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# Multicriteria and multiperiod programming for scenario analysis in Guadalquivir river irrigated farming

MJ Baldovin

Q1 *ETSIAM Avda Menendez Pidal s/n, Cordoba, Spain*

A multiperiod model based upon a multicriteria objective function has been developed for a representative area of the Guadalquivir Valley, dividing the irrigated area into homogeneous types of farming as identified by cluster analysis. The model was applied to different future scenarios with a time horizon of 10 years and several different farming environments. A set of eight sustainability indicators has been evaluated for the model. The results show that the evolution of crops over time is closely related to the political environment regarding the Common Agricultural Policy (CAP) and the application of the Water Framework Directive (WFD). Methodological innovation has included the successful simultaneous introduction of MCDM and multiperiod programming techniques applied to agriculture and scenario development.

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## Introduction and objectives

Irrigated agriculture is a special type of agriculture that has a close relationship to environmental policy. European normative changes in both environmental and agricultural policy make this type of agriculture a special interest for researchers.

The Water Framework Directive (WFD) (2000/60/CE), requires EU Member States to apply full cost recovery of water services, subject to environmental and social considerations. The Spanish Water Act of 1985 and its latest reform (Law 46/1999) included provisions for integrating WFD in the Spanish water management system, being specifically normative for cost recovery of water services, both in the water supply itself (urban, industrial and agricultural) and for sanitation (mainly urban and industrial).

At the same time, the Common Agricultural Policy (CAP) that has brought about a stable and profitable environment for farming in the EU is under pressure to implement changes driven by internal (financial and environmental constraints) and external (free trade and WTO agreements) factors.

This paper presents a model that has been developed to bring the study of long-term planning of optimal decision processes as close as possible to real decision-making by farmers, in order to analyse the long-term economic, social and environmental sustainability of irrigated agriculture in Europe. The model has been utilized to simulate the impact of WFD and CAP scenarios with integration of long-term investment in orchards, olive groves and irrigation systems.

Most agricultural literature describes models of a short-term static nature, in which most of the crops are annual and there is no need to include links between periods such as required by dynamic programming. An innovative feature of this study has been application to scenario analysis by using both multicriteria methodology and multiperiod models. We apply this to the agricultural sector, focusing on irrigated farming.

This paper applies scenario analysis to the study of the possible evolution of some indicators of sustainability for agriculture as a consequence of changes in European policy. The current '*status quo*' (SQ) scenario is tested against an alternative scenario, where the implementation of the WFD implies an increase in water price, while the CAP scenario implies a decrease in pesticide use, a rise in labour costs and a reduction in public support via direct subsidy and via price reduction.

We base our analysis on evolution of indicators, in the different scenarios, where parameters to be measured as significant criteria are economic (incomes and subsidies), social (employment) and environmental (pesticide risk, nitrogen leaching, water use, diversity, soil cover). The scenarios simultaneously study potential developments in water and agricultural policy. We aim to contribute to the

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Q2 *Correspondence: MJ Baldovin, ETSIAM Avda Menendez Pidal s/n, Cordoba, Spain.*
E-mail: berbel@uco.es

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evaluation of the impact of agriculture through the use of models with ecological, economic and social sustainability indicators.

## Description of irrigated area and farm types

### *Area of research*

The project was carried out in the Fuente-Palmera Irrigated Area, in Southern Spain, based upon a cooperative water management system known as an 'Irrigation Community', which manages the water resources of 5250 ha. in the Mid-Guadalquivir Valley. The area lies at an average elevation of 80 m above the river, which means that irrigation comes at a high-energy cost compared to most systems in the region. This has implications for technology decision-making. Recent trends in crop areas show increases in the area of crops that can be irrigated by drip systems, such as olive and citrus, vegetables and corn, against traditional wheat, cotton and sunflowers.

The growth in water-saving irrigation is impressive, as 60% of the area was drip-irrigated at the time of questioning (December 2001), while during the 1980s, 100% of the area was still irrigated by sprinkler systems. Sprinkler irrigation is now limited to some extensive cereals and industrial crops, where drip irrigation is not competitive. Farmers argue that the reasons for the rapid adoption of water-saving technologies are mainly reduction in the demand for labour, secondly, the increase in yields produced by drip irrigation, and thirdly water saving itself.

### *Farm types*

Cluster techniques were used to generate the typology of farms based upon a questionnaire which contains information about socio-economic (age, education, income level, etc), structural (farm size, irrigation technology, etc) and decision variables (crops cultivated, surface, crop rotation, etc). We used SPSS v8.0 and a hierarchical classification based upon Euclidean distance. The result was four clusters that have a satisfactory degree of homogeneity. These are described below and explained in Tables 1–3. Their main characteristics are:

**Table 1** Cropping pattern by cluster in Fuente Palmera (% of crop area for each cluster)

| *Cluster* | *Bread wheat* | *Durum wheat* | *Corn* | *Cotton* | *Sunflower* | *Potatoes* | *Set-aside* | *Olive* | *Citrus* |
|---|---|---|---|---|---|---|---|---|---|
| A | 0 | 0 | 1.5 | 85.8 | 0 | 7 | 0 | 4 | 1.6 |
| B | 9.2 | 43.6 | 7.5 | 20.3 | 7.8 | 0.4 | 6.3 | 2.5 | 2.3 |
| C | 0 | 15.2 | 42.6 | 16.4 | 4.2 | 11.2 | 7.1 | 0.2 | 3.1 |
| D | 0 | 0 | 8.3 | 1 | 0 | 1 | 0.6 | 59.2 | 29.9 |

Source: WADI, Dec 2001 enquiry.

