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Economic Analysis of an Optimized Irrigation System: Case of Sant' Arcangelo, Southern Italy

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Abstract

Owing to its climate diversity and abundant natural resources, the Mediterranean basin is considered one the greatest areas for agricultural activities. Although, the Mediterranean agriculture plays an important role in the economic development of several countries by providing food and raw material for industrialization, it confronts a number of issues amongst them, water scarcity that has been increasing as a result of climate change affecting the seasonal fluctuation of rainfalls, and anthropogenic impact delineated by overexploitation and pollution. Accordingly, targeting the most efficient water use is crucial to sustain economically important irrigated crops under the mentioned circumstances. In this paper, we tried to ensure an optimal and sustainable productivity for farmers by analysing different scenarios in order to achieve the most suitable decision that fulfils the desired goals in terms of efficient water use. This analysis is performed with the software GAMS (General Algebraic Modeling System), which is a static and non-linear optimization model. It allows from intergrating different data to reach a maximizing farmer's utility that gives the optimal cropping pattern close to the real one. Considering several possible constraints and by using an optimisation software (GAMS), we obtained the optimal cropping pattern giving the maximum profit to the farmers within the study area of Sant' Arcangelo.

Keywords: Water Management, Cropping Pattern, Non-linear Optimization Model, GAMS Programming, Farmer's Utility, Farm Profit.

Introduction

To meet the increasing demand for food as a result of population growth, it has been a necessity to either provide additional areas for cultivation and/or increase the production per unit area. Generally, productivity generated from irrigated agriculture are estimated to be 2-3-fold higher than the one produced from rainfed agriculture. However, expanding irrigated areas for agriculture requires larger water usage, deriving to a serious competition with domestic and industrial sectors in regard to water demand. In such a manner, the resources allocation optimization including land and water is a noteworthy option to fulfill the maximum production yield per unit area and per drop of water (Gadge, Gorantiwar, Kumar, & Kothari, 2014).

A farmer at the start of each irrigation season needs to have optimum cropping pattern and irrigation programs, which will maximize the economic return. Under these circumstances there is a crucial need to introduce efficient techniques in land and water resources management for optimal utilization of the available land and water resources (Cortignani & Dono, 2018).

In common, farmer decision-making is a complicated process (Öhlmér, Olson, & Brehmer, 1998). This complication appears from the fact that multiple factors can affect this process and also because of their inter-dependency (Altieri, 2018). In fact, in order to maximize his profit, the farmer has to take into consideration several aspects simultaneously such as the climate condition, the scarcity of resources, the policy restrictions, the agronomic constraints, the choice between different production activities and diverse production techniques, etc. Thus, these aspects constitute a big challenge for both farmer and decision makers.

In the fifties and sixties of the last century, a large number of simulation and optimization models have been used for the appropriate planning and management of water use in irrigated agriculture (Patel & Bhavsar, 2018; Shenava & Shourian, 2018). Soon after the simplex algorithm was found by Dantzig in 1947 (Dantzig, 1963), agricultural economists started to use linear programming for farm planning. Early publications related to linear programming in agriculture is one of the best tools for optimal allocation of land and water resources (Afshar & Mariño, 1989; Maji & Heady, 1980; Smith, 1973) either aimed at disseminating the mathematical knowledge by explaining the characteristics of the procedure (Boles, 1955; Heady, 1954)or at pointing out its possible applications and general potential for farm management (McCorkle, 1955; Swanson, 1961) and applied linear programming to the hypothetical agricultural holding in order to find optimal production plans by maximizing total gross margins (Zgajnar, Erjavec, & Kavcic, 2007). On the other hand, the positive mathematical programming (PMP) are widely used for agricultural economic policy, this PMP approach uses the farmer's crop allocation in the base year to generate self-calibrating models of agricultural production and resource use, consistent with microeconomic theory, that accommodate diverse quality of land and livestock (Howitt, 1995; Kasnakoglu & Bauer, 1988; Quinby & Leuck, 1988) by introducing non-linear terms in the objective function such that optimality conditions are satisfied at observed levels of decision variables (Heckelei, Britz, & Zhang, 2012).

The simulation models can quantitatively describe complex interactions among plant, soil, water, atmosphere, and groundwater. After proper calibration and validation, these models can be adopted to do scenario analysis for searching preferable management strategies. In the last two decades, many softwares and models (e.g., COPAM,IPANET,SWAP,SWAT, DRAINMOD and SimDualKc) have been widely used for improving irrigation schedules and methods as well as drainage system design (Jiang, Feng, Huo, Zhao, & Jia, 2011; Lamaddalena & Sagardoy, 2000; Pereira et al., 2009; Rossman, 1999; Singh, 2012; Sun & Ren, 2014). Otherwise, the optimization models have been widely applied in irrigation planning and management as part of a strategy to find the optimal utilization of limited water and land resources (Singh & Panda, 2012). Its application involves the optimization of irrigation scheduling, water allocation, water conveyance operation, and cropping pattern, etc. Furthermore, the optimization methods with uncertainties (e.g. stochastic programming, fuzzy goal programming efficiently for modeling and solving land-use planning problems in agricultural systems for optimal production of several seasonal crops in a planning year and interval-parameter programming etc.) are also employed in conventional optimization models for considering uncertainty and randomness in optimization parameters (Biswas & Pal, 2005; Ganji, Ponnambalam, Khalili, & Karamouz, 2006; Li & Guo, 2015; Zhang & Li, 2014).

In the present research a called General Algebraic Modeling System (GAMS) is used, the idea is presented at the International Symposium on Mathematical Programming (ISMP), Budapest 1976. Then it becomes a commercial product in (Development Research Center in Washington DC. Since 1987), this model allows selecting the optimal cropping pattern under the given conditions, as well as simulating several scenarios based on different water prices, in order to determine the best pricing tariff that help for saving water (i.e. reducing water demand) without a large decrease of farm income (Bussieck & Meeraus, 2004).

In order to identify the optimal cropping pattern for our study area, as well as water demand during the peak period to be considered in the design of the irrigation system, a mathematical programming system was used. It consists of a static and non-linear optimization model which maximizes farmer's utility defined as the expected revenue minus risk aversion towards price variation, subject to a set of agronomic and resources constraints (Norton & Hazell, 1986).

The model had been developed using GAMS, this model allows selecting the optimal cropping pattern under the given different conditions, as well as simulating several scenarios based on different water prices, in order to determine the best pricing tariff that help for saving water (i.e., reducing water demand) without a large decrease of farm income.

Methodology

Description of the study area

The project area, Sant' Arcangelo, is located in the municipality of Sannicandro, province of Bari in the Apulia region (Southern Italy), at approximately 40.99° N and 16.80° E and an average altitude about 183 m above sea level. The study area is characterised by semi-arid Mediterranean climatic conditions, with hot and dry summer and moderately cold and wet winter.

The total cultivable area is 201.88 ha in which the total irrigable area is about 164 ha, 7% of it is occupied by roads and buildings that reduce the net irrigable area to 153 ha. Major land use is for agricultural purposes: olives, orchards, almonds, and horticultural crops are widespread, and, in some areas, high quality vineyards can be found. Additionally, the landholding at the location are farmers (Alobid & Szűcs, 2019).

Optimization model

In general, farmer decision-making is a complicated process. As mentioned earlier, this complication arises from the fact that multiple factors can affect this process and their interdependency. Indeed, to maximize his profit, the farmer has to take into account simultaneously several aspects such as the climate condition, the scarcity of resources, the policy restrictions, the agronomic constraints, the choice between different production activities and diverse production techniques, etc. Thus, these aspects constitute a big challenge for both farmer and decision makers. While in the positive mathematical programming PMP analysts are required to construct models for systems time-series data are absent or are inapplicable due to structural changes in a developing or shifting economy (Just, Zilberman, & Hochman, 1983; Just, Zilberman, Hochman, & Bar-Shira, 1990).

