytic network process and goal programming for interdependent information system project selection. Computers & Operations Research 27: 367–382.

MAPA, (2006). Hechos y Cifras de la Agricultura, la Pesca y la Alimentación Española (2006). 8ª Edición, Revisada, Actualizada y Ampliada. Secretaría General Técnica. (Disponible en: http://www.mapa.es/es/ministerio/pags/hechoscifras/introhechos.htm).

Metzidakis, I.; Martinez-Vilela, A.; Castro Nieto, G.; Basso, B. (2008). Intensive olive orchards on sloping land: Good water and pest management are essential. Journal of Environmental Management 89(2): 120-128.

Morales-Sillero, A.; Rapoport, H.; Fernández, J.E.; Troncoso, A. (2008). Olive fruit pulp and pit growth under differing nutrient supply. Scientia Horticulturae 117(2): 182-184.

Moreno, B.; García-Rodríguez, S.; Cañizares, R.; Castro, J.; Benítez, E. (2009). Rainfed olive farming in south-eastern Spain: Long-term effect of soil management on biological indicators of soil quality. Agriculture, Ecosystems and Environment 131(3-4): 333-339.

Niemira, M.P.; Saaty, T. (2004). An analytic network process model for financial-crisis forecasting. International Journal of Forecasting 20: 573–587.

OECD (2001). Multifunctionality: Towards an Analytical Framework. OECD, Paris.

OECD (2003). Multifunctionality. The policy implications. OECD, Paris.

Parra-López, C.; Groot, J.C.J.; Carmona-Torres, C.; Rossing, W.A.H. (2008). Integrating public demands into model-based design for multifunctional agriculture: an application to intensive Dutch dairy landscapes. Ecological Economics 67: 538–551.

Parra-López, C.; Calatrava-Requena, J.; De-Haro-Giménez, T. (2007). A multi-criteria evaluation of the environmental performances of conventional, organic and integrated olive-growing systems in the south of Spain based on experts' knowledge. Renewable Agriculture and Food Systems 22(3): 189–203.

Restrepo-Diaz, H.; Benlloch, M.; Navarro, C.; Fernández-Escobar, R. (2008). Potassium fertilization of rainfed olive orchards. Scientia Horticulturae 116(4): 399-403.

Rodríguez-Lizana, A.; Ordóñez, R.; Espejo-Pérez, A.J.; González, P. (2007). Plant cover and control of diffuse pollution from P in olive groves: Use of plant cover for control of agricultural nonpoint source pollution from soluble P in ecological olive groves. Water, Air, and Soil Pollution 181(1-4): 17-34.

Romero, P.; Castro, G.; Gómez, J.A.; Fereres, E. (2007). Curve number values for olive orchards under different soil management. Soil Science Society of America Journal 71(6): 1758-1769.

Saaty, T. (2004). Fundamentals of the Analytic Network Process. Dependence and Feedback in Decision-Making with a Single Network. Journal of Systems Science and Systems Engineering 13(2): 129-57.

Saaty, T.; Takizawa, M. (1986). Dependence and Independence - from Linear Hierarchies to Nonlinear Networks. European Journal of Operational Research 26(2): 229-37.

Saaty, T. (1980). The Analytic Hierarchy Process. McGraw Hill, New York. Reprinted in 1996 by RWS Publications, Pittsburgh.

Saaty, T. (1996). Decision Making with Dependence and Feedback: The Analytic Network Process. RWS Publications. 386 pp. Reprinted in 2001.

Tabatabaei, S. J. (2006). Effects of salinity and N on the growth, photosynthesis and N status of olive (Olea europaea L.) trees. Scientia Horticulturae 108(4): 432-438.

Trapero, A.; Blanco, M.A. (2008). Enfermedades. In: El cultivo del olivo (Ed. Barranco, D. et al.). Madrid, Ediciones Mundi-Prensa y Junta de Andalucía. pp.595-656.