Contract no. **688320**

MADFORWATER

DevelopMent AnD application of integrated technological and management solutions FOR wasteWATER treatment and efficient reuse in agriculture tailored to the needs of Mediterranean African Countries

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CONTENT

LIST OF ACRONYMS

TWW	Treated Wastewater
MACs	Mediterranean African Countries
WUE	Water Use Efficiency
EGP	Egyptian pound
DH	Morocco Dirham
DT	Tunisian dinar
IAMB	Centro Internazionale di Alti Studi Agronomici Mediterranei- Istituto Agronomico Mediterraneo di Bari
UPM	Universidad Politecnica de Madrid

Abstract

The general objective of the MADFORWATER project is to develop an integrated set of technological and management instruments for the enhancement of wastewater treatment, treated wastewater reuse for irrigation and water efficiency in agriculture, with the final aim to reduce water vulnerability in selected basins in Egypt, Morocco and Tunisia.

In particular, Work Package 3 “Adaptation of technologies for efficient water management and treated wastewater reuse in agriculture” aims to investigate several technological and non-technological solutions to enhance the use of treated waste water as alternative source of water for the irrigation sector, and to adapt them to the local contexts of Egypt, Morocco and Tunisia.

Among the non–technological solutions, in Task 3.3 an agro physical (yield and water balance) - economic integrated model for land and water use optimization has been built and calibrated in the three case studies area of MADFORWATER, which are: the irrigated farming system in the Kafr-El- Sheikh Region in Egypt, the citrus farming system in Souss-Massa region in Morocco and the Nabeul Governorate in Tunisia.

This deliverable presents the integrated model by describing the objective function to be maximized and the numerous physical (water resources availability, land use and climate change), technological, socio-economic (production costs, labour, prices) and water policy (pricing, licensing) constraints to be considered. In addition, the main outputs to be estimated have been identified, and the needed data to run the model that have been collected and used to calibrate it for the three case studies areas are also presented.

1. Introduction

Among the technologies developed in WP3 of the MADFORWATER project, an integrated physical and economic model for land and water use optimization has been built, capable to integrate technological solutions and related economic and regulatory instruments into basin-scale strategies for water and land management in agriculture.

This Deliverable is organized as follows: in chapter 2, a brief literature overview about the use of integrated models in the agriculture sector is presented, then the structure – objectives function, constraints - of the integrated model is described as well as the input data needed and the expected output.

In chapter 3, case study areas (the irrigated farming system in the Kafr-El- Sheikh Region in Egypt, the citrus farming system in Souss-Massa region in Morocco and the Nabeul Governorate in Tunisia) are briefly introduced and the input data related to the current scenario are described. By considering all the relevant data and after the calibration process, the model identifies the optimal land and water allocation that better replicates the actual conditions in terms of cropping pattern, in the three case studies area. The identified solution, described in terms of cropping pattern, water and fertilizer consumption and farmer income, represents the 'baseline scenario'. In the last part of the MADFORWATER project, the baseline scenario will be compared with different 'future scenarios', characterized by different inputs in terms of water resources availability, water policies and irrigation technologies.

Conclusion and planned activities are finally presented in chapter 4.

2. Integrated physical and economic model for land and water use optimization (Task 3.3)

2.1. Model description: model structure, input needed, output expected

2.1.1. Introduction

Integrated biophysical (agronomic and hydrologic) and economic models have long been used in order to analyse the impact of certain policies and environmental trends on water resources and agriculture. The main aim of these models is the integration of technical, economic, environmental, social and institutional aspects into a coherent framework of Integrated Water Resources Management (IWRM). In this manner, combined agro-hydrological and economic models are able to bridge the traditional lack of integration between models of biophysical and agricultural systems with the human environment with which they interact.

The use of agro-hydrologic and economic models started in the early 1960s and 1970s in some semi-arid regions, such as Israel or the southwest of the US (Harou et al. 2009). Since then, numerous applications have been developed in order to analyze issues such as the inter-sectoral allocation of water (Brown et al., 2006; Reynaud and Leenhardt, 2008), expansion of water supply infrastructures (Rosenberg et al., 2008), conjunctive use of groundwater and surface water (Burt, 1964; Maneta et al. 2009), transboundary water management (Fisher et al., 2002), water pricing and policy (Blanco-Gutierrez et al. 2013; Varela-Ortega et al. 2011), land use management (Bateman et al., 2006), climate change (Booker, 1995; Esteve et al. 2015), and water conflicts (Cetinkaya et al., 2008). Please, refer to Harou et al. 2009 for a comprehensive review of applications.

The integration of the agro-hydrologic and economic models creates a challenge, mainly due to the differences in scale (temporal and spatial) and modeling resolution techniques (McKinney et al., 1999; Brouwer and Hofkes, 2008; Cai, 2008).

However, in spite of these limitations, combined agro-hydrological and economic models have proved very successful in providing accurate estimates on how to optimize the allocation of water resources among competing uses in order to obtain the maximum economic value of water, subject to the biophysical constraints (Varela-Ortega et al. 2011).

Different classifications of hydro-economic models are reported based on how agro-hydrologic and economics models are integrated. Braat and Lierop (1987) distinguish between 'holistic' hydro-economic models and 'departmental' or 'modular' hydro-economic models. In holistic models, all the components of the system are tightly connected to a consistent model. They permit a fluid transfer of information between the economic and hydrology modules, but need to be simplified in order to avoid complex and unfeasible model resolutions. On the other hand, compartmental models are organized into independent modules. Usually, the output data from one of the modules is entered as input data into the other module. The main

problem is in providing communication and data exchange between the different subsystems. Although models of the modular type are increasingly becoming more spread (Harou et al. 2009), in practice most hydro-economic models are based on a holistic approach. Given that in this study we do not rely on the necessary data to develop a modular model, our work will be based on a model of the 'holistic' type.
Holistic models include in one single model an objective function subject to several constraints. The objective function is intended to reflect the social or economic goal to be achieved (e.g. maximising revenues or minimizing costs), while the set of constraints aim at reflecting biophysical or operational limitations on flows and water and agronomic capacities (Jenkins et al., 2004; Medellín-Azuara et al., 2009). In empirical terms, this type of models are usually developed by means of software packages. Among them, the Generic Algebraic Modelling System (GAMS) is among the most commonly used in order to develop programming models (Brooke et al., 1996). Given that it operates non-linear solvers and allows for simulation and calibration while integrating traditional datasheets, it constitutes a powerful tool of optimization suitable for the estimation of complex integrated biophysical and economics models (Graveline, 2016).
Hydro-economic models aim to capture the complexity of interactions between water management systems and the economy. By integrating hydrology, water management, environmental conditions and socio-economic aspects of water resources management in a coherent modelling framework (Harou et al., 2009), they attempt to find a suitable combination out of many feasible combinations of resources and their allocations, with maximizing the benefit or minimizing the cost subject to given constraints (Amir and Fisher, 1999; Valunjkar, 2007).

Optimization models related to water allocation and management problems can have multi objective functions and purposes i.e. to maximize the satisfaction of water demand for different sectors, maximize the yearly profit with less water consumption, minimize the cost of wastewater treatment, minimize yield losses with maximum total net income, minimize the salt concentration in the water system and irrigated land, and minimize the total operational cost of the system (Graveline, 2016). Buwalda and Smith (1988) presented a mathematical model for predicting fertilizers requirements for a specific crop (kiwi), through the prediction of fruit yield, annual growth and hence nutrient uptake for different levels of production. George *et al.* (2011) presented an integrated modelling framework for water resources planning and management. This framework can be used to analyze alternative policy scenarios for water allocation and use. The power of the model resides in the fact that it allows policymakers to consider physical and economic dimensions of water distribution, and considers water to be an economic good.

In order to identify the optimal allocation of treated wastewater among the different irrigated crops under different water scenarios, in the MADFORWATER project an integrated physical and economic model has been developed, able to simulate the very complex process of farmers' decision-making. In particular, a non-linear, stochastic, single-year static mathematical programming model, named WWT_2016, has been used and applied at farming system scale, defined as "a population of individual farm systems that have broadly similar resource bases, enterprise patterns, household livelihoods and constraints, and for which similar development strategies and interventions would be appropriate " (World Bank, 2008).
For each possible scenario, the proposed model allows to identify optimal farmers' choices related to cropping patterns and agro-techniques. The model also allows to estimate the effects of such choices on water consumption, water distribution among crops, land use changes and farmer income.