**Table 2** Features of the clusters Fuente Palmera

| *Cluster name (Main crop)* | *A: cotton* | *B: wheat* | *C: corn* | *D: groves* |
|---|---|---|---|---|
| % farmers | 19.7% | 31.5% | 32.9% | 15.7% |
| Cluster area (ha) | 125.2 | 691.3 | 489.7 | 201.9 |
| % of total area | 8.3% | 45.8% | 32.4% | 13.3% |
| % income from agriculture | 80% | 40% | 70% | 40% |
| Average size (ha) | 8.3 | 28.8 | 19.6 | 16.8 |
| Median size (ha) | 5.5 | 6.7 | 7 | 4 |
| % farmers that use external labour | 73,4 | 58,3 | 44,0 | 83,3 |
| Main irrigation system | drip | sprinkler | drip | drip |
| % of surface occupied by main crop | 85.8% | 52.8% | 42.6% | 89.1% |

Source: WADI, Dec 2001 enquiry.

**Table 3** Main agricultural indicators in Fuente Palmera

| | *Socio-economic* | | | *Environmental* | | | | |
|---|---|---|---|---|---|---|---|---|
| *Cluster* | *Farm returns €/ha* | *Subsidies €/ha* | *Labour man days/ha* | *Water demand $m^3$/ha* | *Pesticide risk index* | *N balance Kg N/ha* | *Number of crops* | *Soil cover %* |
| A | 1,844.8 | 2,122.6 | 12.9 | 5,295 | 22,265 | 75.8 | 5 | 54.3 |
| B | 915.4 | 1,019.5 | 6.3 | 2,540 | 7,935 | 88.2 | 7 | 47.0 |
| C | 1,389.6 | 855.5 | 8.6 | 4,560 | 17,613 | 98.4 | 7 | 45.3 |
| D | 4,328.4 | 2,482.2 | 33.4 | 3,951 | 6,068 | 81.4 | 5 | 94.0 |

Source: WADI, Dec 2001, enquiry.

*Cotton-orientated.* This crop accounts for around 85% of farms area in the cluster and is mainly drip-irrigated. Farms in this cluster have an average size of 8.3 ha, farming is full-time and most of the farms (73.4%) need to hire external labour, mostly seasonal (activities of sowing and harvesting).

*Wheat-orientated.* This type specializes in durum wheat (43.6%), but the remaining crops shown in Table 1 are also grown. The average size is 28.8 ha and the main irrigation system is sprinkler. The typical farmer works part-time and around half of the farmers need to hire external (seasonal) labour.

*Corn-orientated.* Corn has the highest share of acreage sown (42.6%), but other crops are also cultivated, especially cotton, durum wheat and vegetables. The average size of the farms in this cluster is 19.6 ha, which is mainly irrigated by drip systems. The typical farmer is full-time and he usually hires seasonal and permanent labour, but less than other clusters.

*Grove-orientated.* Olives and citrus fruits occupy 89.1% of the area. The average size of farm in this group is 16.8 ha, and is fully drip irrigated. Part-time farmers predominate and the intensive labour input required at harvest-time produces a need for seasonal labour.

We can see that clusters A and B show subsidies higher than farm returns because the dominant crops in them are very CAP-dependent, especially as the production costs of cotton are enormous. (It is regarded as a social crop because it requires a great amount of labour.)

## Materials and methods

### *Methodology*

A range of different methodologies can be employed to build a model for scenario simulation. Mathematical programming has been widely used for this purpose, because among the advantages of this methodology is the possibility it offers of modifying various parameters simultaneously or independently. The shortcomings of mathematical programming derive from the unavoidable simplification that most of models impose on the real world, among which we may note the linear nature of the constraints and technical functions. Nevertheless, successful models of agricultural systems include environmental impacts (Annetts and Audsley, 2002).

Multicriteria programming improves classic monocriterion models by integrating the preferences of decision-makers as regards relevant criteria such as profit, risk, leisure, etc. The methodology is based upon a well-tested technique that uses a farmers' surrogate multiattribute utility function based on goal programming (see Rehman and Romero, 1993; Amador *et al*, 1998; Gómez-Limón and Berbel, 2000). We use this surrogate utility function to simulate decisions as close to reality as possible as we try to mimic real cropping patterns.

The surrogate utility function is based upon the present situation, and we make the assumption that it has a stable structural nature as it responds to farmer's psychological behaviour, which is supposed to be part of the cultural heritage and it has a relatively stable evolution. Finally, it is worth noting that the homogeneous groups obtained in this way can be regarded as 'fixed' in the short and medium terms. As noted above, the decision criteria are based on psychological characteristics of decision-makers, which is why they may be regarded as structural characteristics of producers. These psychological features, and thus the criteria, are unlikely to change in the short and medium term. This means that the selection variables chosen allow farmers to be grouped into clusters that are robust to changes in the policy framework.