The aim of this study is to try to capture and implement all these aspects in an optimization model to represent farmer's behaviour and anticipate his reaction to exogenous shocks such as the change of market prices and policies. Furthermore, with this model profit increases – with increased freedom to optimizes cropping pattern; with greater water availability. The main specification of this model is developed in the following section.

Objective function

It consists to maximize farmer's utility defined as the expected income minus its standard deviation due to risk averse towards price variation (Moschini & Hennessy, 2001). This means that the only source of risk accounted is the market price variation.

Where:

- ϕ: Risk aversion coefficient [ranged from 0 to 2]
- σ: Standard deviation of the expected income (€)
- U: Farmer's Utility (€)
- Z: Expected net income (€)

The risk aversion coefficient (ϕ) measures the degree of risk aversion of the agent. This coefficient measures farmer perception to risk. A high value for this coefficient, means that the farmer is risk averse and he will grow various crops in order to avoid the risk and, inversely, a low value (close to zero or negative) means that the farmer is less risk averse (risk lover) and thus he will prefer to grow the risky crops (i.e., crop with high price variation) because they have high profit. Often exogenously specified related to the farmer and its value is often ranging from 0 to 2. If ϕ=0 implies that farmer is risk neutral, as the risk aversion coefficient increases the diversification of cropping pattern increases. In this study, since we have run the model with different coefficients ranging between 0 and 1.65 and then we select the one that they gave an appropriate crop pattern. We have chosen ϕ=1.25, because only prices variation is considered, and this value gives the best fit between the predicted crop pattern and the expected one.

The expected farm income (Z) (Z is equal to the sum of net income generated from different optimal crops) is computed as follows considering several parameters including the average yield and prices of crops.

$$Z = \sum_{c,t} (\Pr ice_c * Yield_{c,t} - V\cos t_{c,t}) * X_{c,t} + \sum_{c,t} (Dpay,c * X_{c,t})$$
$$- \sum_{c,t} (K\cos t_c * X_{c,t}) - Wtarif * iLand - \sum_{w} (Wprice_w * QW_w)$$

Where:

Z: Expected farm income (€); c: Crops index ; t: Irrigation techniques index; $\text{Yield}_{c,\mathbf{t}}$: Crop yield (ql/ha); $\text{Vcost}_{c,\mathbf{t}}$: Variable costs (€/ha) ; X: Crop activity level (ha).[1]; Dpay_c: Direct payments (for all crops and for strategic crops) (€/ha); Kcost_c: Fixed cost (€/ha) (i.e., plantation for perennial crops); Wtarif: Fixed water tariff (€/ha of irrigable land); iLand: Irrigable land (ha); Wprice_w: Block-rate water tariff (€/m3); QW_w: Annual amount of used water per block (m3); W: Water block index; Price_c: Average crop price (€/ql).

Risk is an important aspect in agriculture. The uncertainties of weather, market, government policies, and other factors can cause wide swings in farm income. The risk aversion coefficient, which is related to the farmer, measures the degree of risk aversion of the agent. As the risk becomes increasingly important, the risk aversion coefficient increase, and the diversification increase as well, so the activity of less risk will increase. In this case study the risk aversion coefficient was set to 1.65, meaning that the farmer is highly risk averse. This value gave us the closest crop pattern to the real one and because only market risk is considered. To estimate the risk related to the price variation, different scenarios were simulated to assess the impacts of changing the price on crop pattern, farm income, water use, water agency revenue. First, a set of crop prices are randomly generated using the normal distribution function, the average and the standard deviation of prices. Second, the generated prices are used to compute the random incomes (ZK) defined over different states of nature (k), as follows:

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[1] This is an endogenous variable (i.e., generated by the model) and represents the area (in ha) of each crop selected in the optimal solution.

$$ZK_k = \sum_{C,t}(\Pr ice\_k_{c,k} * Yield_{c,t} - V\cos t_{c,t}) * X_{c,t} + \sum_{ct}(Dpay, c * X_{c,t})$$
$$- \sum_{ct}(K\cos t_c * X_{c,t}) - Wtarif * iLand - \sum_{w}(Wprice_w * QW_w)$$

Where:

- ZK_k: random income over states of market k (€)
- $Price\_k_{c,k}$: Random prices (€/ql)
- k: States of market (ranged from K1 to K50)

$$\sigma = \sqrt{\sum_k \frac{(ZK_k - Z)^2}{N_k - 1}}$$

Where:

- ZK_k: Random farm income (€)
- N_k: Number of states of market for price variability (N=50)
- σ: Standard deviation of farm income (€)
- Z: Expected farm income (€)
- k: States of market [1-50].

Equations for gross margin calculation

For the computation of the gross margin ($Gm_{c,t}$, in €/ha), the gross irrigation requirement ($GIR_{c,t}$, in mm) of each crop, and the applicable water per month ($Watapl_{c,t,m}$, in m^3/month) the following formulas were used:

$$Gm_{c,t} = \Pr ice_c * Yield_{c,t} - V\cos t_{c,t} + Dpay$$

Where:

$Gm_{c,t}$: gross margin(€/ha); $Price_c$: average crop price (€/ql) ; $Yield_{c,t}$: crop yield (ql/ha); $Vcost_{c,t}$:variable costs (€/ha); Dpay: direct payment (subsidies).

$$Nm_{c,t} = \Pr ice_c * Yield_{c,t} - V\cos t_{c,t} - K\cos t_{c,t} + Dpay$$

Where:

$Nm_{c,t}$: net margin (€/ha); $Kcost_{c,t}$: fixed (i.e., plantation) cost (€/ha); $Price_c$: average crop price (€/ql); $Yield_{c,t}$: average crop yield (ql/ha) ; $Vcost_{c,t}$: variable costs without water costs (€/ha) ; Dpay: direct payment (€/ha) ; $GIR_{c,t}$: gross irrigation requirements (mm) ; $NIR_{c,t}$: net irrigation requirements (mm) (GIR minus different requirements such as leaching, runoff, deep percolation etc.).

Constraints

A set of constraints have been implemented in our model. They can be classified in two groups: resource and crop rotation constraints.

Resources constraints

Land constraint

➢ **Total land:** this constraint expresses that, for each month, the cultivated land cannot exceed the total available land.

$$\sum_{ct}(L\_use_{c,m} * X_{c,t}) \leq fland$$

Where:

- fLand : total available land (ha)
- $L\_use_{c,\mathbf{m}}$ **:** monthly land use coefficients
- $X_{c,t}$: crop activity level per technique (ha)

Irrigable land: this constraint expresses that the area allocated to irrigated crops in each month cannot exceed the total irrigable land.

$$\sum_{ct} (L\_use_{c,m} * X_{c,ti}) \leq iland$$

Where:

- ti : irrigated technique index
- $L\_use_{c,m}$: monthly land use coefficients
- $X_{c,ti}$: crop activity level per technique (ha)
- iLand: Irrigable land (ha)

Water constraint

Water is available from 1st April to 31st October, on demand pressurized irrigation network will be used for water distribution to the farms where sprinkler and drip irrigation methods are used, and it has 2 main constraints:

The first constraint expresses that, in each month, the total water requirement for cropping cannot exceed the monthly water availability.

$$QWAT_m \leq Watav_m$$

In which:

$$QWAT_m = \sum_{C,ti} (watapl_{c,ti,m} * X_{c,ti})$$

Where:

- $Watapl_{c,ti,\mathbf{m}}$: monthly water requirement per crop and technique (m^3)
- $QWAT_m$: monthly water consumed (m^3)
- $Watav_m$: monthly water availability (m^3)
- $X_{c,ti}$: crop activity level per technique (ha)

The second water constraint has been defined related to the upper bound of each water block (tariff by block). This constraint specifies that the amount of water consumed by block cannot exceed the water availability by block, knowing that total consumed water under different blocks must be equal to the sum of water consumed in each month.