2.1.2.Model structure

The model chosen to optimize land and water use is an holistic agro-hydro-economic model written in GAMS (General Algebraic Modeling System) language. It is based on a mathematical programming of a farm model widely applied in the economic-agricultural analysis and in the irrigated agriculture analysis. Due to the lack of hydrologic data, the economic and agronomic parts of the model will be quite detailed in comparison to the hydrologic part, that will be strongly stylized and restricted to the use of water at farm level.
The WWT_2016 model maximizes farmers' utility subject to a set of resources (land and water), agronomic and economic constraints, and offers the possibility to simulate and analyze different scenarios. It aims at

the identification of the optimal cropping pattern of the study area and the calculation of the relative water demand .

The objective function of the model maximizes farmers' utility defined as the expected revenue minus its standard deviation due to risk averse towards price/yield variation.

$$MaxU = Z_p - \phi * \sigma(Z_p) \qquad (1)$$

Where:

U: Utility to be maximised

Z_p: Average (expected) farm revenue (€)

ϕ: Risk aversion coefficient

σ: Standard deviation of the expected income

p: farming type/position

The farm revenue per farm type, Z_p, is defined as the difference between the value of production and variable and fixed costs, except for the cost for the irrigation and the cost of fertilizers. Where it is relevant, as in the Egyptian case, also a specific cost for energy is included .

It is given by the following equation:

$$Z_p = \sum_{c,i,q,} Pr_c * Y_{c,q} * X_{c,iq,p} - Vcost_c * X_{c,i,q,p}$$
$$- Fcost - (Fertreq_{c,q,f} * Fertpr_f) - PrWat_q * QWat_{q,p} - TarWat_q * irrland_q - EnCon_p * DrWat_p \qquad (2)$$

where

c: crop:s

q: type of water

i: irrigation technique

f: type of fertilizer

$X_{c, i, q, p}$: the crop activity level (ha)

Pr_c: average crop price (€/ql)

$Y_{c,q,t}$: crop yield (ql/ha)

$Vcost_{c,t}$: variable costs (€/ha)

Fcost: fixed costs (€)

$Fertreq_{c,q,f}$: amount of fertilizer (kg)

$Fertpr_f$: fertilizer price ((€/kg)

$PrWat_q$: water tariff per m3 or per type of water

$QWAT_{q,p}$: annual used water (m^3) per type of water

$TarWat_q$: water tariff per ha and per type of water

$Irrland_{q,p}$: irrigated land (ha) by type of water

DrWat : drained water

EnCon: energy required (KwH/m^3)

The value of production refers to the product sold for final consumption or processed. Variable costs are given by the specific cropping expenses including costs for temporary labour and mechanization, seeds, fertilizers and pesticides, hire charges, fuel, insurance, electricity, etc.).

Costs of irrigation water are not included in the variable costs since they are an endogenous variable. They have been defined in two ways: i) as the volume of water used multiplied by the price of water per cubic meter and/or ii) as a fixed water tariff to be paid for each hectare of irrigable land or for total agricultural land.

Risk is present in all management decisions of agricultural systems, as a result of price, yield and resource uncertainty and the risk aversion coefficient (ϕ) measures the degree of risk aversion of the agent. This coefficient is related to the farmer and its value is often ranging from 0 to 1.65. If σ: =0 implies farmer is risk neutral, as the risk aversion coefficient increases the diversification of cropping pattern increases.
σ , standard deviation of farm income (€) is given by the following:

$$\sigma(Z) = \sqrt{\sum_{k} \frac{(Z - ZK_{sn,sm})^2}{N}} \tag{3}$$

where
ZK :the random income (€)
N : number of states of market for price/yield variability (N=50)
sn : states of nature
sm: state of market

The random income Zk_k is calculated using the same equation applied for calculating the expected income Z; the unique difference was that the average price/yield are replaced, by the random price/yield over state of nature (k) where price_$k_{c,sm}$ and yield_$k_{c,sn}$ are vectors of independent random numbers normally distributed (i.e. they are calculated using a normal distribution function based on the average and the standard deviation of price and yield).

Water and fertiliser use, WATused and FERTused, are defined by specific equations as follows:

$$WATused_{q,p} = \sum_{c,i} \left(\frac{NIR_c}{htech_{i,p}} \right) \cdot X_{c,i,q,p} \tag{4}$$

$$FERTused_{f,c,q} = \sum_{c,i,p} fertreq_{f,c,q} * X_{c,i,q,p} \tag{5}$$

Where:

- **NIR:** net irrigation requirements of crops(m3/ha)
- **htech**: technical efficiency of irrigation system
- **fertreq**: amount of fertiliser for each crop(Kg/ha)

Farmers' decisions are clearly constrained by numerous factors such as quantity and quality of input, mainly land and water, water policies, and are made subject to an often considerable uncertainty (yields, prices, costs, resources). The main constraints adopted by the model include:

Agricultural **land constraint:** it imposes that the total land requirement for cropping cannot exceed agricultural land availability.

$$\sum_{c,i,t,q} \left(Luse_{c,m} \times X_{c,i,q,p} \right) \leq Land\ (p) \tag{6}$$

Where
L use$_{c,m}$: Land occupation coefficient for each crop per month;
m: Month
Land$_p$: Agricultural land availability in the different field section (ha).

The total land constraint imposes that the set of crops grown, including uncultivated land and no-tillage, doesn't exceed the available land; it is defined on monthly basis through setting up a production schedule that specifies the land use per crop.

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The **water constraint** imposes that the sum of water requirement for irrigated crops over the year cannot exceed the yearly water availability:

$$WATused_{q,p} \leq WATav_{q,p} \tag{7}$$

Where:
$WATav_{q,p}$: Water availability(m3).

2.1.3. Input needed

Farmers' decisions, in terms of cropping pattern and irrigation strategies, take into account several data: agronomic data - such as crop water requirements, irrigation scheduling, fertiliser crop requirement, crop yields -; irrigation system data; market data such as price of input (energy, water, seed, fertiliser, etc) and crop price and cost of cultivation. Further, climatic conditions and soil properties define the set of all the crops that can be cultivated in the area while technical and agronomic considerations allow to define the possible combinations among crops, irrigation methods and water quality. All these data have been collected from the case studies areas and described in the following paragraphs in order to build the model and to calibrate it against the current situation.

2.1.4. Calibration of the model, expected output and simulated scenarios

In order to obtain a model able to represent the concrete decision process, so as to make it usable for policy analysis, its simulation capacity has to be tested and model calibration is needed. The calibration consists in feeding the model with input data of the actual situation and comparing one or more simulated outputs with the observed one. There are no formal tests of calibration for mathematical programming models (Hazell and Norton 1986), but measures of goodness of fit can be used to check how closely the model calibrates the empirical levels of cropped areas, production, prices and/or levels of input use. In our case, cropping pattern, that is the main decision variable and is easily observable in the field, has been used to compare the actual and the simulated scenarios. The underlying assumption of this choice is that the current cropping pattern is likely to be the optimal one for a given farming system and the current conditions in terms of water availability, irrigation technologies and water policies. Both the risk aversion coefficient (ø) and the coefficient of price elasticity (ε) [1] can be used to calibrate the model. In this work, their values have been changed inside specific ranges until the attainment of an optimal situation where the percent absolute deviation (PAD) between observed and predicted cropping pattern is not significant.