The previous section illustrated a farmer typology deduced from observations of crop decisions, that tries to avoid aggregation errors (Berbel and Rodríguez, 1998). We assume that this typology remains stable during the planning period and is independent of the institutional scenario simulated.

## Multicriteria programming: surrogate utility function

The general utility function thus takes its simplest mathematical form as follows, as our purpose is to improve monocriteria models so as to approach closer approximations to real-life decision-making processes.

$$U_i = \sum_{j=1}^{n} w_j r_{ij} \quad i = 1, \ldots, m \tag{1}$$

where $U_i$ is the utility value of alternative $i$, $w_j$ is the weight of attribute $j$ and $r_{ij}$ is the value of attribute $j$ for alternative $i$.

Mathematical requirements for the assumption of an *additive* utility function are somewhat restrictive but from a practical point of view, the basic condition that needs to be satisfied is that the attributes considered $r_i$ should be mutually utility-independent. Although this condition is somewhat restrictive, some authors (Edwards, 1977; Farmer, 1987), have shown that the additive utility function yields extremely close approximations to the hypothetical true utility function even when these conditions are not satisfied. For this reason, additive utility functions for modelling farmers' behaviour have been widely employed.

Given this justification for the use of the additive utility function, we take the further step of assuming that the individual attribute utility functions are *linear*. Hence, the method is based on an extension of Weighted Goal

Programming (WGP) (Amador *et al*, 1998) and can be summarized as follows:

(1) Each attribute is defined as a mathematical function ($f_i$) of decision variables, $x$ (ie crop area); $f_i = f_i(x)$. These attributes are proposed '*a priori*' as the more relevant decision criteria used by farmers (usually profit, risk, labour, etc). After simulation, we select profit maximization estimated through discounted cash flow (CF) and also we included minimization of labour (MO) as a relevant criteria for farmers' decision-making process as we explain below:

(a) *Maximize net present value* (*NPV*)

We use the average CF for the past 5 years ($CF_c$) as the estimator of economic criteria.

$$CF = \sum_{c=1}^{q} CF_c X_c$$

where $X_c$ is the area for each crop ($c = 1,\ q$) for each year.

We need to use cash flow as we are going to calculate NPV, which brings some advantages when CF is used instead of profit.

(b) *Minimization of labour* (*MO*)

The scarcity of casual labour is the main reason for the rapid adoption of the drip irrigation system mentioned in the previous section. Sprinkler systems require a much greater labour input than drip irrigation (in general, drip irrigation needs 20% fewer hours/ha than sprinkler and it has also more convenient timing). When this activity is performed by the farmer himself, the convenience of irrigation scheduling and performance is greatly appreciated by both full-time and part-time farmers. This objective is related to management complexity and other objectives than profit.

Computation of this criterion is straightforward:

$$MO = \sum_{c=1}^{q} MO_c X_c$$

where $X_c$ is the area for each crop ($c = 1,\ q$) for each year and $MO_c$ is the labour required by the crop per hectare and year (computed as the most frequent value).

(2) The pay-off matrix, where each element $f_{ij}$ is the value of attribute $i$ under objective $j$ is optimized. The main diagonal is the 'ideal' point defined by the individually obtained optima.

(3) The following system of $m + 1$ equations is solved:

$$\sum_{j=1}^{m} w_j f_{ij} = f_i, \quad i = 1, 2, \ldots, m \quad \text{and} \quad \sum_{j=1}^{m} w_j = 1 \quad (2)$$

where $m$ is the number of '*a priori*' relevant objectives, $w_j$ is the weight attached to each objective (the solution), $f_{ij}$ are the elements of the pay-off matrix and $f_i$ the real values reached in the observed behaviour of farmers obtained by direct observation.

(4) Normally, there is not an exact solution to system (2), where in our case $m = 2$ and we therefore need to solve a problem, where we minimize the sum of deviational variables in order to find the closest set of weights.

$$\mathrm{Min}\left(\frac{n_1 + p_1}{f_1} + \frac{n_2 + p_2}{f_2}\right)$$

subject to

$$\begin{aligned} w_1 f_{11} + w_2 f_{12} + n_1 - p_1 &= f_1 \\ w_1 f_{21} + w_2 f_{22} + n_2 - p_2 &= f_2 \\ w_1 + w_2 &= 1 \end{aligned} \qquad (3)$$

It has been demonstrated (Dyer and Sarin, 1979) that the weights obtained in (3) conform to the following separable and additive utility function:

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

where $k_i$ is a normalizing factor. Therefore, we assume the definition of parameter $k_i$, that compute it as the difference between maximum and minimum values for objective '$j$' in the pay-off matrix (Romero and Rehman, 1989).

$$U = \sum_{i=1}^{j} w_i \frac{f_i(x)}{f_i^* - f_{i^*}} \qquad (4)$$

The proposed algorithm thus gives us an expression that provides a functional representation of the behaviour followed by the farmers in the area studied and that theoretically attempts to maximise the multiattribute utility function when a decision is made (ie a crop plan).

## Multiperiod programming: long-term planning

Our model will combine herbaceous annual crops and tree crops, because we should include in the model both olive trees and citruses. Olive trees are the fastest-growing crop in the area and this crop needs long periods for maturation of investment.