$$QWw \leq watQ_w * iLand$$

Where:

- QW_w: the used water per block (m^3)
- w: blocks of water tariffication (W1 to W3)
- $watQ_w$: the water available per block (m^3/ha)
- iLand**:** irrigable land (ha)

Knowing that, the sum of water used per block should be equal to the sum of water consumed per month.

$$\sum_w QW_w = \sum_m QWAT_m$$

Where:

- $QWAT_m$: monthly water consumed (m^3)
- QWw : used water per block (m^3)

Crop rotation constraints

Two crop rotation constraints have been introduced:

Rotation constraint for annual irrigated crops:

A three-annual rotation for annual irrigated crops was imposed, where the area of each crop cannot exceed one third of irrigable land, excluded the surface assigned to permanent crops.

$$\sum_{ti} X_{crot,ti} \leq (iland - \sum_{ct} X_{cp,ti})/3$$

Where:

- $X_{crot,ti}$: the area of annual crops that require rotation (ha).
- $X_{cp,ti}$: activity levels of permanent crops (ha).
- cp :permanent crop index
- crot : index of annual crops that require rotation.
- ti : irrigation technique index

Rotation constraint for Solanaceous crops:

This rotation concerns only crops belonging to the Solanaceous family (i.e., eggplant, early potato, and tomato). It implies that these crops, which are already included in the three-annual crop rotation, cannot be cultivated one after the other to avoid diseases and pests problems.

$$\sum_{csol,ti} X_{csol,ti} \leq \frac{1}{3}(iLand - \sum_{cp,ti} X_{cp,ti})$$

Where:

- $X_{csol,ti}$: level of solanaceous crops.
- $X_{cp,ti}$: level of permanent crops
- iLand: irrigable land (ha)

Data set

Land and water resources

The total available area is 164 ha from which 153ha is an irrigable land. The irrigation water is obtained from 2 wells with a discharge of 80 l/s. The water availability has been determined on a monthly basis with 24 hours per day working time:

$$Monthly\ \ Water\ \ Availability = [80*(86400*24*30)/1000] = 207360\ m^3$$

Combination of crops and irrigation techniques

We used four irrigation techniques, implemented in the model. Based on climatic, soil and socio-economic conditions, as well as the existing cropping pattern in the region, a number of annual and perennial crops were chosen for simulation.

- **Tree crops**: Peach, Grapevine, Olive trees and Cherry.
- **Field crops**: Autumn Sugar beet, Wheat, sunflower, and maize.
- **Horticultural crops:** Eggplant, Lettuce, Tomato, Early Potato, eggplant, and Watermelon.

Some of them can be grown only with irrigation and others can be either rainfed or irrigated.

- **T0 :** Rainfed
- **T1 :** 100% NIR - Full irrigation
- **T2 :** 75% NIR - Partial irrigation

- **T3 :** 50% NIR - Complementary irrigation

The following Table 1 shows the possible combinations between crops and irrigation techniques.

Table 1. Possible combinations of crops and irrigation techniques

Crops	T0	T1	T2	T3
Wheat	1	1	1	1
Autumn_Sugarbeet		1	1	1
Sunflower		1	1	1
Early_Potato	1	1	1	1
Eggplant		1	1	1
Watermelon		1	1	1
Tomato		1	1	1
Lettuce	1			
Peach		1	1	1
Cherry		1	1	1
Grapevine	1	1	1	1
Olive_trees	1	1	1	1

Distribution of land use for simulated crops

Table 2 summarizes the monthly land occupation for the different crops. It is based on the difference of crops' growing cycle and the land use repartition along the year.

Table 2. Crops land use

Crops	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Wheat	1	1	1	1	1	1	0	0	0	0	1	1
Autumn_Sugarbeet	1	1	1	1	1	1	1	0	0	0	1	1
Sunflower	0	0	0	1	1	1	1	1	0	0	0	0
Early_Potato	1	1	1	1	1	0	0	0	0	0	0	0
Eggplant	0	0	0	1	1	1	1	1	1	0	0	0
Watermelon	0	0	0	1	1	1	1	0	0	0	0	0
Tomato	0	0	0	1	1	1	1	1	0	0	0	0
Lettuce	1	1	1	0	0	0	0	0	0	0	1	1
Peach	1	1	1	1	1	1	1	1	1	1	1	1
Cherry	1	1	1	1	1	1	1	1	1	1	1	1
Grapevine	1	1	1	1	1	1	1	1	1	1	1	1
Olive_trees	1	1	1	1	1	1	1	1	1	1	1	1

Considering the distribution of cropping cycles, it is possible to produce two different crops in the same land during the same year. For example, it is possible to combine lettuce either with tomato, watermelon, eggplant, or sunflower.

Monthly net irrigation requirement (NIR)

Table 3 below represents the results of NIR for each crop. It is generated by FAO CROPWAT model, for estimating the total water requirement per crop and irrigation technique.

Table 3. Monthly net irrigation requirements (mm/month)

Crops	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Wheat	0.0	0.0	0.0	40.2	73.8	0.0	0.0	0.0	0.0	0.0	0	0
Autumn_Sugarbeet	0.0	0.0	0.0	33.8	107.0	159.1	216.9	0.0	0.0	0.0	0	0
Sunflower	0.0	0.0	0.0	0.0	68.3	145.3	168.3	55.5	0.0	0.0	0	0
Early_Potato	0.0	0.0	6.6	55.9	73.8	0.0	0.0	0.0	0.0	0.0	0	0
Eggplant	0.0	0.0	0.0	0.0	24.0	76.3	164.8	167.4	64.0	0.0	0	0
Watermelon	0.0	0.0	0.0	0.7	68.3	117.7	130.1	0.0	0.0	0.0	0	0
Tomato	0.0	0.0	0.0	4.7	70.5	145.3	182.2	111.4	0.0	0.0	0	0
Lettuce	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0
Peach	0.0	0.0	0.0	21.2	63.9	98.4	140.5	117.8	41.7	0.0	0	0
Cherry	0.0	0.0	0.0	24.4	73.8	110.8	156.1	127.4	49.8	0.0	0	0
Grapevine	0.0	0.0	0.0	3.1	39.5	73.5	109.2	92.2	31.6	0.0	0	0
Olive_trees	0.0	0.0	0.0	4.7	29.6	48.7	78.0	63.5	13.3	0.0	0	0

Crops yields and prices

Table 4 below represents the average yield for each combination crop-irrigation technique for the study region. These data are estimated using the curves of crop yield response to water obtained from CROPWAT model (Alobid & Szűcs, 2019).

Table 4. Crop yield per irrigation technique (ql/ha)

Crops	T0	T1	T2	T3
Wheat	33.2	50.0	44.9	40.7
Autumn_Sugarbeet		800.0	721.2	575.1
Sunflower		45.0	38.2	31.5
Early_Potato	155.6	200.0	192.2	184.4
Eggplant		350.0	286.5	223.1
Watermelon		700.0	633.2	508.5
Tomato		750.0	634.5	484.9
Lettuce	450.0			

The average crop prices and their standard deviation obtained from regional statistical data base are represented in table5 (Contò & La Sala, 2012).

Table 5. Crop average prices (euro/ha) and their standard deviation (Price_std)

Crops	Price	Price_std
Wheat	26.7	8
Autumn_Sugarbeet	3.1	0.1
Sunflower	30.7	3.1
Early_Potato	26.7	15
Eggplant	36	5.3
Watermelon	15.3	7
Tomato	24	5

Crops	**Price**	**Price_std**
Lettuce	32	25
Peach	49.2	15
Cherry	227	90
Grapevine	37.4	8
Olive_trees	49	8

Production Cost

Production cost including variable and fixed costs were obtained from regional economic data. Variable cost is given depending on irrigation techniques used in the model, and the fixed cost (only for the perennial crops) is strictly for the plantation. Annual values for the data are summarized in the table6 below.