All the collected data have been used as input in the integrated model and to calibrate it towards the current situation. The identified optimal solution, considered as 'baseline scenario', will be described in terms of:

- Land use, cropping pattern and production
- Water use: Consumption from different sources, Water productivity (€/m3), Water marginal value
- Fertililser use
- Drained water
- System performance index, defined as the ratio between water supplied and water demand
- Socio-economic variables (Farm income, Labor use, Public cost)

[1] A coefficient of price elasticity (ε) that measures the reaction of the crop activity level to a unitary change of the price of products can be introduced in the model to properly calibrate it when price's variation strongly affects the behavior of farmers. Prices of products thus become an endogenous parameter given by:
$Pr_c = Pr_{ext} - Pr_{ext} * \varepsilon * diff_c$,
where **Pr_{ext}** is the price of crops in the market**,** **IniArea** refers to the initial area for each crop (ha) and **diff**: $\frac{\sum_{c,q,} X_{c,i,q,p} * Y_{c,q} - \sum_{c,q} IniArea_c * Y_{c,q}}{\sum_{c,q} IniArea_c * Y_{c,q}}$

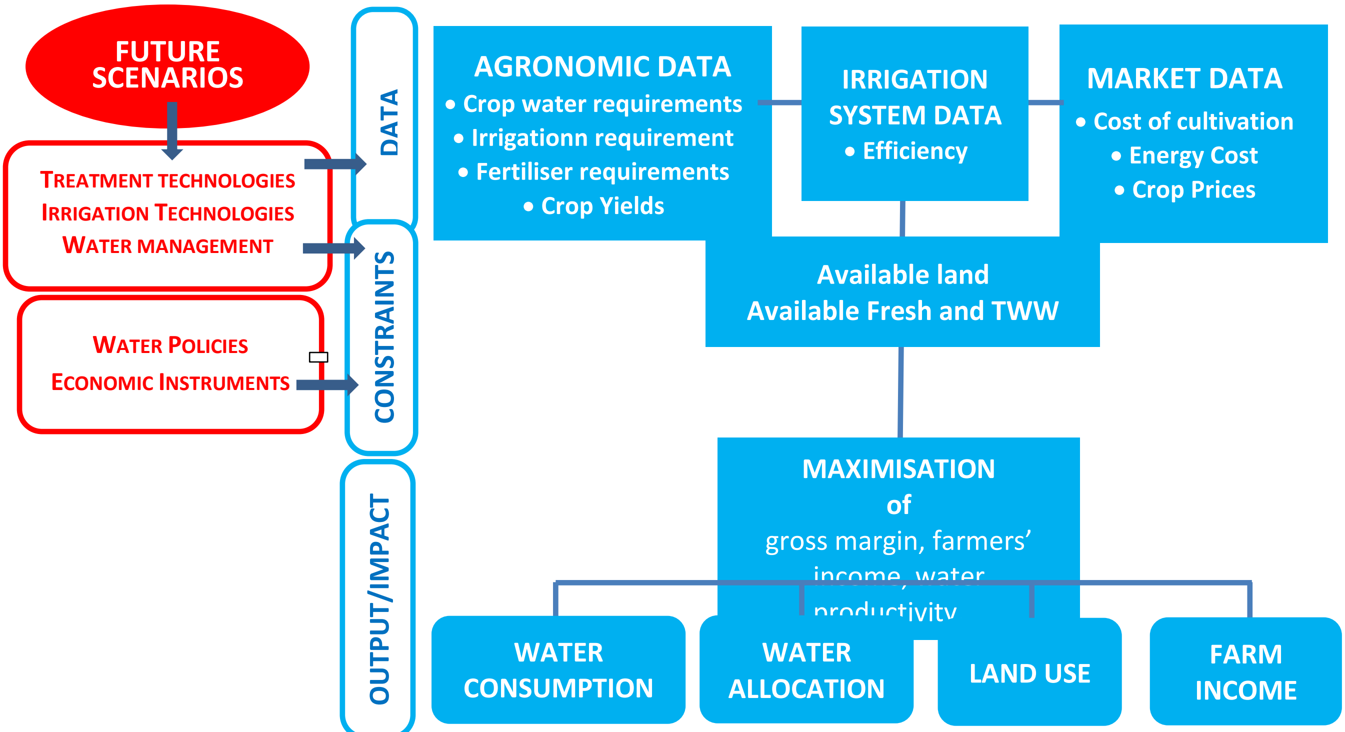


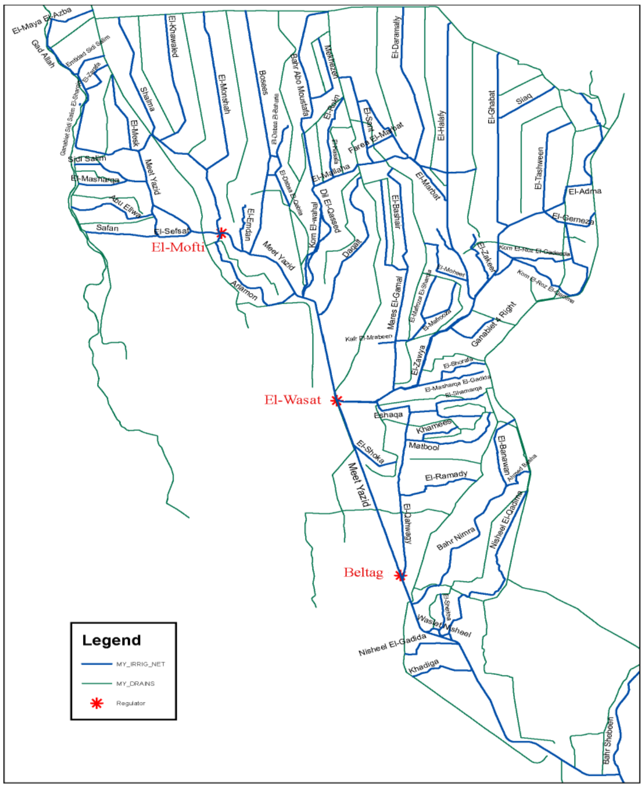
Fig. 1 General Framework of the optimization model

3. Implementation of the model in the different case studies

3.1.1. Egypt: the irrigated farming system in the Kafr-El- Sheikh Region

The Egyptian case study refers to the irrigated farming system in Kafr-El- Sheikh region in Northern Egypt with a total population of about 3 million inhabitants. El Wasat command area, located in the northern part of Kafr-El -Sheikh and supplied from Mit Yazeed main canal, was selected for the study. Mit Yazeed canal is 63 km long and feeds 19 branches for a total area of 88,200 ha.
The model was applied on Daqalt branch canal, which is an earthen branch canal 11.42 km long, serving a total of 2,344 ha, and located at km 41 of Mit Yazeed on the right side.
Property and responsibility for operation and maintenance of canal and sub – branch canal are public.
The public sub-branch canal delivers water to private channels called "Mesqas". Each Mesqa serves an area of about 20 to 83 hectares. Mesqas feed farm ditches called "Marwas". Each Marwa serves up to 8.3 hectares. Operation and maintenance of Mesqas and Marwas are done by the water users and/or Water Users Associations.

Fig. 2 Localisation of Kafr-El- Sheikh, Egypt case study



The Irrigation Improvement Project (IIP) enabled the operation of Daqalt canal on a continuous flow through automatic downstream control gates with aim to guarantee greater flexibility in the timing of irrigation applications, as compared to the rigid rotation schedules of the traditional system, in order to meet crop water requirements. The flow in the branch canal is determined by regulation of the discharge at the head of the canal and accounts for the area served by the canal and the cropping pattern. The former rotational system resulted in inefficient application of irrigation water, water losses, and an inequitable water distribution but with IIP, water delivery services to the farmers improved and the flexibility of the water management system increased. However this improvement program did not solve the problem of inequity of water availability between head and tail areas along the branch canals.
In this study, six sample tertiary canals were selected to represent the head, middle and tail of the Daqalt sub-branch canal (Abdelmoneim, 2016).
During a fieldwork carried from February to April 2016, several sites and institutions were visited such as the Ministry of Agriculture and land reclamation, the Ministry of Water Resources and Irrigation (MWRI) and the National Water Research Centre. The different data sources were merged in the best possible way to ensure

reliability and compatibility, even though the difficulty to unify data from different sources still remain a challenge. Where necessary, data have be updated in a second shorter field work dine during December 2018.

Input data

- *Land and crop data*

According to the data provided by the National Water Research Centre, in the six selected Mesqas 348 farmers cultivate around 185 ha where 75 ha are in head position, 50 ha in the middle and 59 ha in the tail of the canal. As in all the North Delta, two seasons are differentiated in the selected Mesqas: summer season (mid of March-mid of September) and winter season (October-February). The main summer crops are rice, cotton and maize. In the winter season, alfalfa, wheat and sugar beet are the dominant crops. Farmers usually divide their land holdings into thirds, rotating between cereals and break crops. Popular winter-summer rotations include the following: wheat followed by rice, and wheat or alfalfa followed by maize (FAO, 2015).

