Introduction

This is the user guide for the Decision Support Tool (DST) relative to wastewater management and water & land management in agriculture, developed in the MADFORWATER project. The DST is an integrated agro-economic model developed in Tasks 3.3 and 5.3, aimed at integrating water reuse and irrigation technologies with economic instruments into basin-scale strategies to enhance the use of treated wastewater.

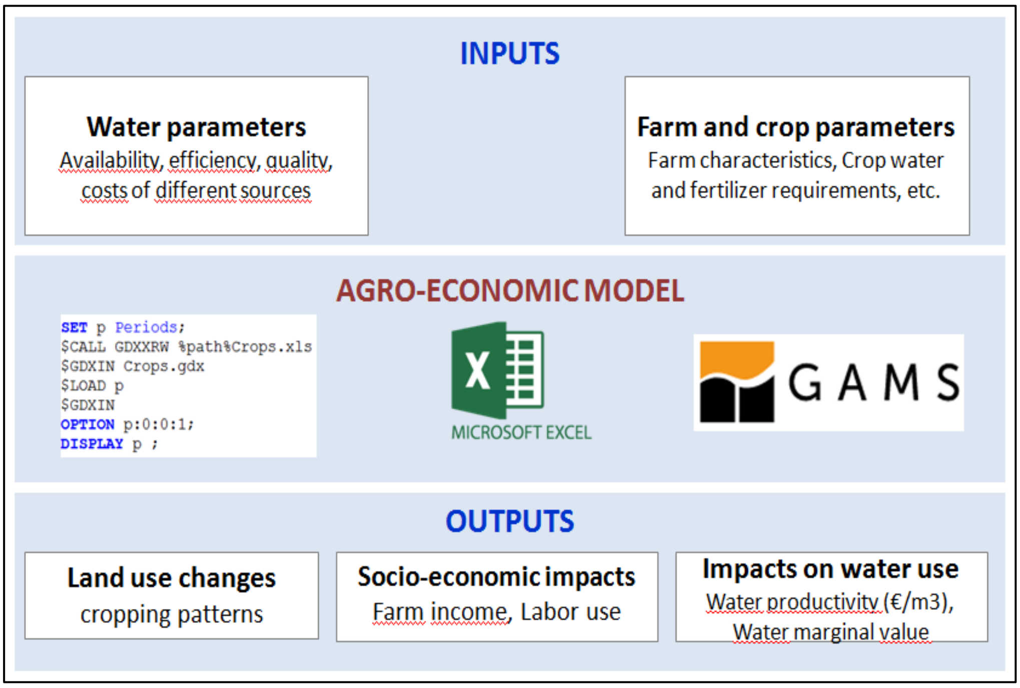
DST Description

The DST is an integrated agro-economic model useful to basin authorities, water planning and management agencies, water users' associations and farmers and environmental organizations, to develop strategies for water reuse and water & land management in agriculture.

The general objective of the DST (agro-economic model) is to develop water and land management strategies as a response to different technological and socioeconomic scenarios defined in the project. The aim is to achieve an optimal exploitation of the irrigation technologies and to assess the impact of economic instruments for improving irrigation efficiency and for enhancing treated WW reuse in agriculture.

A common structure of the DST has been framed to be comprehensive and flexible in order to include different types of crops, intensification levels, use of fertilizers, as well as different types of water sources and different water delivery periods.

The general structure of the agro-economic model can be illustrated as follows:



The agro-economic model is written in GAMS (General Algebraic Modeling System) language and it is based on a mathematical programming of a farm model.

The objective of this model is to guide the farmers' choices under different scenarios and risk situations.

The agro-economic model maximizes farmers' utility defined as the expected revenue minus its standard deviation due to risk adverse towards price/yield variation.