Table 6. Annual variable and fixed costs for simulated crops (€)

Crops	**Variable cost**				**Fixed cost**[2]
	T0	**T1**	**T2**	**T3**	
Wheat	680.0	858.0	780.0	702.0	
Autumn_Sugarbeet		2037.525	1940.5	1746.45	
Sunflower		761.88	725.6	653.04	
Early_Potato	4903.7	6057.5	5769.0	5192.1	
Eggplant		4073.37	3879.4	3491.46	
Watermelon		4008.16	3817.3	3435.57	
Tomato		5979.96	5695.2	5125.68	
Lettuce	4128.5				
Peach		8993.6	8993.6	8993.6	465.0
Cherry		8793.2	8793.2	8793.2	372.0
Grapevine	4543.6	6180.0	6180.0	6180.0	952.9
Olive_trees	1261.0	1907.7	1907.7	1907.7	132.9

*****Without water costs

Direct payments

According to the last reform of the Common Agricultural Policy (CAP), all crops are assumed to receive decoupled payments. Its amount is set for our region to 179 €/ha, an additional payment is given to olive trees, wheat and tomatoes considered as strategic crop in the studied region. The amount of these coupled payments is set to 278 €/ha for olive trees, 150 €/ha for wheat and 160 €/ha for tomato.

Water tariffication

The binomial water tariffication is based on fixed and variable tariffs used in the model table7.

- The fixed tariff depends only on irrigable land without taking into consideration water consumption.

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[2] These costs are for permanent crops and represent mainly the cost of plantations.

- The variable tariff varies according to the quantity of water consumed under each block.
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Table 7. Water tariffs

	Water Blocks	Level (€)	Max Amount of Water per Block (m^3/ha)
Fixed Tariff (€/ha*) *Irrigable land	-	30	-
Water Price (€/m^3)	**W1**	0.09	≤ 2000
	W2	0.18	2000-3000
	W3	0.36	3000-13000

Results and discussion

Model results and analysis

After collecting the required input data for running the model, several simulation scenarios were tested, and their results were reported and analyzed.

Basic scenario: based on average computed data of monthly net irrigation requirement annexes 2&3 and effective rainfall. This scenario was used to determine the optimal cropping pattern as well as water demand in an average year after implementation of the irrigation project.

Simulation scenarios: A set of scenarios referring to different water irrigation prices was implemented annex 4. The aim of these scenarios is to determine the best price tariff that can reduce water demand with an acceptable decrease of farm income.

Table 8 below shows the total cultivated area as well as the irrigated area under the basic scenario in comparison to irrigable land.

Table 8. Cultivated area and irrigated areas in the project area

Irrigable area (ha)	Cultivated area (ha)	Irrigated area (ha)
153	201.88	124.52

The difference between the available irrigable area and cultivated area is due to the succession of some annual crops cultivated in the same land within the year (lettuce).

Sensitivity analysis for different risk aversion coefficient (ϕ)

Before defining the optimal cropping pattern, we assessed the impact of the risk aversion coefficient (ϕ) on model outcomes. The value of this coefficient was increased from 0 to 1.65 in order to see its impact on crop pattern, farm income and water use. As shown in the table 9 below, the increase of ϕ leads to more diversified cropping pattern. In fact, only 3 crops were selected at $\phi = 0$, then that number increased to 6 crops with $\phi = 1.65$. A reverse impact is observed for farm income as it decreases when the value of ϕ increases. As expected, with the increase of risk aversion coefficient, the risk part in the objective function will be more important leading to a decrease of farm income.

A risk aversion coefficient of 1.25 was used in our model, because it gives the best fit between the model's predicted crop pattern and the expected one and to be close to the real situation of the study area.

Table 9 shows the impact of different risk aversion coefficient (ϕ) on model outcomes.

Table 9. Analysis for different risk aversion coefficient (ϕ)

Crops	**Technique**	**Risk aversion coefficient**								
		0	**0.25**	**0.5**	**0.75**	**1**	**1.25**	**1.5**	**1.6**	**1.65**
watermelon	T1	51	51	37	9		16	32	33	34
watermelon	T2				21	26	13			
tomato	T1	51	51	37	29	26	28	32	33	34
lettuce	T0	164	164	121	99	72	38	23	20	19
peach	T1					16	24	22	21	20
cherry	T1			43	65	58	44	36	33	32
olive_trees	T0					18	39	43	44	45
profit_ha	Level	16044	16044	14940	14297	12702	10286	9069	8743	8618

The optimal cropping patterns

From the combination of different crops and production techniques, and taking into account land, water and crop rotations constraints, and a selected risk aversion coefficient (ϕ=1.25), the following cropping pattern was generated by the model for the average year which corresponds to the basic scenario figure1. This figure shows the percentage of the area of each crop in respect of the total land use. From 12 crops and 4 irrigation techniques just 6 crops have been selected. These crops are cultivated under full irrigation technique (T1) except watermelon irrigated under T2, olive trees and lettuce that give an acceptable or full yield even in rainfed conditions (T0). The choice of these crops is driven by several factors among them, the net margins, and the standard deviation of prices this means that T1 and T2 are more profitable than T3 in this case. This depends on many factors such as the water prices, the relation between the yield and water use coming from CROPWAT (Alobid & Szűcs, 2019).

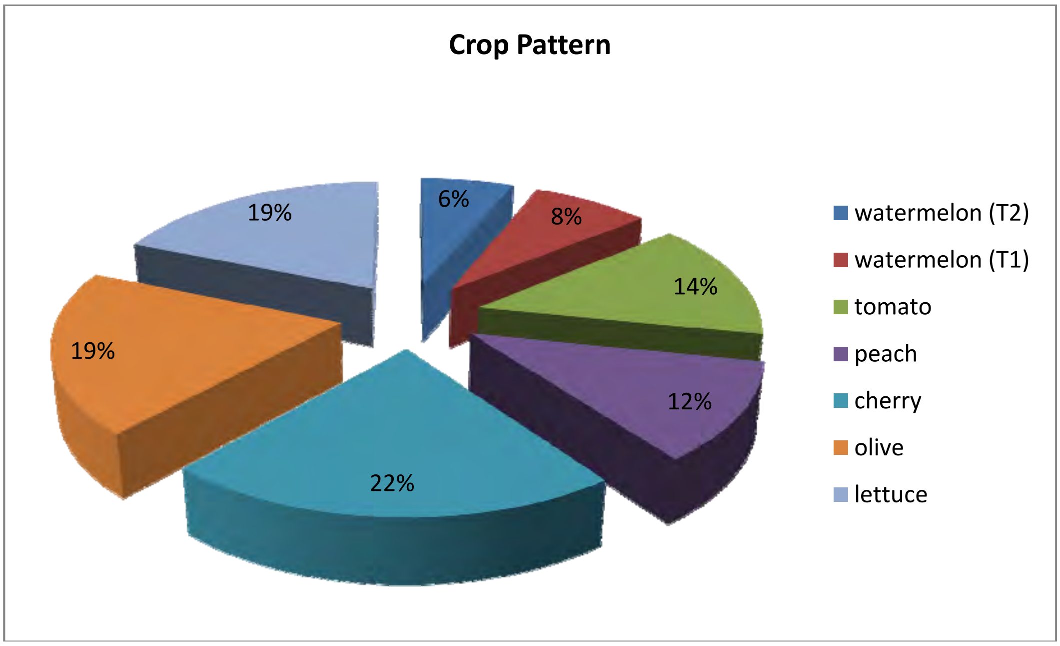


Figure 1. Optimal cropping pattern for the studied crops

Table 10 below summarizes the results concerning the optimal cropping pattern.