Tab. 1 Cropping pattern in the selected Mesqa, Egypt case study

			WINTER				SUMMER		
Canal	Position	Meska Code	Alfalfa	Wheat	Sugar Beet	Other	Cotton	Rice	Maize
Daqalt	H	MD01	45.81%	38.87%		15.32%	41.64%	55.52%	2.83%
		MD02	37.09%	56.62%		6.29%	42.52%	42.52%	14.96%
	M	MD03	24.37%	33.41%		42.22%	29.63%	59.26%	11.11%
		MD04	40.46%	30.51%		29.12%	33.36%	64.87%	1.85%
	T	MD05	43.99%	30.72%	4.42%	20.87%	27.21%	54.42%	18.37%
		MD06	17.04%	37.78%		45.19%	23.85%	69.93%	6.22%

Source: NWRC

Crops yields' data have been collected and used to obtained the average yield and its variability.

Tab. 2 Crop Yields, Egypt case study

ton/ha	2007	2008	2009	2010	2011	2012	2007-'12	2013
Cotton	16.2	12.9	14.3	12.5	16.8	12.6	14.2	11.6
Maize	8.7	8.2	8.2	9.0	8.9	8.7	8.6	8.7
Rice	10.0	9.8	9.4	9.2	9.4	9.1	9.5	8.9
Wheat	6.7	6.4	6.4	6.4	6.4	6.4	6.4	6.3
Alfalfa	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Vegetables	n.a	34.9	34.8	32.9	n.a.	32.5	33.8	34.3
Sugarbeet	50.8	49.3	48.7	47.5	47.6	48.0	48.6	47.8

Source: Agricultural Statics in Kafr El Sheikh, Economic Affairs Sector, MALR, various years

Finally, cost of production and domestic prices data have been collected.

Tab. 3 Cost of production, Egypt case study

Tab. 4 Prices of products, Egypt case study

Direct costs, Euro/ha	
Cotton	532
Maize	467
Rice	489
Wheat	419
Alfalfa	n.a.
Vegetables (Potatoes)	1 003
Sugarbeet	929

Source: CFC, 2016

Price, Euro/ha	
Cotton	971
Maize	157
Rice	240
Wheat	209
Alfalfa	512
Vegetables (Potatoes)	209
Sugarbeet*	34

Source: MALR

- *Water data*

Irrigation permits double and even triple cropping on most of the arable land and enabled farmers to switch the crop rotation from a three- to a two-year cycle. Irrigation method applied for all crops except for rice, is the traditional surface irrigation with an irrigation efficiency that can be estimated around 60%. For the paddy system used to cultivate rice, the irrigation efficiency is 50%. Available water per season and per position of the Mesqa in the sub-branch canal highlights relevant differences.

Tab. 5 Available water per season and per position of the Mesqa,, Egypt case study

Water Supply (m3)	Summer	Winter	Total
Head	1 052 770	390 050	1 442 820
Middle	721 053	230 405	951 458
Tail	675 714	218 502	894 216
Total	2 449 537	838 957	3 288 494

Source: our elaboration on NWRC

Tab. 6 Net Irrigation requirement per crop, Egypt case study

WINTER								SUMMER					
Alfalfa		Wheat		Sugarbeet		Vegetables		Cotton		Rice		Maize	
Date	mm/ha	Date	mm/ha	Date	mm/ha	Date	mm/ha	Date	mm/ha	Date	mm/ha	Date	mm/ha
15/1	120.3	15/1	45.3	15/10	40.3	15/10	40.8	15/03	56.0	15/05	60.3	29/5	54.6
30/1	15.5	30/1	29.3	30/10	20.5	30/10	36.3	30/03	36.0	30/5	71.4	13/06	42.9
15/1	20.4	15/1	27.3	15/11	20.2	14/11	36.0	14/04	44.9	14/06	84.7	28/06	54.5
30/1	22.0	30/1	27.4	30/11	22.1	29/11	36.5	29/04	59.8	29/06	96.2	13/07	75.2
14/01	21.8	14/1	28.8	15/12	24.3	14/12	27.2	14/05	80.1	14/07	86.0	28/07l	93.3
29/01	23.3	29/01	32.0	30/12	26.5	29/12	25.0	29/05	100.0	29/07l	84.8	12/08	89.3
13/02	27.5	13/02	38.5	14/01	29.9	13/01	24.4	13/06	98.5	13/08	82.6	27/08	85.6
28/02	32.2	28/02	46.1	29/01	29.4	28/01	25.1	28/06	101.9	28/08	79.7	11/09	80.5
15/03	39.0	15/03	47.8	13/02	34.7	12/02	28.2	13/07	99.3	12/09	69.6	26/09	71.1
30/03	45.0	30/03	55.2	28/02	40.8			28/07	97.0	27/09	48.9	01/10	
14/04	45.9	14/04	64.3	15/03	48.8			12/08	88.9	29/09			
29/04	36.7	29/04	60.6	30/03	55.0			27/08	73.7				
1/05		14/05	36.9	14/04	57.8			11/09	59.3				
				29/04	54.1			26/09	43.7				

Source: our elaboration on Abdelmoneim data, 2016

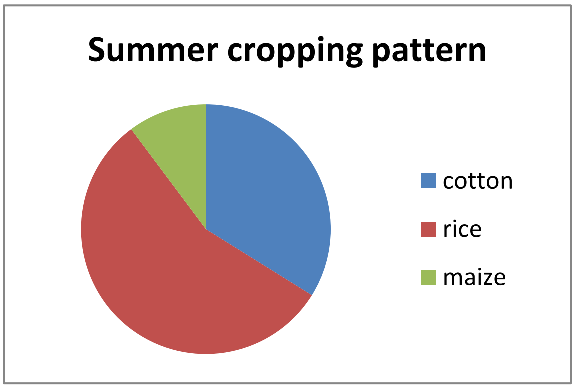
Efficiency changes along the sub-branch canal according to the position of the mesqa as given in the following table

Tab. 7 System irrigation efficiency, Egypt case study

Efficiency	
Paddy.Head	55%
Paddy.Middle	50%
Paddy. Tail	45%
Furrow.Head	65%
Furrow.Middle	60%
Furrow. Tail	55%

Model output: the baseline scenario

The simulation results for the baseline scenario show the same **cropping pattern** of the actual situation, where the total area of 185 ha is divided as follows:



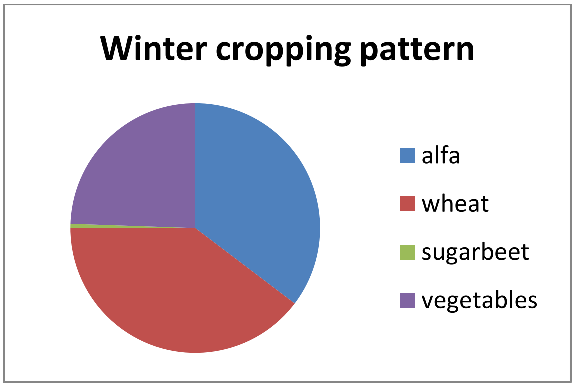


Fig. 3 Cropping pattern in summer and winter season, Egypt case study

The total and per hectare yearly water demand (corresponding to the gross irrigation requirements) predicted by the model in the three different portions of the canal is given in Tables 8 and 9, together with the amount of **drained water**. In the WWT_2016 model the volume of drained water refers to the amount of water supplied to farmers in excess of the net requirement of the plants, released in the drainage system and reused.

Tab. 8 Water demand, Egypt case study

Water used (m^3)	
Total	4 226 196
Per ha	22 851
Head_ha	21 717
Middle_ha	22 529
Tail_ha	24 560

Tab. 9 Drained water, Egypt case study

Drained Water (m^3)	
Total	90 509
Per ha	4 892
Head_ha	5 859
Middle_ha	6 095
Tail_ha	2 641

The capacity of the system to satisfy the demand of water of the farmers under the current conditions can be estimated by calculating the **System performance index** that in the baseline is equal to :

Tab. 10 System performance index, Egypt case study

System performance index	
Total	0.78
Head	0.89
Middle	0.83
Tail	0.61

Finally, **farmer's income** is also estimated by the model and it is equal to an average amount of 3 630 Euro/ ha/y; it is also important to mention that the **cost of the energy** paid by the farmers to pump the water currently represents about 1/3 of the total variable cost of cultivation.