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

Where: **U**: Utility to be maximized, $\mathbf{Z_p}$: Average (expected) farm revenue (€); ϕ: Risk adversion coefficient; σ: Standard deviation of the expected income (€); **p**: farming type/position

and

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

Where: **c**: crops , **q**: type of water, **i**: irrigation technique, **f**: type of fertilizer, $\mathbf{X_{c,i,q,p}}$: the crop activity level (ha), $\mathbf{Pr_c}$: average crop price (€/ql), $\mathbf{Y_{c,q,t}}$: crop yield (ql/ha), $\mathbf{Vcost_{c,t}}$: variable costs (€/ha) , **Fcost**: fixed costs (€), $\mathbf{Fertreq_{c,q,f}}$: amount of fertilizer (kg), $\mathbf{Fertpr_f}$: fertilizer price (€/kg) , $\mathbf{PrWat_q}$: water tariff per m3 or per type of water, $\mathbf{QWAT_{q,p}}$: annual used water (m3) per type of water, $\mathbf{TarWat_q}$: water tariff per ha and per type of water, $\mathbf{Irrland_{q,p}}$: irrigated land (ha) by type of water.

HOW TO CHANGE THE OBJECTIVE

The DST can be changed in order to achieve different objectives, such as the maximization of food production or of the amount of treated wastewater reuse. This change is possible but that requires a deep modification of Equation 1 and of other sections of the code.

The agro-economic model maximizes farmers' utility subject to a set of resources contraints (land and water), agronomic and economic conditions, and offers the possibility to simulate and analyze different scenarios.

HOW TO CHANGE THE CONDITIONS AND CONSTRAINTS

- Agronomic and economic conditions can be changed by changing the related parameters: yields, prices, cost of cultivation, cost of technologies, level of subsidies, cost and aumount of fertilisers, efficiency of irrigation methods.

- Constraints can be changed by changing the availability of the inputs such as land and water

Scenario simulations can combine in different ways technological and policy scenarios, 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).

HOW TO CHANGE THE SCENARIOS

The water availability scenario

Availabillity of the fresh and treated wastewater can be changed in the 'TABLE watsup(p,q,s)'.

Given the characteristics of the TWW and their nutrient content, crops fertilizer requirements and crops yields could be changed in the 'TABLE fertreq(c,q,f)' and 'TABLE y (c,q,t)'.

The policy scenarios

Different water pricing policies can be simulated by changing the price for freshwater and for treated wastewater in the parameter ' WATPR (q)'.

Also, in combination with the 'technology scenarios', a public subsidy to the farmer to cover the cost of the innovative irrigation technologies can be also simulated in the parameter 'sub_lev(q)'.

The technology scenario

The cost of the innovative irrigation technologies can be also simulated in 'TABLE tech_cost(c,q)'.

The effect of the new technology could appear in the efficiency of the irrigation system through the parameter 'eff(i,q)'.

For each possible scenario, the proposed DST allows to identify the most efficient scenario for farmers and water managers: the optimal allocation of land and of different quality irrigation waters among crops is identified and, ultimately, the level of adoption of the different water reuse and irrigation technologies developed in MADFORWATER will be estimated. By identifying the optimal choices of farmers in relation to cultivation and agro-technical systems, the model allows to estimate the impacts of the adoption of technological innovations and economic and regulatory tools that can be put in place to encourage the practice of water reuse. The model provides also the impacts of different key parameters for irrigated farms, such as farm income, labor use, water consumption, marginal value of water etc. in each of the selected MADFORWATER scenarios.

Input data of the DST include: cultivated and irrigated surface, crop surface, crops irrigation requirements and schedules, water availability and price, variable costs of inputs for crop production, crop prices, crop yields, performance indicator of irrigation technologies and crop intensification levels.

Main output include: land allocation changes, farmers' income, water use per crop and per quality of water, water productivity and water marginal value.

Handbook: DST for water reuse and water & land management in agriculture

The hydro-agro-economic DST consists of statements that define the data first, followed by the model and the solution statements. The DST is contained in a computer code constructed with the text editor GAMS IDE. The file has the file extension .gsm and can be read using any text editor. To run the DST, it is necessary to install the GAMS IDE software. The code has been written in order to be usable also with the demo version of GAMS, that can be freely obtained at the following link: https://www.gams.com/download/. At the same link, it is possible to freely download the GAMS software, for Windows, Linux or MAC operating systems.