According to previous studies (McCarl and Spreen, 1997; Attwood *et al*, 2000) long-term planning always needs a previous definition of some relevant parameters; first, the starting date and then the final planning horizon. Simulation starts in 2002 and field research was done in 2001. The interval is 1-year iterations applied to an inventory definition that consists of the accurate area of trees and irrigation in the region, and including olive trees forces the model to use 40 years as the minimum planning horizon for the introduction of olive trees in the model decisions.

A discount rate is applied to all criteria in the model, including CF and total labour, the latter converted, where appropriate to monetary values by multiplying by the standard agricultural wage rate. The reason for discounting both criteria is both theoretical, as any criteria should be preferred 'today' compared to future values, and practical, because if we apply different discount rates to the criteria involved in the model, the effect will be a change in the weights estimated for the utility function.

We have selected a discount rate with a risk premium (Amegbeto and Featherstone, 1992; Bjornson, 1992). The rate employed applies the Capital Asset Pricing Model (CAPM) to agricultural activities (following Segura and Ribal, 2002; Ribal, 2003). There is a specific figure for the Andalusian irrigated area, which is defined as 7.98%, of which 3.15% is the risk-free rate and 4.83% is estimated using Sharpe's (1994) model.

## Model

### *Decision variables*

The key variable is $x(t, c)$, which is defined as the area sown to crop '$c$' at year '$t$', and its application for annual crops is quite simple. However, there is an additional complexity for olive and orange planting as the age of the tree (year of planting) determines all attributes including decision criteria (CF and labour demand). In each cluster, the variable $x(t, olive)$ is composed of existing olive in 2001, plus all olive trees planted in each subsequent year, $x(t, citrus)$ is defined similarly. Therefore $x(t, olive)$ and $x(t, citrus)$ are vectors of characteristics as a function of the age of the plantation.

$Z(t)$ is a instrumental variable which represents the area on which the irrigation system has been changed to drip from the existing sprinkler system (it is related to annual investment costs).

### *Multicriteria and multiperiod utility function (PUF)*

We have applied the WPG model to the four clusters described above, separately. The results are shown in Table 4, derived from applying the model (1–4) to the crop area. We may observe that weightings are obtained by comparing projected *versus* actual results, and we have the 2001/2002 data as a validating set; therefore although the weights are obtained in the 'short term' they are used for long-term simulation.

**Table 4** Criteria Weightings by cluster

| *Criteria weight (%)* | *Cluster A* | *Cluster B* | *Cluster C* | *Cluster D* |
|---|---|---|---|---|
| $w_1$ (CF) | 99.5 | 83.8 | 96.3 | 99.5 |
| $w_2$ (labour) | 0.5 | 16.2 | 3.7 | 0.5 |

The weightings found are consistent with the features of crops, for example the wheat-oriented cluster (B) has a higher weighting for labour minimization than fruit-oriented (D), or cotton-oriented (A) clusters. Although weightings for casual labour are negligible in two of the clusters, we maintain the second objective in our utility function because it is interesting to compare this result with other clusters. Farmers in clusters A and D are more innovative, with smaller farms fully irrigated by drip systems.

Once we have defined the weights in Equation (4), we use them for the long-term simulation with discounted flows as follows:

$$\text{Max.}\, PUF = w_1 * NPV/(f^*_{NPV} - f_{NPV^*}) - w_2 * LAB/(f_{LAB^*} - f^*_{LAB}) \qquad (5)$$

where $f^*_{NPV}$ and $f^*_{LAB}$ are ideal values of $NPV$ and $LAB$ and $f_{NPV^*}$ and $f_{LAB^*}$ are anti-ideal values of $NPV$ and $LAB$. $NPV$ and $LAB$ are computed by hectare in the following way:

$$NPV = \sum_t \sum_c \left( \frac{X(t,c) * CF(t,c) - Z(t) * 1500}{(1+r)^{t-1}} \right) \qquad (6)$$

$$LAB = \sum_t \sum_c \left( \frac{X(t,c) * MO(t,c)}{(1+r)^{t-1}} \right) \qquad (7)$$

where $r$ is the utility discount rate, $t$ varies from 1 to 40, $c$ is the crop, $CF(t, c)$ is the annual CF per hectare, $Z(t)$ is the area (ha) of sprinkler irrigation replaced by drip irrigation in year $t$ and 1500 € is the investment required (€/ha) to implement the change and $MO(t, c)$ is the casual labour input per ha for crop '$c$' in year '$t$'.

## Constraints

Finally, there are some constraints in the applied model that we will use for simulation, and where the weights have been found by solving the above explained general WGP program. The model is applied to each cluster separately and therefore, some of the constraints below are 'cluster'-specific, but which are described below in global terms:

(a) *Area constraint*: $\Sigma X(t, c) = 100$, so the result $X(t, c)$ is a percentage (for all years).
(b) *CAP regulation:* According to the EU's Agenda 2000, set-aside needs to be a minimum of 10% of subsidized annual crops and 20% as a maximum in case of voluntary land retirement. Furthermore, production of durum wheat is limited to historical growers, so we have limited it to the maximum reached in the period 1992/93 to 2000/01 and similarly, with cotton (limits expressed as a percentage).
(c) *Crop rotation:* We have used a frequency constraint so that any annual crop is less than 50% of total herbaceous area. Additionally according to farming

practices we include other frequency constraints to control crop succession, (eg cotton and sugar beet should not succeed corn neither themselves but it can be followed by wheat or sunflower).