3.1.2. Morocco: the citrus farming system in Souss-massa region

- *Study area description and data collection*

Sous-Massa is one of the twelve regions of Morocco. It covers an area of 51,642 km² and it has a population of 2,676,847 as of the 2014 Moroccan census. The capital of the region is Agadir. Agriculture is the most important economic activity in the region; Souss Massa is in fact considered a leading region in the production of several fruit and vegetable crops such as tomato and citrus.

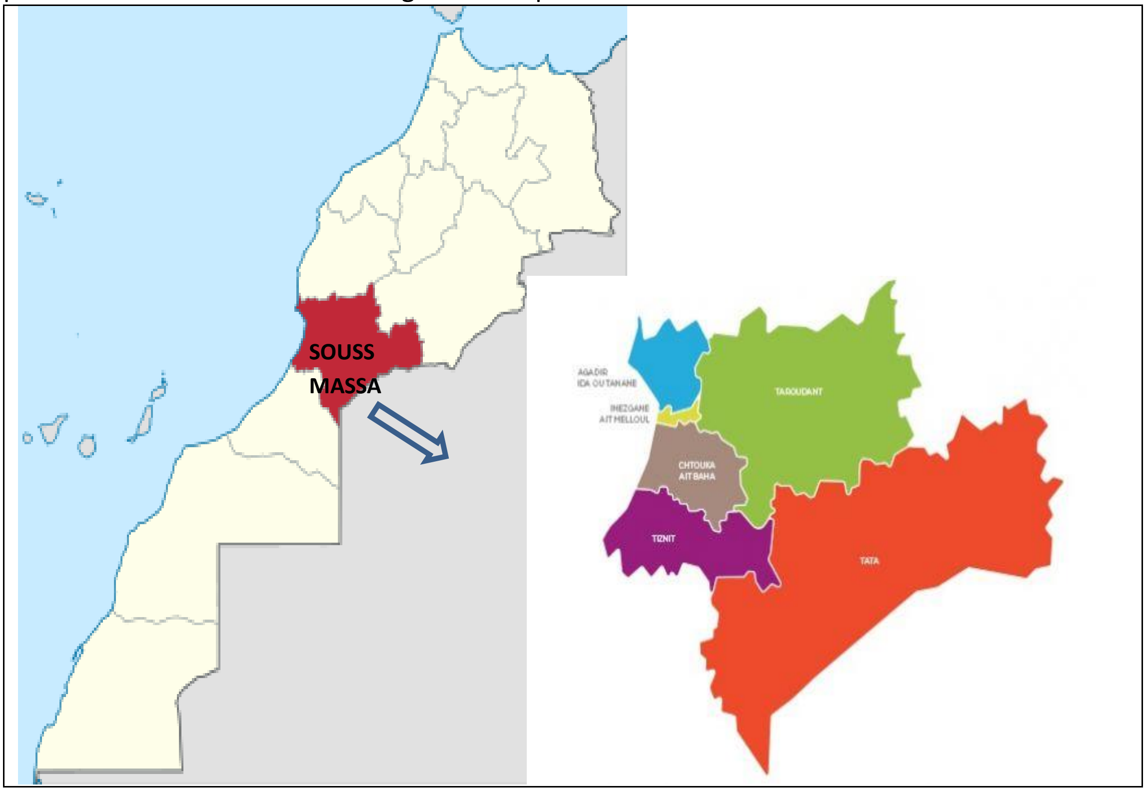


Fig. 4 **Localisation of Souss Massa region, Morocco case study**

Citrus production occupies an area of 40343 ha, which represents one third of the total citrus area in Morocco. 30 % of farms , which represent 99 % of the total area) of the region, have an average farm area of more than five hectares (Abaouz, 2013. Their prime objective is the economic profit; this objective determines the management strategies of their activity.

To achieve the maximum profit, farmers choose carefully the varieties and the rootstocks to be planted. The choice of the variety is based on its productivity, response to stress, resistance to certain diseases and market demand.

The most used varieties in the region are Clementine (31%), Maroc late (22%), Navel, (12%), Nour (12%), Nadorcott, Ortanique and Salustiana cover the remaining part.

Farmers rely on external labor, permanent and seasonal, which is generally paid every two weeks.

Through the years, farmers in the study region have developed ways to organize their activities, and so they have created cooperatives, each of which combines a number of farmers. This form of organization allows farmers many advantages, such as technical consultancy, assistance with irrigation, fertilization and phytosanitary treatments, and commercialization of the produce to the international market.
Once collected, the product is packaged and sent to the markets of destination according to the demand. Cooperatives in the region deal mostly with the European Union, Russia, China and the United States of America. These markets require some specifications and directives (such as Global Gap, BRC …) which impose certain hygiene and sanitation instructions through the whole production chain (nurseries, farms, transport means and packaging factories). Cooperatives assist farmers also in the implementation of these directives, and periodic audits are carried out to insure the respect of these instructions.
In the framework of this project, the citrus farms system in Souss Massa region was chosen as the first case study in Morocco where to apply the integrated model: relevant data were collected for two months (April, May 2018) and the Safe Irrigation Management (SIM) model was calibrated in order to: i) predict irrigation schedule and nutrient uptake, as well as to estimate yield losses; ii) assess soil quality in terms of soil salinity under treated wastewater irrigation and; iii) identify a proper irrigation and fertilisation strategy based on higher water use efficiency and lowest possible yield losses.

Input data

- *Water data*

Due to the exhaustion of local aquifers, farmers rely on surface water for a part of their irrigation needs. Water is delivered from nearby dams, for an average price of 0.15 Euro/m^3. This tariff does not vary according to the volume of water consumed, and there is no fixed tariff applied for each unit of cultivated land. Each farm is equipped with a storage basin, in order to store water coming from the dam to be used when needed. In order to manage the irrigation and fertilization procedures, farmers are requested, by the cooperative, to do soil and water analysis at the beginning of the year, in addition to leaf analysis during the growing cycle. In addition to that, and on a daily basis, farmers receive text messages on their mobile phones, with climate parameters (ETo, humidity, temperature) to help them determine the amount of water to be applied for the irrigation event. To maximize water efficiency, all farms are equipped with drip irrigation systems. The model however defines a set of irrigation techniques (surface, sprinkler and drip irrigation). The efficiency for drip irrigation systems is set to 95%.
The net irrigation requirements have been calculated from the data collected from the study area for the five citrus chosen varieties. NIR are supposed not to change among the fresh and treated wastewater.

Tab. 11: Annual water requirements (mm) for selected varieties on a fortnightly basis, Morocco case study

Crop	jan1	jan2	feb1	feb2	mar1	mar2	apr1	apr2	may1	may2	jun1	jun2
Clementine	14	14	24	21	24	26	28	28	32	34	33	48
Navel	14	15	23	20	23	25	31	31	31	33	32	46
Maroc Late	14	15	26	23	26	28	35	35	35	38	37	53
Nour	13	14	24	21	24	26	28	28	32	34	29	42
Nadorcott	27	28	9	7	22	35	40	45	52	63	65	51
	jul1	**jul2**	**aug1**	**aug2**	**sep1**	**sep2**	**oct1**	**oct2**	**nov1**	**nov2**	**dec1**	**dec2**
Clementine	37	40	32	34	16	16	13	14	14	14	9	13
Navel	46	49	41	43	23	23	19	22	21	21	8	12
Maroc Late	53	56	47	50	24	24	19	22	21	21	8	13
Nour	33	35	28	30	16	16	13	15	14	14	8	13
Nadorcott	60	76	74	80	76	74	49	45	35	17	4	18

In the area, the wastewater is treated in the treatment plant to a tertiary level using Ultra Violet rays, which requires the use of technology and energy, and thus, the treatment cost is higher, equal to 0.23 Euro/m3.

- *Crop data*

Yields per variety, during the period of 2016/2017 for the normal irrigation -100 % (Crop evapotranspiration) ETc -, prices at which crops are sold in the international market, along with their standard deviations and variable costs of production - including external labor for required during the production cycle to perform farming tasks, inputs (seeds, treatments) and machinery and excluding fertilizer and water that have been considered as separated – have been collected from the cooperative in charge for product commercialization, official websites of authorities responsible for exports (EACCE) and the FAO statistics website (FAOSTAT).
Tables below show the yields per variety for the study region, during the period 2016/2017 for the normal irrigation (100 % ETc) and the prices at which crops are sold in the international market, along with their standard deviations. These data were collected from the cooperative in charge for the product commercialization, official websites of authorities responsible for exports (EACCE) and the FAO statistics website (FAOSTAT).