Table 10. The Optimal Cropping Pattern for the studied Crops

Crops	Irrigation techniques		
	T0	T1	T2
watermelon		15.92	12.56
Tomato		28.48	
Lettuce	37.88		
Peach		23.59	
Cherry		43.97	
Olive trees	39.48		
Irrigated land (ha)	124.52		
Land use (ha)	201.88		
Total profit (€)	1.7 million		
Total water use (m^3)	**643542,67**		

Table 11 below presents the area of the selected crops, their net margins with and without water costs and the farm profit. Thus, in this table we report both the net margin without and with the water costs (profit (€/ha)), knowing that the selection of the optimal crop pattern depends on net margin with water costs. Water cost can be known only after running the model because the quantity of consumed water is calculated by the model based on the optimal crop pattern.

Table 11. Net Margin and Profit for the Cropping Pattern

CROPS	Area (ha)	Net Margin* (€/ha)	Total Water Cost (€/ha)	Profit (€/ha)	Profit (€)
Watermelon	12,56	6049,9	528,4	5521,5	69360,9
	15,92	6880,8	694,6	6186,3	98464,9
Tomato	28,48	12359	1108,5	11250,6	320399,5
Peach	23,59	10400,4	1044,3	9356,1	220729,8
Cherry	43,97	13713	1167,8	12545,2	551639,5
Olive	39,48	791,8	21,6	770,2	30407,1
Lettuce	37,88	10450,5	0,0	10450,5	395863,6
Total					1.7 million

* Without water cost

Table 12. Crop Total Water Use

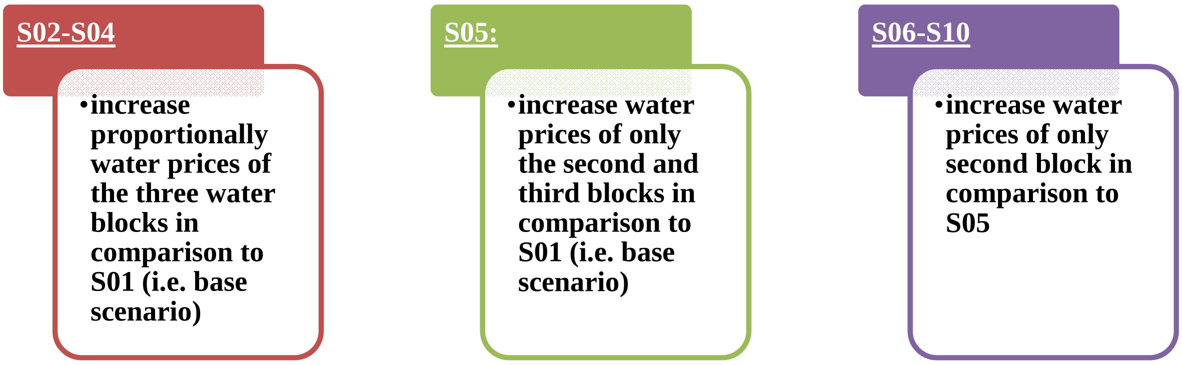
Crop	Technique	Area (ha)	Water dmd (m3)	% Water consumption
watermelon	**T2**	12.56	33159.17	5.15
	T1	15.92	56019.67	8.70
Tomato	**T1**	28.48	162659.76	25.28
Peach	**T1**	23.59	126730.11	19.69
Cherry	**T1**	43.97	264973.96	**41.17**
Olive	**T0**	39.48	0	0
Lettuce	**T0**	37.88	0	0
	Total	**201.88**	**643542.67**	**100**

Table 12 shows the total water use per crop and irrigation technique corresponding to the optimal cropping pattern. According to the results presented cherry has the highest water use with 41.17% of the total water consumption. On the other hand, lettuce and olive tree are cultivated under rainfed conditions.

Simulation of water tariff

To assess the impact of water pricing on crop rotation, profit and consumption of water, several simulations of pricing of water has been made, they are based on data of the year with average rainfall and are grouped into different scenarios Table 13. The first scenario S01 which corresponds to the basic scenario is used as a reference for assessing the impact of other scenarios.

The simulation consists of keeping the fixed water tariff per irrigable area unchanged and varying the water price in the different blocks for each scenario as following figure 2:



S02-S04

- **increase proportionally water prices of the three water blocks in comparison to S01 (i.e. base scenario)**

S05:

- **increase water prices of only the second and third blocks in comparison to S01 (i.e. base scenario)**

S06-S10

- **increase water prices of only second block in comparison to S05**

Figure 2. The water price in the different blocks for each scenario

Table 13. Simulation Scenarios, levels of Water Price per Blocks

Blocks	**s01**	**s02**	**s03**	**s04**	**s05**	**s06**	**s07**	**s08**	**s09**	**s10**
w1	0.09	0.11	0.3	0.4	0.09	0.09	0.09	0.09	0.09	0.09
w2	0.18	0.25	0.4	0.5	0.65	0.68	0.71	0.72	0.73	0.74
	0.36	0.4	0.8	0.9	0.75	0.75	0.75	0.75	0.75	0.75

Scenarios S1: S4

Water consumption under scenario S1 to S4

As expected, water consumption decreases with the increasing of water price from S1 to S4. It passes from 4200m^3/ha to around 3800 m^3/ha. Indeed, a continuous increase in water prices generally reduce the amount of water consumed accompanied by a remarkable drop in profit Figure 3.

Crop pattern allocation under scenario S1 to S4

Different cropping pattern is found under each scenario according to increasing water price. As we can see from the figure4 below, a change in their area especially between irrigated crops.

- From S1 to S2 we can observe that with a small increasing in water price, the change in crop pattern is also small. Hence, the water consumption still almost the same because this crop pattern is still profitable.
- Water price increasing from S2 to S3 is quite high, that's why we find big change in the crop pattern. Notice that in S3 watermelon is to be irrigated fully (T1) that can be explained by the less water consumption compared to other crops such as cherry and peach.

- From S1 to S3 and S4, we notice a decrease of the area of crops which the water consumption is high. Also, the watermelon area switched from fully (T1) to partially irrigated (T2).
- The increase in water prices for the three blocks resulted in an increase of the area of olive trees.