An extremely wide documentation on the use of GAMS, including a relevant library of GAMS codes, is available at this link: https://www.gams.com/31/docs/

When GAMS is 'run', the file containing the program (the input file) is submitted to be processed. After this processing has finished, the results, which are in the output file(s), can be inspected. By default the GAMS log appears on the screen while GAMS runs, keeping the user informed about progress and error detection. The output from GAMS contains many components in support for checking and comprehending the model.

In order to use the DST the following steps are needed :

1. Install GAMS and the IDE on your computer making an icon 

2. Open the IDE through the icon
3. Go to the file selection in the upper left corner to Create a project.
4. Define a project name and location. Put it in the directory you want to use.
5. Create or open an existing .gms file with GAMS instructions
7. Run the file with GAMS by pushing the ‘run’ button
8. Open and navigate around the output

DST components

Data

SET declarations and definitions to be included in the DST are the following:

C crops

CS(c) summer crops

CW(c) winter crops

T irrigation methods

P field sections

Q water quality

F fertiliser

I irrigation techniques

M month

S season

SM(m) summer months

WM(m) winter months

Kp random prices

Ky random yields

PARAMETERS to be entered as scalar are the following:

phi risk aversion_coefficient

el_pr price elasticity
landf(p) available land

PARAMETERS to be entered as list are the following:
eff(i,q) application efficiency of irrigation methods
WATPR (q) price of water (euro per cubic meter)
fertpr (f) price of the fertilisers (euro per kg)
pr (c) price of the crop (euro per 1000kg)
pr_dev (c) Coefficient of variation of croprs price
sub_lev(q) percentage of technology cost subsidized
VC (c,q) Crops variable costs (euro per ha) ;

PARAMETERS to be entered as tables of two or more dimensions are the following:
TABLE L_use (c,m) Land use (yes or no)
TABLE Combi1 (c,i,t,p) Possible combination of crop/irrigation methods/field sections/ irrigation techniques
TABLE nir (c,t,m) Net irrigation requirements (m3 per ha)
TABLE fertreq(c,q,f) Fertiliser requirements (kg per ha)
TABLE y (c,q,t) (yields ton per ha)
TABLE y_dev (c,q,t) (% of variation of random yields)
TABLE vc(c,q) variable cost (euro per ha)
TABLE tech_cost(c,q) cost of technology (euro per ha)
TABLE iniarea(c,p) observed cropping pattern (ha)
TABLE watsup(p,q,s) water availability (m3 per ha)

Data entered using assignment statements are the following:
GIR (c,i,t,m,q) Gross irrigation requirements (m3 per ha) ;
GIR(c,i,t,m,q)= (NIR(c,t,m)/eff(i,q));
Pr_k (c,kp) Random prices ;
pr_k(c,kp) =normal(pr(c),pr_dev(c)) ;
Y_k (c,q,t,ky) Random yields ;
y_k(c,q,t,ky) = normal(y(c,q,t),y_dev(c,q,t)) ;

Model
VARIABLES are declared and positive variables are specified as follows:

VARIABLE
U Utility function (euro)
ZK(ky,kp,p) Random Income (euro)
sigma (p) Standard deviation (euro)
GRMARG Gross margin (euro)
GRMARG_k Random gross margin (euro)
fertused Amount of fertiliser applied (kg)
diff Difference between observed and actual cropping pattern (ha)
techamount Area with the new technology (ha)

POSITIVE VARIABLE
X(c,i,q,t,p) Crop activity level (ha)
Z Expected income (euro)
watreqc Water demand (m3)

pricewat Price of water (euro/m3)
varcosts Variable cost (euro)
tot_cost_wat Cost of water (euro)