Tab. 12: Yields for selected varieties, Morocco case study

Variety	Yield (t/ha)
Clementine	30
Navel	40
Maroc Late	45
Nour	40
Nadorcott	65

Tab. 13 Product price for selected varieties, Morocco case study

Variety	Price (Euro/t)
Clementine	700
Navel	950
Maroc Late	890
Nour	760
Nadorcott	1100

Tab. 14 Production variable costs, Morocco case study

Variety	Variable costs (Euro/ha)
Clementine	4 800
Navel	5 000
Maroc Late	5 000
Nour	4 900
Nadorcott	4 740

The major part of production variable costs is represented by the transport and collection of fruits (26%).
Both water and fertilizers costs have been excluded from the variable costs since they are the parameters that will allow the comparison between the two water quality resources (fresh water and treated wastewater). Due to its richness in some fertilizing elements, the use of treated wastewater could allow to reduce the amount of fertilisers.
The annual requirements of two key fertilizers (Ammonitrate and Mono Ammonium Phosphate MAP) for the five varieties are presented in the table . Nitrogen is supplied to the plant in the form of Ammonitrate, which contains 33 % of N. Phosphorus is supplied in the form of MonoAmmonium Phosphate (MAP), containing 62 % of P_2O_5.

Tab. 15 Annual fertilizers' requirements for the selected varieties, Morocco case study

Crop	Ammonitrate (Kg/ha)	MAP (Kg/ha)
Clementine	570	68
Navel	603	77
Maroc Late	612	78
Nour	571	65
Nadorcott	558	73

The two fertilizers are sold in the market at 0.32 and 0.89 Euro/kg for Ammonitrate and MAP, respectively.

Model output: the baseline scenario

The simulation results for the baseline scenario show a similar cropping pattern to the actual situation to a level of 96.16%, using an elasticity of price coefficient equal to 0.96. The chosen citrus varieties are distributed as follows: Clementine represents 39 % of the total area, Navel occupies 15 %, 28 % is occupied by Maroc late, while Nour is planted on 15 % and Nadorcott on 4 % of the total land.
The total and average water and fertilizers quantities used in the baseline scenario are presented in the following tables.

Tab. 16 Water used, Morocco case study

Water used (m^3)	
Total	218 436 700
Per ha	6 764

Tab. 17 Fertillisers used, Morocco case study

Fertilisers used[2]	
Nitrogen (Kg)	6 057 836
Nitrogen (Kg/ha)	188
Phosphorus (kg)	2 064 593
Phosphorus (kg/ha)	64

Considering all costs and benefits, the total farmers' income is calculated. The average income per unit of area is obtained by dividing the total income by the cultivated land. The results of income for the baseline scenario, the total cost of water and the average cost per unit of area are presented in the Tab. 18 and Tab. 19:

Tab. 18 Water cost, Morocco case study

Water Cost (Euro)	
Total	32 765 505
Per ha	1 015

Tab. 19 Farmers' income, Morocco case study

Farmers' income (Euro/y)	
Total	274 000 034
Per ha	8 485

3.1.3. Tunisia: the Nabeul Governorate (UPM)

- *Presentation of the case study of Nabeul*

Nabeul is a coastal governorate in north-eastern Tunisia surrounded by the Mediterranean sea, except the south west side where it is delimited by the three governorates Zaghouan, Sousse and Ben Arous (Fig. 5). The region of Nabeul covers an area of 2822 km², which represent 1.8% of the country's surface. Nabeul is characterized by a semi-arid Mediterranean climate with mean annual values of precipitation, temperature, and potential evapotranspiration of about 450 mm, 20°C and 1300 mm, respectively.

The population of Nabeul governorate amounted 787,920 inhabitants in the year 2014 (INS, 2019). Population is mostly urban with a rate of urbanization of 67 % (INS, 2019). Agricultural areas dominate the entire region. With 3 % of the agricultural area of Tunisia, Cap Bon (Nabeul) represents 16% to the nation's total agricultural production. Besides the importance of the region's production in terms of quantity, Nabeul is known by several crop cultivations. In fact, the region accounts for 85% of the national citrus production, 63% of the national tomato production, 97% of the national strawberry production and 40% of the vine products. The governorate also accounts for 712 industrial enterprises, particularly in the transformation of agricultural products such as tomato and vine (Ministry of agriculture, 2018).

Water scarcity is considered the main problem faced by farmers in Nabeul. Then, it is important to look for solutions for the adaptation of the Nabeul agricultural sector to cope with water scarcity and to provide recommendations on how to reduce the effects of water scarcity based on some scenarios development.

[2] Nitrogen is supplied to the plant in the form of Ammonitrate, which contains 33 % of N. Phosphorus is supplied in the form of MonoAmmonium Phosphate (MAP), containing 62 % of P_2O_5

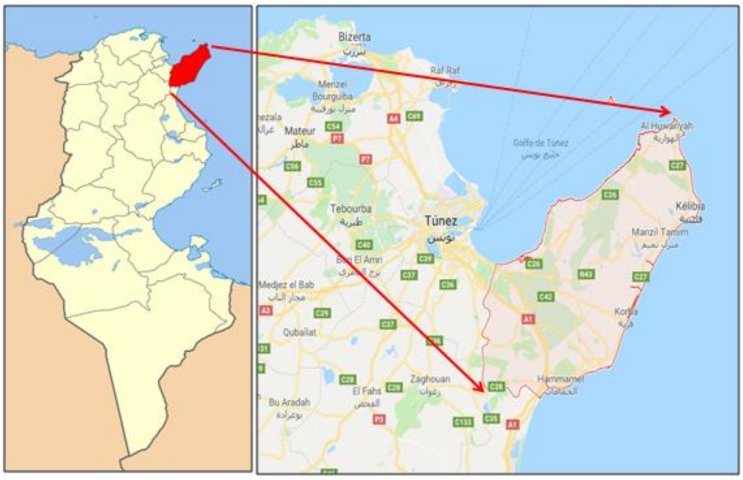


Fig. 5 Localization of Nabeul governorate, Tunisia case study

- *Fieldwork number 1:* from 6th to 29th August 2018

In order to provide relevant structural data on the agricultural sector in the region of Nabeul (Tunisia) and to establish a benchmark for the current agricultural system, a fieldwork mission was carried out in the region from August 6th to August 29th 2018 in the context of the MADFORWATER project activities. During this fieldwork, several sites and institutions were visited such as the Ministry of Agriculture of Tunisia, the Regional Commissariat for Agricultural Development (CRDA), Agricultural development group (GDA). In addition, 33 farmers from different delegations (Somaa, Grombalia, Beni Khalle and others) were surveyed to collect specific farm information.

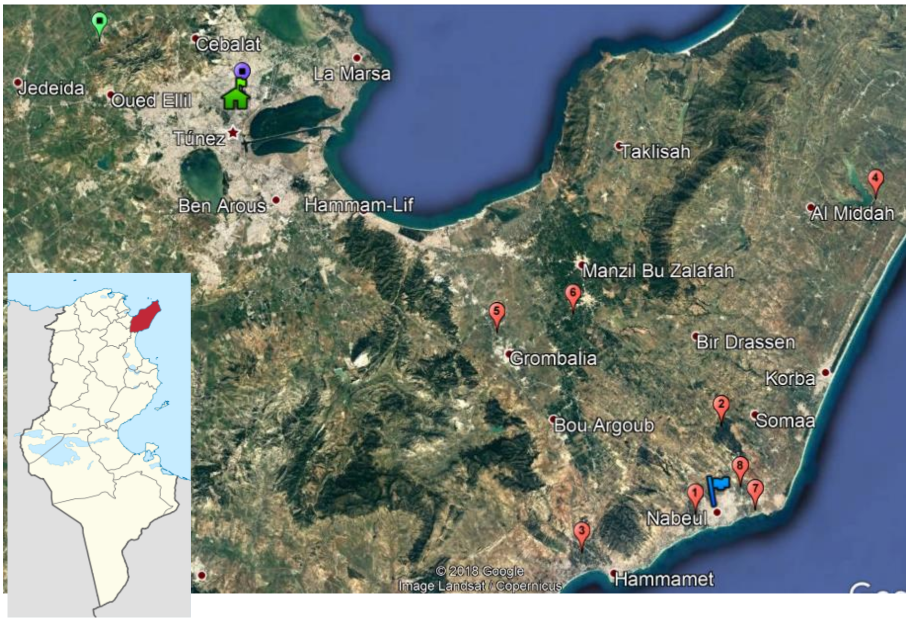


Fig. 6 Visited sites during the fieldwork[3], Tunisia case study

[3] : Higher Institute of Biotechnology Sidi Thabet, : Ministry of Agriculture, : National Agency for Environmental Protection, : CRDA Nabeul, : visited sites ((1) Souhil (Nabeul); (2) Somaa; (3) Hammamet: (4) Lebna; (5) Grombalia; (6) Beni Khalled; (7) Messadi (Nabeul); (8) Bir Romena (Nabeul).