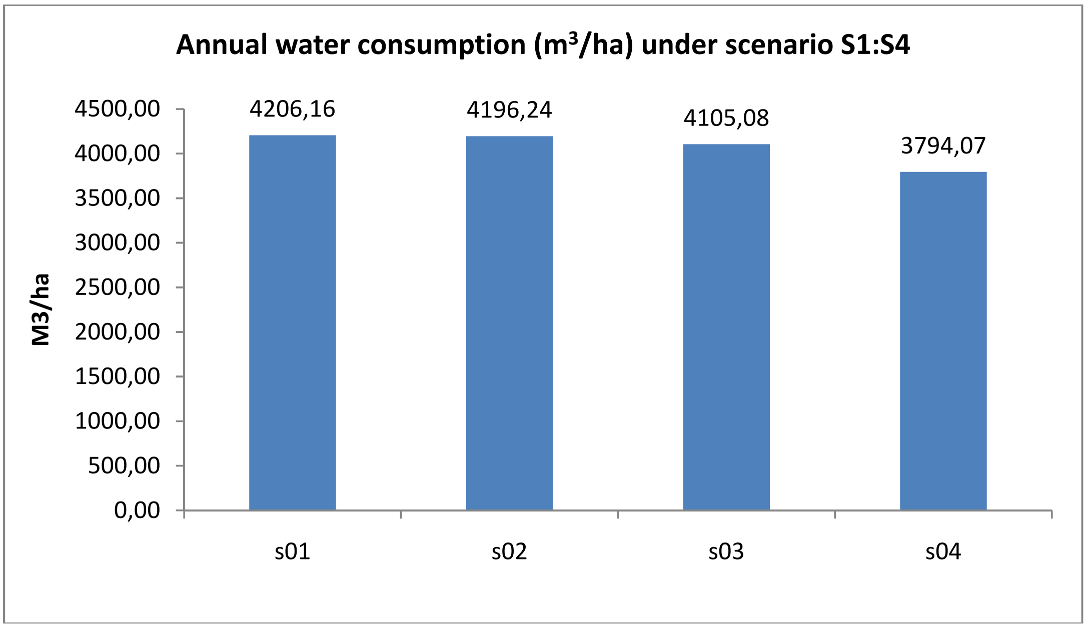


Figure 3. Annual water consumption (m3/ha) under scenario S1:S4

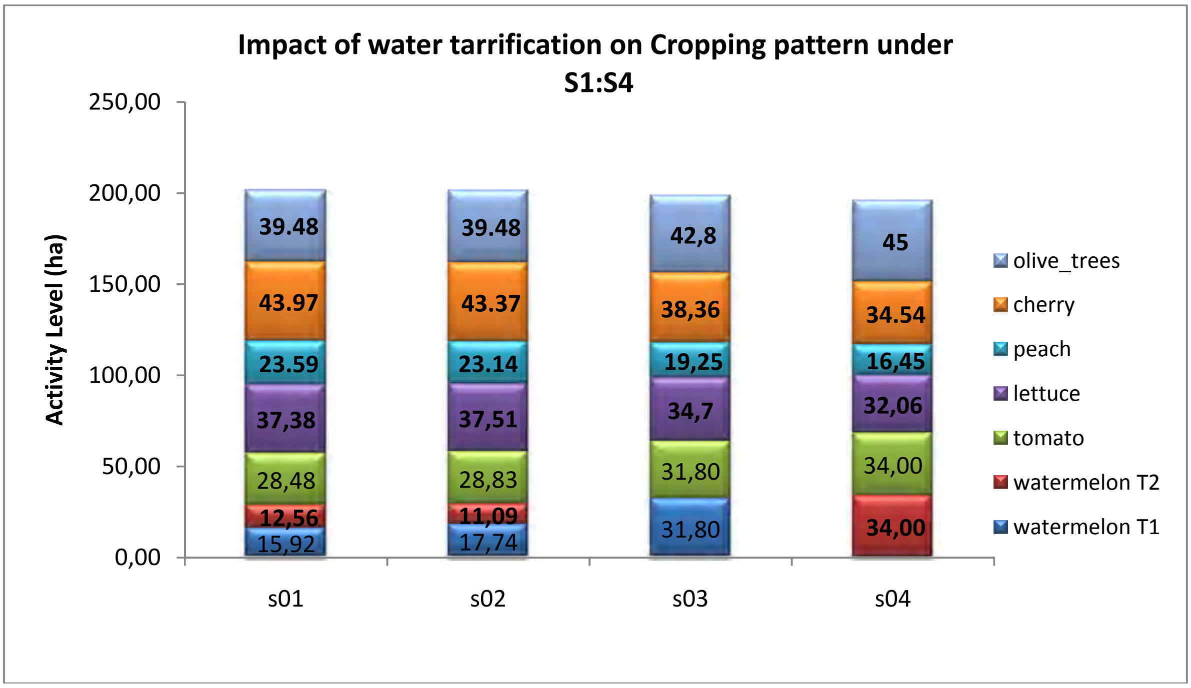


Figure 4. Impact of Water Tarriffication on Cropping Pattern Under S1 to S4

Profit under scenario S1 to S4

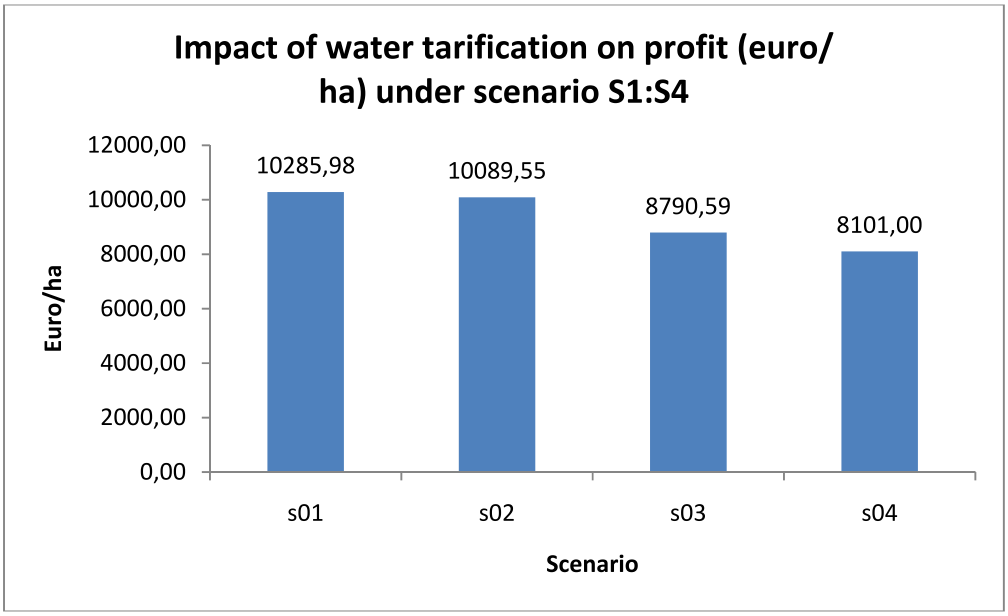


Figure 5. Profit (Euro/ha) Under Scenario S1 to S4

From Figure 5, we conclude that the increase of water cost leads to a decrease in farm income. The reduction of the farm income is due to both the increase of water cost and its effect on the land allocation.