EQUATION declarations and EQUATION definitions
Equations included in the model can be distinguished in two main blocks.
The first one is related to the objective function and to all its nested components.

```
objective.. U =e= Z('c_land') - phi* SIGMA('c_land') ;
differ(c).. diff(c) =e= ((sum((i,q,t,p), X(c,i,q,t,p)$Combi1(c,i,t,p))) - (sum((p),(Iniarea(c,p)))))/( sum ((p),(Iniarea(c,p)))) ;
GM(c,t,q,p).. (Y(c,q,t) *(Pr(c)-Pr(c)*0.957*diff(c)) - tech_cost(c,q)*sub_lev(q) - vc(c,q) -sum (f, fertreq(c,q,f)*fertpr(f)) =e= GRMARG(c,q,t,p);
GM_k(c,q,t,p,ky,kp)..(Y_k(c,q,t,ky)*(Pr_k(c,kp)-Pr_k(c,kp)*0.957*diff(c)) - tech_cost(c,q)*sub_lev (q)- vc(c,q) -sum (f, fertreq(c,q,f)*fertpr(f)) =e= GRMARG_k(c,q,t,p,ky, kp) ;
income_e(p).. Z(p) =e= (sum((c,q,t,i),GRMARG(c,q,t, p) *X(c,i,q,t,p))- tot_cost_wat(p) );
income_k(ky,kp,p).. Zk(ky,kp,p) =e= (sum((c,q,t,i), GRMARG_k(c,q,t,p,ky,kp)*X(c,i,q,t,p)) - tot_cost_wat(p)) ;
std_dev(p).. SIGMA (p) =e= sqrt(sum ((ky,kp), sqr(ZK(ky, kp,p)-Z(p)))/(card (Kp)*card (ky)));
fert_tot(f,q).. sum ((c,i,t,p), fertreq(c,q,f)*X(c,i,q,t,p)) =e= fertused(f,q) ;
tech_amount(q).. sum ((c,i,t,p), tech_cost(c,q)*X(c,i,q,t,p)) =e= techamount(q) ;
var_costs (c,q).. sum ((i,t,p), vc(c,q)*X(c,i,q,t,p)) =e= varcosts (c,q) ;
swater_tot_tot_c (p).. tot_cost_wat(p)=e= sum ((c,q),pricewat(p,q,c));
swater_totc (p,q,c).. watreqc(p,q,c)*watpr(q) =e= pricewat(p,q,c);
```

The second one is related to the constraints of the optimization, mainly, land and water availability. As for water, four equations are included one for each season, summer and winter, and each water quality, q1 and q2.

```
fland(p,m).. sum((c,i,t,q), X(c,i,q,t,p)) =e= landf(p) ;
water_totcs1 (p,'q1',cs).. sum((i,t,m), gir(cs,i,t,m,'q1') * X(cs,i,'q1',t,p)$Combi1(cs,i,t,p)*L_use(cs,m) )=e=watreqc(p,'q1',cs);
water_totcs2 (p,'q2',cs).. sum((i,t,m), gir(cs,i,t,m,'q2') * X(cs,i,'q2',t,p)$Combi1(cs,i,t,p)*L_use(cs,m) )=e=watreqc(p,'q2',cs);
water_totcw1 (p,'q1',cw).. sum((i,t,m), gir(cw,i,t,m,'q1')*X(cw,i,'q1',t,p)$Combi1(cw,i,t,p)*L_use(cw,m) )=e=watreqc(p,'q1',cw);
water_totcw2 (p,'q2',cw).. sum((i,t,m), gir(cw,i,t,m,'q2')*X(cw,i,'q2',t,p)$Combi1(cw,i,t,p)*L_use(cw,m) )=e=watreqc(p,'q2',cw);
suwatfs1(p,'q1','sm').. sum(cs,watreqc(p,'q1',cs)) =l= watsup(p,'q1','sm')*landf (p) ;
suwatfs2(p,'q2','sm').. sum(cs,watreqc(p,'q2',cs)) =l= watsup(p,'q2','sm')*landf (p) ;
suwatfw1(p,'q1','wm').. sum(cw,watreqc(p,'q1',cw)) =l=watsup(p,'q1','wm')*landf (p) ;
suwatfw2(p,'q2','wm').. sum (cw,watreqc(p,'q2',cw))=l= watsup(p,'q2','wm')*landf (p) ;
```

MODEL DEFINITION
The model statement is used to collect equations into groups and to label them so that they can be solved. The simplest form of the model statement uses the keyword all: the model consists of all equations declared before the model statement is entered.