(d) *Vegetables* (*potatoes*): There are some horticultural processing plants, but we only take into account potatoes as main vegetable crop) in the area and their capacity is increasing, but it is assumed that historical levels of production will be maintained for the next few years.

The preceding constraints are classical and must be used for the short-term static WGP model; however, there are some additional constraints specific to the multiperiod programming model.

(e) *Financial constraint*: any crop plan should guarantee the farmer an income at least equivalent to the rental value of the land (396.5 €/ha in this area). This is necessary because land rent is not paid in CF computations as most of the land is cultivated by owner. The RHS in Table 5 appears multiplied by 100 because the annual rental value is calculated for an ideal farm of 100 ha, in order to obtain percentage figures.

(f) *Water supply:* the theoretical supply in the irrigated area is 5,000 m$^3$/ha and this was set as the maximum available water.

(g) *Inventory initial conditions:* these are cluster-specific and set the initial area of olives, citruses and drip irrigation in year 2001.

(h) *Tree age:* tree age is linked to the preceding year area by crop and year of planting.

(i) *Irrigation technology*: similarly, drip irrigated area may increase but this implies an investment cost and reduces the area under sprinkler systems, investment is computed in the CF computations and integrated into NPV equation.

**Table 5** Summary of constraints of the model

| | | |
|---|---|---|
| $\sum_c x(t,c) = 100$ | $\forall t$ | Area |
| $x(t, \textit{set-aside}) \geqslant 10\% * (x(t, \textit{durum-wheat}) + x(t, \textit{wheat}) + x(t, \textit{durum-wheat\_dry}) + x(t, \textit{wheat\_dry}) + x(t, \textit{sunflower}) + x(t, \textit{sunflower\_dry}) + x(t, \textit{corn}))$<br>$x(t, \textit{set-aside}) \leqslant 20\% * (x(t, \textit{durum-wheat}) + x(t, \textit{wheat}) + x(t, \textit{durum-wheat\_dry}) + x(t, \textit{wheat\_dry}) + x(t, \textit{sunflower}) + x(t, \textit{sunflower\_dry}) + x(t, \textit{corn}))$<br>$x(t, \textit{durum-wheat}) + x(t, \textit{durum-wheat\_dry}) \leqslant$ specific maximum percentage<br>$x(t, \textit{cotton}) \leqslant$ specific maximum percentage | $\forall t$ | CAP |
| $x(t,c) \leqslant \frac{50}{100} * \left(100 - \sum_{\textit{olive}} x(t, \textit{olive}) - \sum_{\textit{citrus}} x(t, \textit{citrus})\right)$ | $\forall\ t,\ c$ | Frequency |
| $x(t,\textit{cotton}) \leqslant x(t,\textit{durum-wheat}) + x(t,\textit{wheat}) + x(t,\textit{sunflower}) + x(t,\textit{corn})$<br>$x(t,\textit{durum-wheat}) + x(t,\textit{wheat}) \leqslant x(t,\textit{sunflower}) + x(t,\textit{corn})$<br>$x(t,\textit{corn}) \leqslant x(t,\textit{durum-wheat}) + x(t,\textit{wheat}) + x(t,\textit{sunflower})$ | $\forall t$ | Succession |
| $x(t,\textit{vegetables}) \leqslant$ Max_vegetables per cluster | $\forall t$ | Vegetables |
| $\sum_c (x(t,c) * FC(t,c) - z(t) * 1500) \geqslant 100 * 396.5^1$ | $\forall t$ | Financial |
| $\sum_c \textit{waterdemand}(t,c) \leqslant$ Water endowment per area | $\forall t$ | Water supply |
| $x(t, \textit{olive}) = x(t-1, \textit{olive})$<br>$x(t, \textit{citrus}) = x(t-1, \textit{citrus})$ | $\forall t$ | Tree crop and irrigation system area (*) |
| $\text{Drip}(t) = \text{z}(t) + \text{Drip}\ (t-1)$<br>$\sum_c x(t, \textit{cotton}) + x(t, \textit{corn}) + x(t, \textit{vegetables}) \leqslant \textit{drip}0 + \text{Drip}(t)$ | $\forall\ t,\ c$ | Irrigation technology |
| $\sum_c \textit{Pesticide}(t,c) \leqslant \text{Max\_pest}$<br>$\sum_c \textit{Nitrogen}(t,c) \leqslant \text{Max\_N}$ | $\forall t$ | Agro-chemical use |

Source: Authors.

*Initial inventory conditions for year $t = 0$ are cluster specific and they are set equal to 2001 for citruses and olive trees area and drip irrigated area.

(j) *Agro-chemicals use*: nitrogen balance and a pesticides risk indicator are used for calculating a potential risk for the environment. Both environmental indicators will be limited in one of the studied scenarios, 'global sustainability', that will be explained below.

The full set of constraints is shown in Table 5.