Scenarios S1: S5

Water consumption under scenario S1: S5

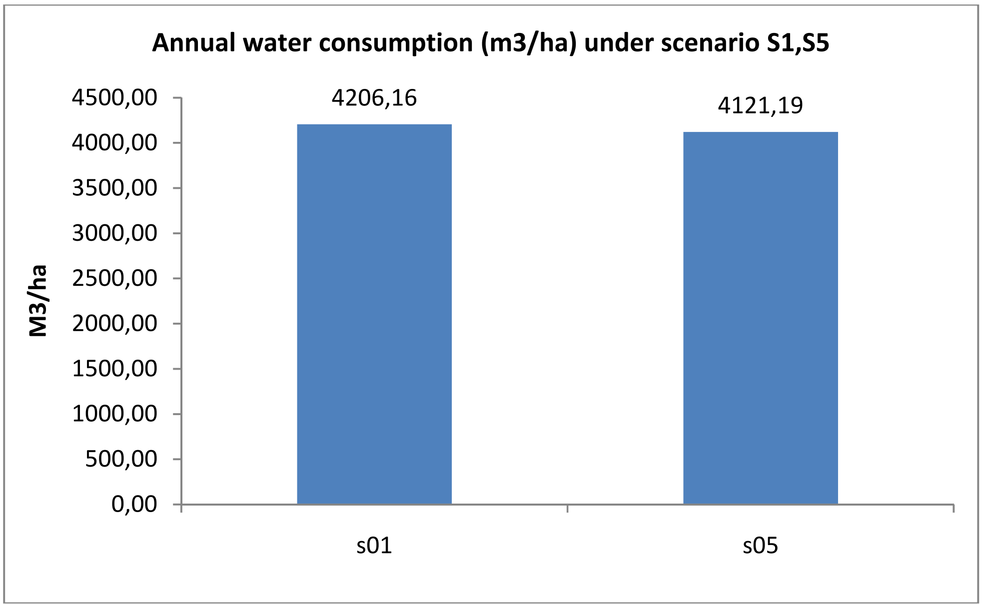


Figure 6. Annual Water Consumption (m^3/ha) Under Scenario S1:S5

Crop pattern allocation under scenario S1: S5

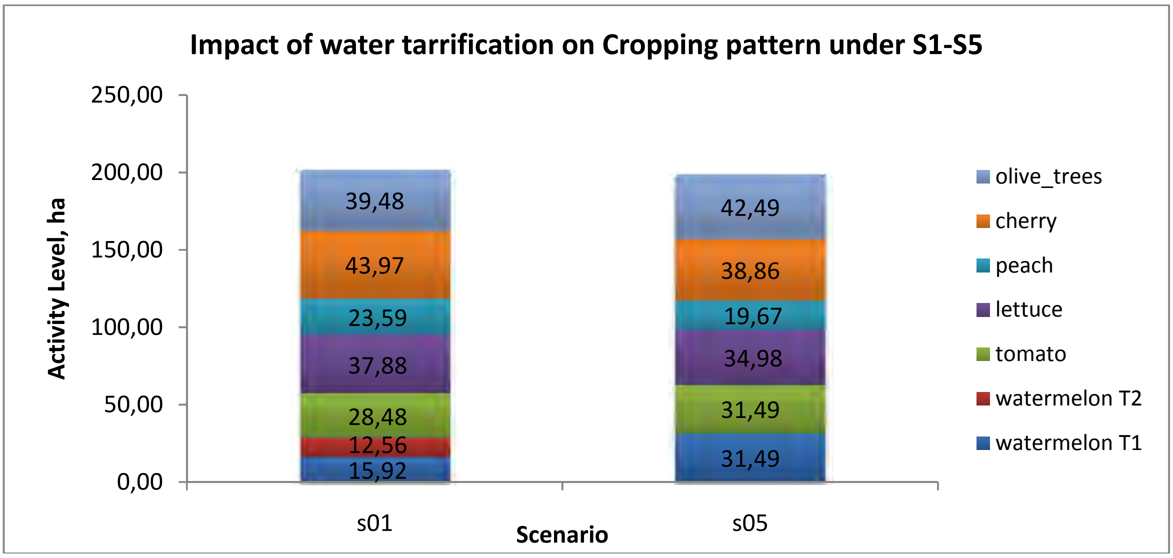


Figure 7. Impact of Water Tarriffication on Cropping Pattern Under S1 :S5

Profit under scenario S1: S5

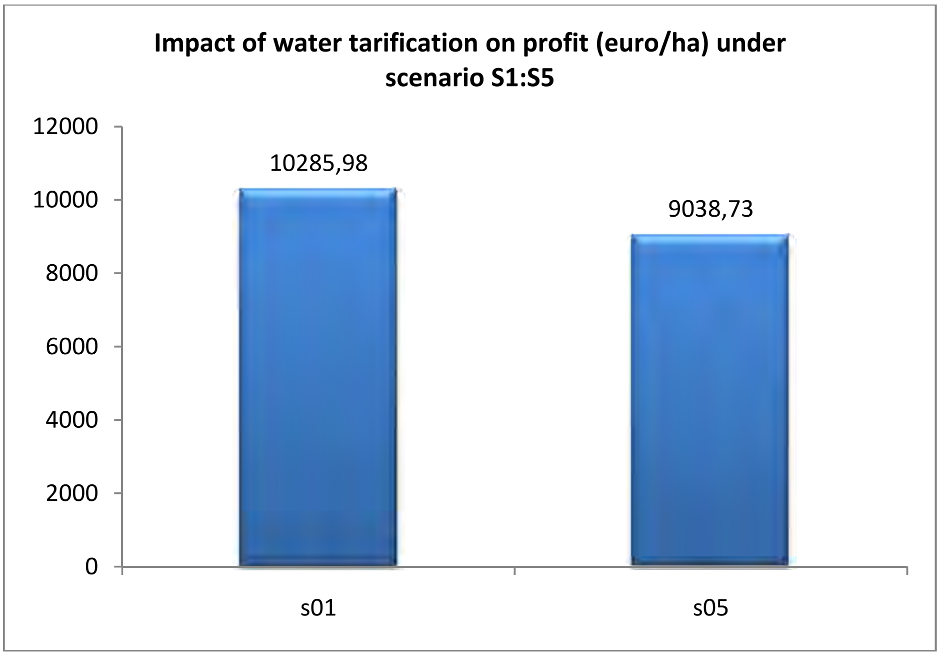


Figure 8. Profit (Euro/ha) Under Scenario S1: S5

As shown in Figure 8, the decrease of profit is due to high increase in water price between S1 and S5 because the farmer, who is risk averse, switch from the more profitable crops to the most stable crops and less water requirement.