The survey conducted is organized in different sections such as socio-economic, agriculture, water and policies. The main topics that are covered in the survey are: general data (date, delegation and others), farmer data (name, age, gender, education level and others), land property data (area, land tenure regime, land sale, land rent and others), crop data (crops, area, sowing date, harvest date, tillage, risky crops and others), water data (water type, cost, quantity applied and others) and workforce data (number, gender, wage and others).

Input data

- *Land and crop data*

According to the field work and based on the surveys conducted with farmers in different areas of Nabeul region, the main crops cultivated in the region are citrus, strawberry, citrus for orange blossom, tomato, pepper, olive, peach, vineyard, almond and tobacco. Each delegation of Nabeul region is known by its main crop cultivation. For example, the most representative crops in Nabeul capital are citrus, fodder, and tobacco and the main activity in the delegation of Beni Khalled is citrus cultivation.
Most of the surveyed farmers have an area that varies between 2 and 5 ha, and cultivate more than 2 crops in this area.

- *Water data*

Thirty-three farmers were surveyed of which thirteen use treated wastewater and twenty use conventional water (surface and groundwater). Surface water comes from the Medjerda-Cap Bon canal and the dams of the region, and is considered the most used water type. The Medjerda Cap Bon Canal plays a key role in the Nabeul agricultural sector. Most of the farms do not irrigate with groundwater due to high salinity that sometimes reaches up 8 g/l, except in some delegations like the delegation of Somaa that is known for the good quality of groundwater, where water comes from communal wells. The price of water includes the price of the volume of water consumed, price per surface and subscription. This price varies between regions and according to the type of water applied, conventional water price varies between 0.102 and 0.135 DT and treated wastewater price varies between 0.06 and 0.07 DT. According to the fieldwork, water prices are well accepted by farmers. With respect to treated wastewater for irrigation, it is more concentrated in the delegation of Nabeul (Bir Romena, Messadi, Souhil) and is more used in the irrigation of fodder and tobacco. According to the fieldwork, the reuse of treated wastewater in agriculture is not fully accepted by farmers in the region, who have a negative perception of treated wastewater, because of its unsightly appearance (smell, color and other) and several farmers say that wastewater reduce the product's quality.

Agricultural water management is mostly done by the Agricultural Development Groups (GDA, Groupe de Développement Agricole). The GDAs are responsible for equipping the irrigation perimeters where they intervene with basic agricultural and rural infrastructures and for supervising the activities of their members and providing advice for the use agricultural techniques with the aim of increasing productivity. GDAs are also responsible for charging water use.

- *Workforce data*

According to the field work, the workforce in the Cap Bon is mostly feminine. The salary varies between 15 dinars and 25 dinars a day depending on the task (collect, sowing, tillage and others). Fixed labor is negligible and usually works on big farms. Fixed labor receives a monthly salary that varies between 500 and 900 dinars, and in most cases, it includes accommodation. With respect to family labor, it is usually covered by the owners which are responsible for supervision, sales, rent and exchange of land, and the means of production.

The duration of a working day varies between 7 and 8 hours per day, depending on the season, the type of farms, the salary, and others.

- *Problems reported by farmers*

According to the farmers, they face several problems such as:

- Water scarcity: Surveyed farmers said that they are facing a severe water scarcity, considering surface and groundwater together. In fact, farmers only cultivate part of the land in some of the plots due to the water scarcity.
- Salinity of groundwater: Due to the salinity of the groundwater, which reaches up to 8 g/l in many regions, most of the farmers use surface water, which is not enough.
- Farmers are generally reluctant to accept treated water although it is cheaper than conventional water. They said that treated water reduces the product's quality due to the low water quality. Also, they added that this type of water has a higher risk of causing bacteria and parasite infections.
- WW can only be used for fodder or permanent crop irrigation. But the number of livestock farms is decreasing due to robbery and costs to shift from fodder cultivation to permanent crops are high making WW less attractive.
- Big investment is needed to adopt new technologies, and most farmers do not receive subsidies, grants nor other type of support.
- Access to capital appears to be difficult.
- Bad conditions that confront the workers: a number of workers in the agricultural sector do not benefit from social security.

- *Fieldwork number 2:* from 22th to 27th April 2019 (work in progress)

A second round of field work was carried out in the region of Nabeul from 22th to 27th April 2019 with the objective of obtaining a more ample database that will permit to upgrade the model so that it will be able to fully simulate different water technologies (WWT and irrigation technologies) as well as water management instruments (tariffs, quotas). During this field work, 17 farms were surveyed. This second fieldwork gives an ample information on some important crops such as strawberry, fodder and potato. The data collected cover different types of data namely economic, social, agronomic, technical and water-related data. Economic data provide information on farm income, costs, market access, cultivation and market risks, and other socioeconomic parameters such as labor use. This complementary field work gives also relevant information on agronomic data such as the types and quantities of fertilizers used that are considered key to analyze the potential fertilizer saving when using treated waste water. To complement the farm-level data, several institutions were visited such as the Agricultural Development Group (GDA) (Fig. 7) and the Regional Commissariat of Agricultural Development (CRDA) to find out how is water assigned to farmers (quotas, availability…) and to get complementary information on key features related to irrigated agriculture in the Nabeul region.

Considering that this new field work has just been carried out and that it is now being processed, its complete analysis has to be completed.

Fig. 7 GDA Souhil (Nabeul), Tunisia case study

Output in the baseline (Calibration results)

Representative farms have been chosen to represent the area of study, both in size and crops grown. They are shown in table 20. Sources of water for irrigation have also been considered. Specifically, farm F1 and F2 use conventional water sources (groundwater and surface water respectively) and F3 uses treated wastewater. Furthermore, they represent the average farms, with the most common crops present in the region of Nabeul. These are horticultural crops such as tomato, potato, pepper, and strawberry, and permanent crops such as olive trees for oil and citrus. Characteristics of the representative farms can be seen below in table

Tab. 20.

Tab. 20: Representative farms selected for the Tunisian case study

Farm name	Farm size (ha)	Crops	Cropping pattern (%)	Water source	Water application (m^3/ha)	Irrigation technique
F1	9	Pepper	20%	Groundwater	5 250	Drip
		Tomato	35%		7 250	Drip
		Potato	35%		3 000	Drip
		Strawberry	10%		4 500	Drip
F2	2	Citrus	100%	Superficial (MCB Canal)	7 250	Drip
F3	1.5	Olive trees (for oil)	67%	Treated wastewater	2 000	Drip
		Citrus	33%		7 750	Drip

Calibration results show similar cropping patterns in the baseline scenario (the modeled farm) in comparison with the defined representative farms. Cropping patterns of the baseline scenario simulation and the comparison with each representative farm can be seen below in Fig. 8.