## Attributes: environmental and socio-economic indicators

The use of a set of indicators is an innovation of this paper, respect to published studies of irrigated farming in Southern Spain. Our model introduces the following subset of OCDE sustainability indicators (OCDE, 2001; Berbel and Gutierrez, 2005). We have selected these indicators:

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- Farm return (€/ha)
- Public-sector support, by direct subsidies for cultivated area (cereals and oilseeds) and price supports for products (cotton, citrus and olive oil) according to the 2002 Normative (€/ha)
- Direct labour in farm activities (man—days/ha)
- Water use ($m^3$/ha)
- Pesticide risk toxicity index. This index has a complex calculation based upon the LD-50 of each active compound and the doses applied
- Nitrogen balance (kg N/ha). Inputs into farm minus output of farmland (exported by crop extractions)
- Genetic diversity. Number of different crops
- Soil cover. Percentage of soil covered by crop during the year.

## Scenario definition

The model has been computed for a planning horizon of 40 years, but detailed results illustrate only for the period 2001–2010 under present conditions (scenario '*business as usual*') and potential future normative changes (*alternative scenario*), as we believe that longer simulations are subject to great uncertainties. We solve the model for each cluster and then we proceed to an aggregation of results at irrigated area level.

### *Scenario generation*

A recent review of global futures under the Foresight Programme (Berkhout *et al*, 1998; DTI, 1999) identifies four linked scenarios, which refer to the evolution of the CAP. The Baseline scenario is taken as the agricultural policy regime in place in 2000/01 and will be used to provide a relative reference point for the definition of future scenarios. The *Baseline or Status quo* (*SQ*) *scenario* is extrapolated to 2010 on the basis of predictions of agricultural markets and prices from the EU, OCDE and other sources. This extrapolated *Baseline* is perceived to be different from the other possible futures, although it shows a tendency, due to the terms of the predicted reform of the CAP and the growing influence of the WTO, towards Global Sustainable Agriculture. We have selected an alternative scenario called 'Global Sustainability' based upon higher environmental protection. Table 6 quantitatively defines the parameters used in both scenarios.

### *Scenario 1: status quo (SQ)*

The existing CAP based upon Agenda 2000 will continue for the near future. The failure of the Cancun meeting in 2003 and an unstable world policy have slowed changes in free trade regulations under the WTO.

### *Scenario 2: global sustainability* (*GS*)

A complete description of this scenario was made by Berkhout and DTI (Berkhout *et al*, 1998; DTI, 1999). GS is characterized by more pronounced social and ecological values, which are evident in global institutions and trading systems. There is collective action to address social and environmental issues. Nutritional values and food safety are also important for consumers. There will be a decrease in

**Table 6** Quantitative description of scenarios (as increase over 2001 levels)

| | *SQ (2001)* | *GS* | *SQ (2001)* | *GS* |
|---|---|---|---|---|
| | *Crops prices* | | *Crops subsidies* | |
| Bread wheat | 100 | 95 | 100 | 95 |
| Durum wheat | 100 | 95 | 100 | 95 |
| Sunflowers | 100 | 90 | 100 | 100 |
| Corn | 100 | 100 | 100 | 80 |
| Citruses | 100 | 100 | 100 | 95 |
| Cotton | 100 | 95 | 100 | 85 |
| Olives | 100 | 90 | 100 | 95 |
| Potatoes | 100 | 100 | — | — |
| Set-aside | — | — | 100 | 100 |

| | *SQ (2001)* | *GS* |
|---|---|---|
| Set-aside quota | 100 | 95 |
| Yields | 100 | 117,5 |
| Chemical use | 100 | 70 |
| | *Input prices* | |
| Fertilizers | 100 | 135 |
| Pesticides | 100 | 140 |
| Energy | 100 | 145 |
| Seeds | 100 | 102,5 |
| Machinery | 100 | 125 |
| Contractor services | 100 | 115 |
| Water prices at farm gate | 100 | 140 |
| Irrigation infrastructure | 100 | 125 |
| Labour | 100 | 132,5 |
| Land rent | 100 | 100 |

arable area, as less favoured soils are devoted to environmental uses (forestry, wetlands, etc) and consequently average productivity increases in order to compensate for reduced total production. Input costs increase due to labour shortages and because of the introduction of an 'ecotax' on chemicals.

For our model we decrease chemical inputs by 30% and increase water price by 3 €/m$^3$ (40%) (Table 6), affecting the profitability and therefore the NPV of crops.

## Results

We thus use Equations (5)–(7) to compute the present multicriteria and multiperiod utility function (PUF), subject to the technical constraints summarised in Table 5 for the current scenario (SQ). Subsequently, in order to simulate scenario GS, we made the changes shown in Table 6. Simulation yields and the efficiency plan for the horizon year 2010, with valuable information on environmental and socio-economic indices, are summarised in Table 7.