Scenarios S5: S10

Water consumption under scenario S5: S10

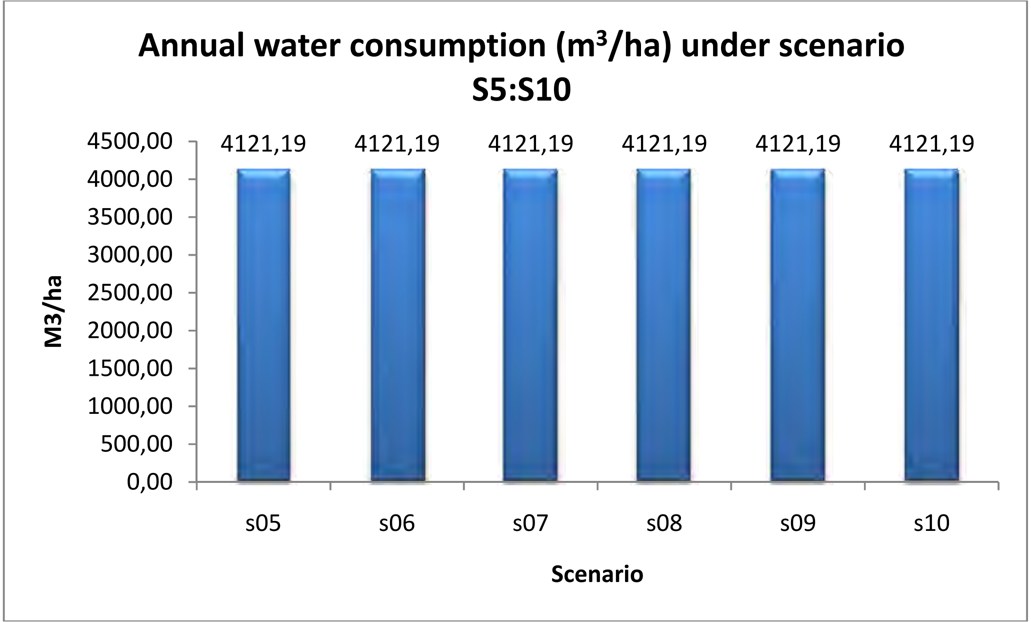


Figure 9. Annual Water Consumption (m^3/ha) Under Scenario S5:S10

Crop pattern allocation under scenario S5: S10

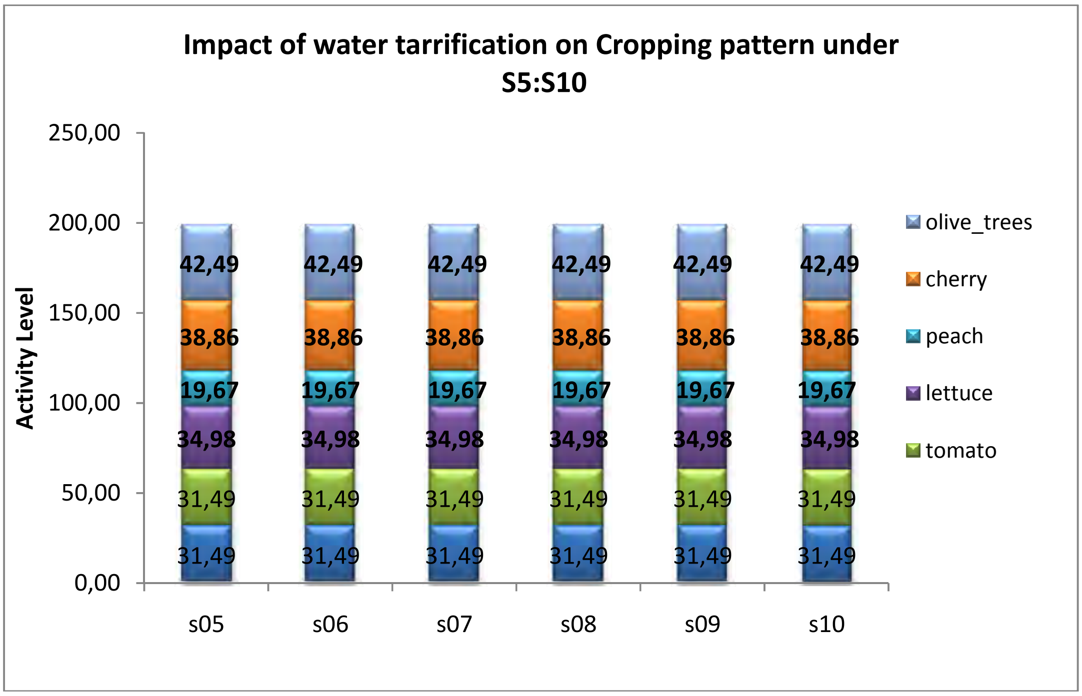


Figure 10. Impact of Water Tarriffication on Cropping Pattern Under S5:S10

Profit under scenario S5: S10

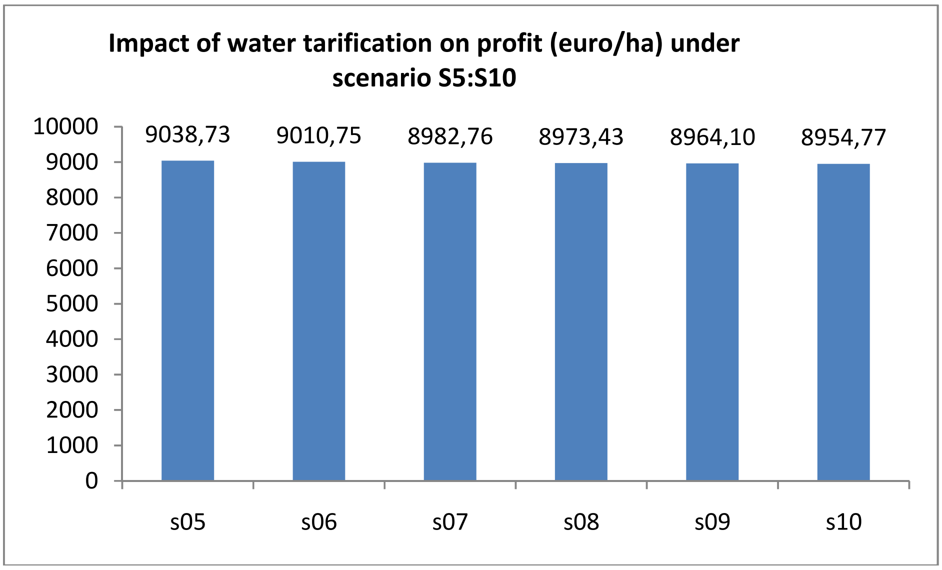


Figure 11. Profit (Euro/ha) Under Scenario S5: S10

Water consumption, farmer income and water agency profit under all scenarios

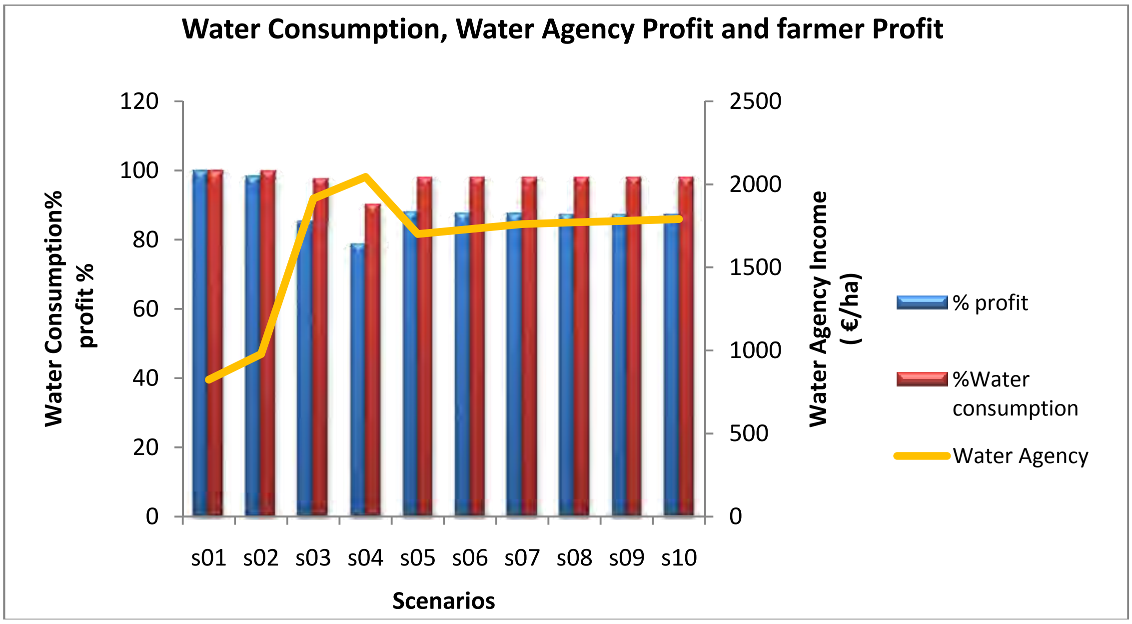


Figure 12. Water Consumption, Water Agency Profit and farmer Profit

The best scenario in term of profit is S1 and in term of saving water is S4. Actually, to select the best scenario a balance should be maintained between saving water, the farm profit and the water agency income which has to recover the maintenance cost (873 euro) to take the right decision.

According to Figure 12, we remark that the lowest level of water use with a reduction of around 10 % in comparison to S01 is observed for the scenarios S04, whereas the lowest water agency profit is recorded for the first scenario and the highest value is observed for the scenario s04. We observe also that the farm profit, the water use and the water agency profit remains the same for the scenarios S06_S10 and this is because the best solution converged to one scenario and increasing the water price for the second block will not any more affects the crops allocation and the solution tends to profit from the first block. Concerning the farm profit, the highest depletion is observed for the scenario S04 and this is because the water cost for the first block was high and the models' selection would punish the farmer in all cases. It is worth to mention that for the scenario S05, the farm profit depletion equal is less than in S02 with almost the same water consumption whereas the water agency profit is equal to 65872 €/year.

Conclusion

Water is critical for agriculture future development but can also become its major limiting factor. In the Mediterranean region, the risk of water shortage is generally at high level and the growth of demand. Gains in efficiency and productivity in water management and utilization to achieve adequate quality in appropriate quantity at the right time can reduce these risks and enable higher levels of sustainable growth.

After the realisation of the economic study, we have considered many possible constraints and by using an optimisation program (GAMS), we noticed the optimal cropping pattern giving the maximum profit to the farmer which is as follow: watermelon (14%), tomato (14%), lettuce (19%), olive trees (19%), peach (12%), cherry (22%). The profit of the project is around 1686865 €. The total GIR for the peak month of July is 1458.4 m^3/ha.

The total irrigable area is 153 ha while the irrigated area is about 124.52 ha, and the total cultivated area is 201.88 ha.

Based on NIR for the peak month of the dry year and the crop allocation, the specific continuous discharge is 0.54 l/s/ha. It was noticed that the scenario S04 has the lowest level of water use, with a reduction of almost 10 % in comparison to S01, as well as the lowest farm profit. Also, it was noticed that the farm profit, water use, and water agency profit are the same for scenarios S05 to S10, the reason is that the water price for the second block reached a level where the best choices are highly related to the first block. The farm profit is depleted the most in scenario S04, this is because the water price is too high for the first block, for which the model has no flexibility in selecting good scenarios for the farmer benefit. The farm profit depletion in scenario S05 is the lowest as well as the water use with 21.24 and 9.8 respectively compared to S01 and a water agency profit of 65872 € per year.

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