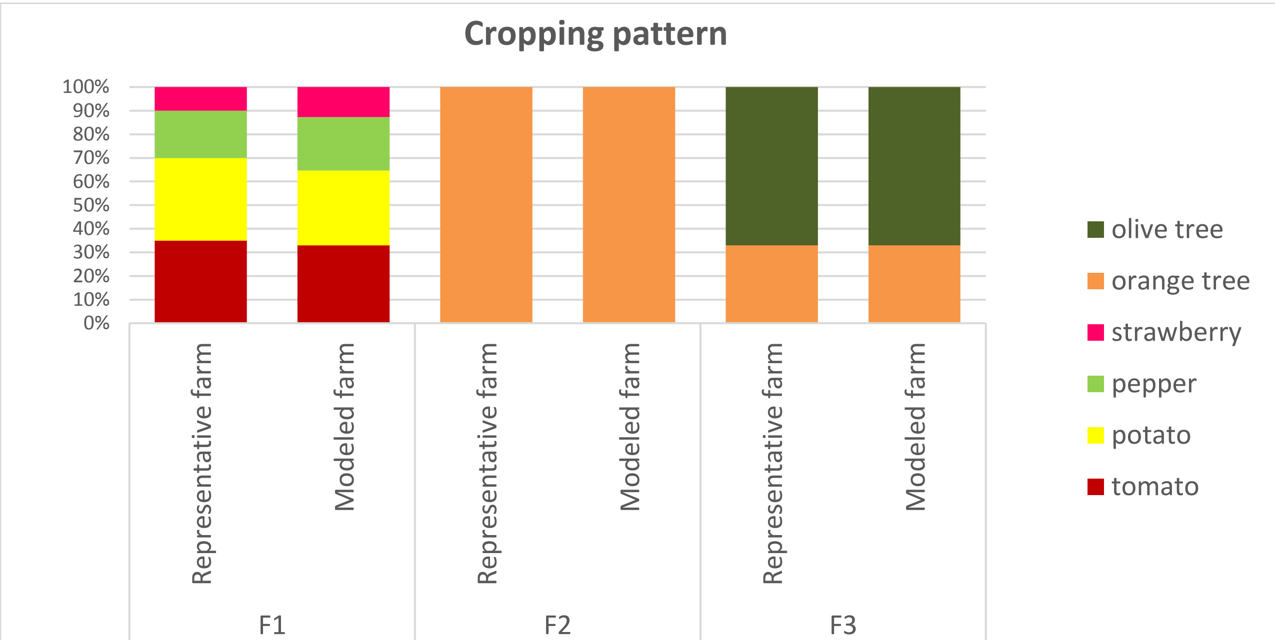
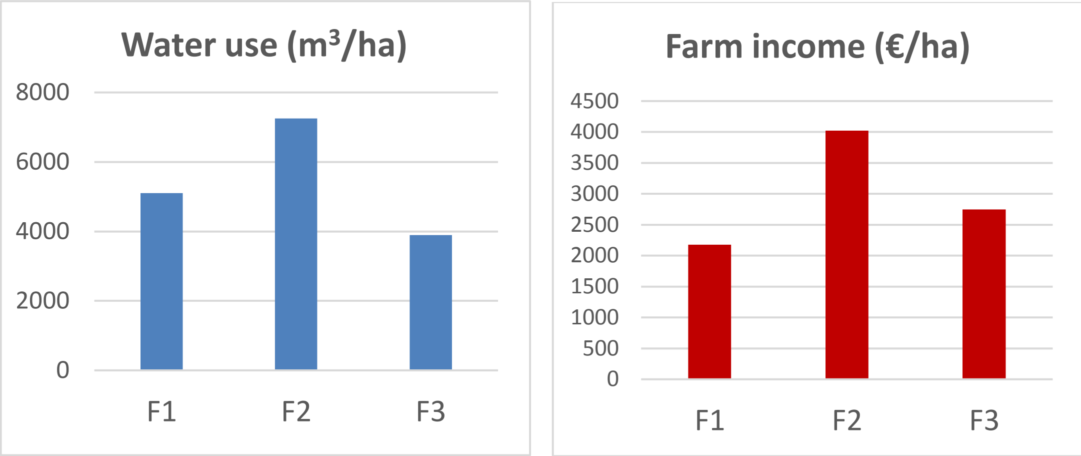


Fig. 8 Comparison between actual and simulated cropping pattern, Tunisia case study

Regarding farm F1, the level of correspondence between representative farm and modeled farm is 94.11% for tomato (3.15 ha in F1 representative farm, and 2.96 ha in F1 modeled farm), 90.54% for potato (3.15 ha in F1 representative farm, and 2.85 ha in F1 modeled farm), 88.42% for pepper (1.8 ha in F1 representative farm, and 2.03 ha in F1 modeled farm), and 78% for strawberry (0.9 ha in F1 representative farm and 1.15 ha in F1 modeled farm). Regarding farms F2 and F3, the level of correspondence between representative farms and modeled farms is 100% since they only have permanent crops.

Fig. 9 shows the amount of water used per hectare for each representative farm. In the Tunisian case study model, water use refers to the water at the farm-gate. It also shows the farm income per hectare for each representative farm. Farm income per hectare refers to the farm gross margin per hectare (as expressed in the general equations of the model).

Fig. 9 Baseline water use and farm income, Tunisia case study



The most relevant parameters for the Tunisian case study have been singled out: Water cost (€/ha and % farm income); Water productivity (€/m3); Water marginal value (€/m3); Water pricing (€/m3). Results for each representative farm can be seen below in

Tab. 20.

Tab. 21: Relevant parameters in the baseline scenario, Tunisia case study

Farm	Water cost (€/ha) (% income)	Water productivity (€/m3)	Water marginal value (€/m3)	Water Price (€/m3)
F1	224.1 (10.3%)	0.43	0.11	0.04
F2	306.9 (7.6%)	0.55	0	0.04
F3	100.5 (3.7%)	0.70	0	0.02

It is important to highlight that treated wastewater in Nabeul region, Tunisia, is subsidized and its price is 0.02 €/m3, which is half the price of conventional water, equal to 0.04 €/m3.

4. Conclusions and planned activities

The MADFORWATER partners IAMB and UPM achieved significant progress in the development of a 'generic' model to be implemented in 3 selected case study areas in Egypt, Morocco and Tunisia. A common structure has been framed to be comprehensive and flexible in order to be able to include all the possible specificities of the three case studies and to incorporate different types of crops, intensification levels, use of fertilizers, chemicals, labor use, tillage operations, water delivery periods, as well as different types of water sources. Further, the possibility to input the data and to export the results through a data sheet will make easier the use of the model in other case studies and by non-expert decision makers.

Thanks to an extensive field work of data collection completed in all case studies - Kafr-El- Sheikh Region in Egypt (IAMB); citrus farming system in Souss-massa region in Morocco (IAMB) and Nabeul Governorate in Tunisia (UPM) -, the developed model has been calibrated with data specifically referred to the target countries in terms of cost of the different technologies, yield and cost of crops production.

The developed decision support tool has been structured to simulate treatment and irrigation technological solutions, related economic and regulatory instruments identified and tested in MADFORWATER. Given the representativeness of the case studies and the generality of the model, the developed tool can be up-scaled and replicated in order to support the definition of strategies and the identification of economic instruments for basin-scale water resource management.

The developed model allows to identify the optimal allocation of water of different qualities that can be made available to agriculture by treating a larger amount of wastewater by using the treatment and irrigation technologies proposed and tested in the framework of the MADFORWATER project.

The upgraded version of the model will allow, in the last part of the project, the integration of the irrigation/water reuse technologies and the optimal cropping patterns in the framework of water & land management strategies, and the evaluation of the impact of the different economic instruments aimed at favoring the implementation of the proposed technologies. Simulations based on these strategies will be combined in different ways with technological strategies, such as an increased amount of water availability (obtained from improved water reuse and the implementation of more efficient irrigation technologies) as well as the decrease in fertilizer requirement (due to high levels of organic matter in treated WW).

When the different scenarios of water resources availability and water policies will be defined, the model will help to design the most efficient strategies for farmers and water managers: the optimal allocation of land and of different quality irrigation waters among crops will be identified and, ultimately, it will be assessed, under the different scenarios, the convenience to adopt treatment and irrigation technologies developed in MADFORWATER.

In general, the reuse of treated wastewater is expected to change the amount of freshwater consumed as well as fertilizer crop requirements with a positive impact on the cost of cultivation. On the other side, the modernization of irrigation systems that in some cases can be associated with the reuse of treated wastewater can affect the irrigation system performance in terms of efficiency, uniformity and/or adequacy. All these factors will be considered in the simulated scenarios. Simulations performed will help to identify the most efficient strategies in response to variations both in water resource availability and in water policies.

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