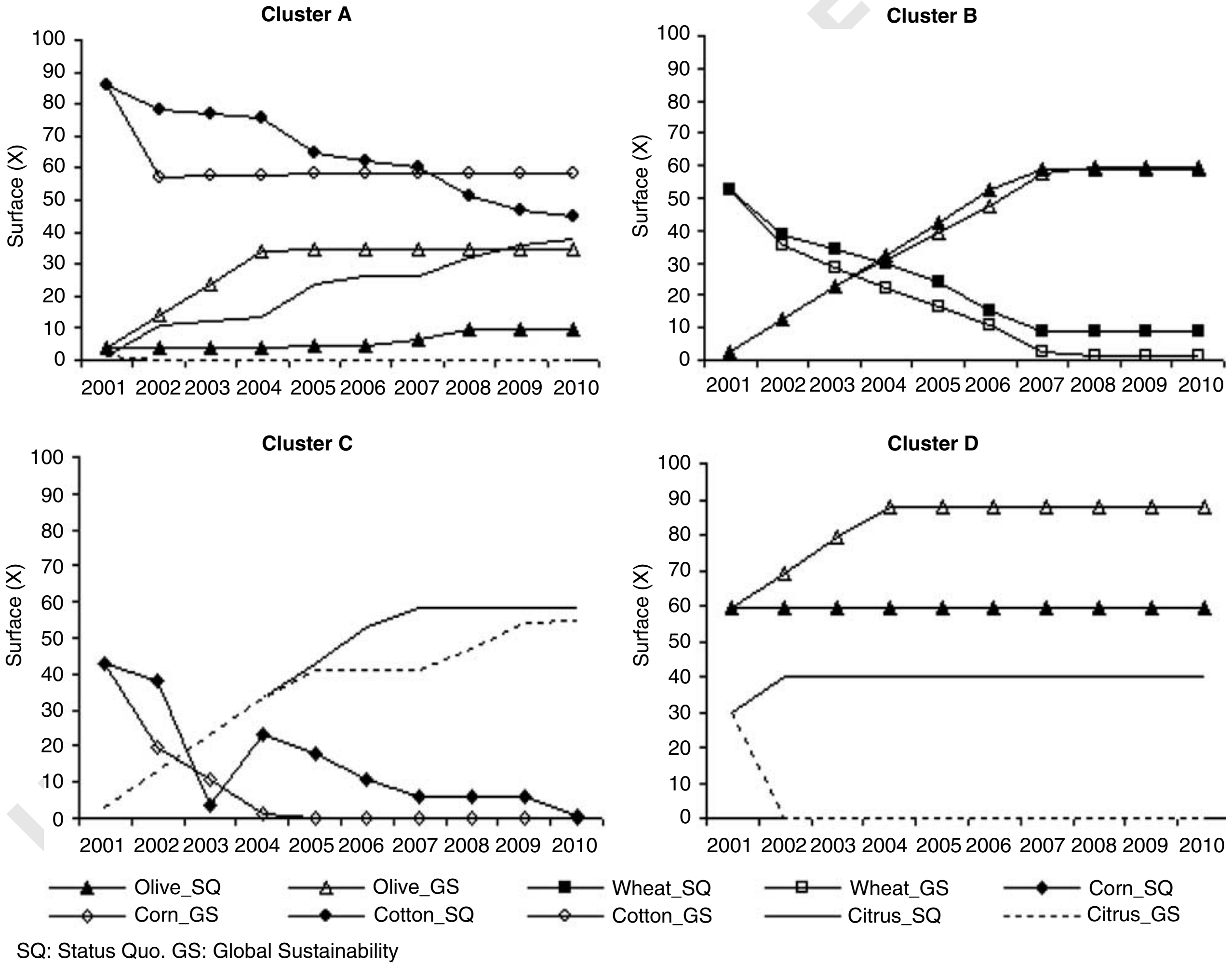
These sets of indices were computed each year for the different plans and scenarios and for each type of farming. Trends in main crops are shown in Figure 1, while Table 7 summarises changes in socio-economic and environmental indicators during the same period (2001–2010).

The main changes in cropping pattern for each cluster are shown in Figure 1 and we can see that the tendency is quite different for each type of farming.

### *Status quo*

- *Cluster A: 'cotton'*

The tendency in this cluster is towards the progressive substitution of the area sown to cotton, most of which will change to citrus and olives (Figure 1 shows most relevant crops). Potatoes maintain their present share of the crop plan (7%). Bearing in mind that 100% of irrigation is



SQ: Status Quo. GS: Global Sustainability

**Figure 1** Crop evolution by cluster in Fuente Palmera (Source: Own data).

**Table 7** Changes in socio-economic and environmental indicators (%)

| | *Changes (2010–2001)* | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | *Status quo* | | | | *Global sustainability* | | | |
| *Indicators* | *A* | *B* | *C* | *D* | *A* | *B* | *C* | *D* |
| *Socio-economic* | | | | | | | | |
| Return | −7.6 | +43 | +33.5 | −1.3 | +6.6 | +35 | +15.8 | −11.2 |
| Subsidies | −19.6 | −36.4 | +28.2 | +7.8 | −31.5 | −7.4 | +36.5 | −28.3 |
| Labour | +39.5 | +42.8 | +74 | +13.9 | +12.2 | +56.2 | +69.1 | −43.4 |
| *Environmental* | | | | | | | | |
| Water | −5.5 | +17.7 | +8.8 | +1.2 | −20.2 | +16.9 | +0.7 | −40.8 |
| Toxicity | −34.8 | −1.1 | +2.7 | −23.9 | −30 | +1.6 | −47.6 | −36.3 |
| N balance | +5.6 | −6.2 | −6.3 | −4 | −4.3 | −16.4 | −25.1 | −9.4 |
| G. diversity | −20 | −14.2 | −14.2 | −40 | −40 | 0 | −28.5 | 0 |
| Soil cover | +26.7 | +40.8 | +48.8 | +5.3 | +20.2 | +41 | +43.2 | −1 |

Source: Own data.

already by drip, conversion from cotton to tree plantations is eased by using the same irrigation system. The main result is the reduction in public-sector support, because subsidies for trees are lower than for cotton and employment will increase by 39% over current levels in 2010. Environmental indicators show mixed behaviour as water is a constraining factor at both the beginning and the end of period, given the 5000 m$^3$ available. The pesticide risk index and soil cover improve and only nitrogen balance shows a negative evolution (Table 7).

- *Cluster B: 'wheat'*

In this cluster, the cropping pattern is highly diversified, even though wheat and cotton are the principal crops. However, the trend is for cotton, corn and vegetables to maintain their current share of the crop plan while wheat and sunflower are replaced by olive trees, reaching 60% of the total area. These changes are accompanied by an increase in the percentage of drip irrigation, which was originally 33% and will reach 89% in the final year. The main result is a major increase in farm income (+43%) accompanied by an important decrease in subsidies (−36.4%). Water consumption increases (+17.7%) while genetic diversity decreases.

- *Cluster C: 'corn'*

This type of farmer increases his area of citrus fruits, which will reach 58.8%, and olives, 24%, at the expense of herbaceous crops, especially wheat and sunflowers (Figure 1). Only potatoes maintain their share of crop area. The area irrigated by drip, now at 73%, will be 96.2% in 2010. The consequences for these indicators include higher employment (74% more), a better return and more public support for this type of farming (Table 7).

- *Cluster D: 'groves'*

This cluster is currently based upon tree cultivation (olives, 59% and citruses 30%), 100% of which is already under drip irrigation. The only changes are that herbaceous crops will disappear and citrus trees will increase by 10%. The main consequence for the indicators is a lowering of toxicity derived from pesticides (23.9%), accompanied by a reduction in genetic diversity.

### *Global sustainability*

- *Cluster A: 'cotton'*

Constraints on pesticides and nitrogen will lead to a decrease in cotton and an increase of 9.8% in the area sown to olives, while potatoes maintain their 7% share (see Figure 1). There will be a general improvement in environmental indicators (lower water consumption, toxicity and nitrogen leaching) and a decrease in public-sector support (Table 7).

- *Cluster B: 'wheat'*

The evolution of the cropping pattern is similar to the SQ scenario. This cluster is currently based upon extensive herbaceous cultivation and the main change will be introduction of olives, which will occupy 59% of sown area, and vegetables 2.3%. This implies a reduction mainly in the area dedicated to wheat. The change of crop will involve a significant increase in drip irrigation, that reaches 89% by the end of the period. The scenario will imply improvements in some environmental indicators without a reduction in genetic diversity, and a major increase in incomes accompanied by a slight decrease in public support (Table 7).

- *Cluster C: 'corn'*

This cluster abandons corn and a conversion to citruses and olives will take place. Vegetables, cotton and sunflower maintain their current areas. Environmental indicators improve but economic indicators have a mixed evolution (Table 7).

- *Cluster D: 'groves'*

The dominance of trees is maintained, with olives remaining the absolutely dominant crop (Figure 1). The environmental indicators improve but changes will be mainly due to new prices and support policy, because the area sown to these crops maintains its present importance.

## Concluding remarks

We have presented a model that simulates changes in the planning horizon for 2010 according to two alternative scenarios, based on the simultaneous application of multicriteria programming and multiperiod programming, because the presence of trees and irrigation system decisions requires the use of the latter technique and the complexities of decision-making imply the use of the former.

We tested the present 'business as usual' or '*status quo*' scenario versus an alternative '*global agricultural sustainability* scenario' (part of the direction of the CAP reform) consistent with both Water Policy and CAP. The alternative scenario is defined by conditions under which, according to the WFD, a higher water price and CAP scenario imply a decrease in pesticide use, a rise in labour costs and a reduction in public-sector support via direct subsidies and price reductions.

The forecast for 2010 under both scenarios predicts changes toward a more sustainable agriculture with improvements in environmental indicators: lower water consumption, pesticide and nitrogen use and increasing soil cover. Set-aside will decrease under the '*status quo*' scenario but will be maintained under the alternative scenario of global sustainability. There is also a synergetic effect in the improvement of environmental indicators. A reduction in pesticide and fertilizer use with a simultaneous decrease in water use will have a positive impact on water quality.

The results of the study under these alternative scenarios would produce quite different agricultural landscapes and the impact would differ according to the type of farmer. Cluster A (cotton) would move under the current '*status quo*' scenario (Agenda 2000) towards citrus and olive cultivation, while the alternative scenario would increase olive plantations but maintain a significant area under cotton. The economic consequences would be higher incomes and employment and lower subsidies. Cluster B (wheat) under both scenarios would move towards olive cultivation, with positive developments in most of the socio-economic and environmental indicators. Cluster 'D' already consists of fruit growers and would maintain this orientation. Cluster C (corn) will turn into citrus growers. Differences in scenarios will be in the speed of transformation, which would be faster under the present CAP Agenda 2000. In conclusion, all farm types move in the direction of olive and citrus growing and reduce the area sown to wheat.

Finally, regarding the use of environmental, social and economic indicators, we believe that the integration of a set of indicators can contribute to the evaluation of the environmental impact of irrigated agriculture and our selection of 'means-based' indicators has proved to be a simple but powerful help for decision-makers.

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