SOLVE
Once a model has been defined using the model statement, the solve statement prompts GAMS to call one of the available solvers for the particular model type.
The proposed model is a Non Linear Programming (NLP) model and the chosen solver is CONOPT.

DISPLAY of results
The display statement in GAMS is a quick way to write data into the listing file user to control the layout and appearance of the output.

While there is no fixed order in which statements have to be arranged, the order in which data modifications are carried out is important. Symbols must be declared as to type before they are used, and must have values assigned before they can be referenced in assignment statements. Each statement is followed by a semicolon except the last statement, where a semicolon is optional.

The output file generated from a GAMS run is called listing file. The listing file has the file extension .lst and can be read using any text editor. By default the listing file has the same file name as the input file, but this can be changed using the command line parameter Output. The main components in the listing file are:

Compilation. The compilation output contains an echo print of the input file, possibly error messages, along with lists of GAMS objects and cross reference maps.

Execution. The execution output contains the results of display statements and possibly execution error messages.

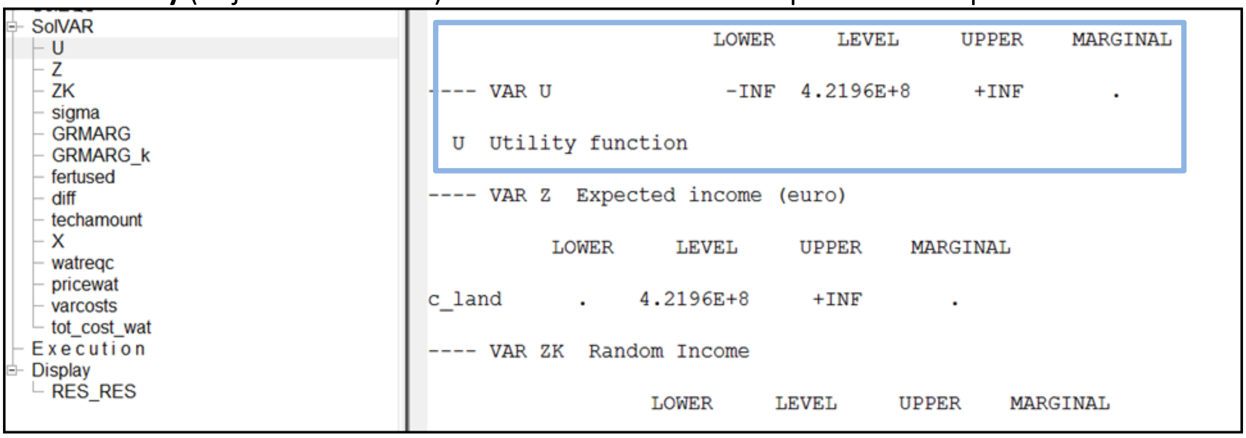
Model Generation. The output generated during model generation contains listings of equations and variable listings as well as model statistics and possibly generation execution error messages.

Solution. The output generated when an external solver program processes the model is the solution report including the solve summary, the solver report, the solution listing and the report summary.

Post-Solution. The final components added to the listing file are the final execution summary and the file summary.

A selection of the most important outputs of the model is shown here below, using the gams screen output following the sequence that appears in the original model:

- **Utility** (objective function) as defined in the model equation in the precedent section



- **Fertilizer use**: as defined in the model equation in the precedent section:

```
SolVAR                pepper_ext.q2.t1.c_land.ky5.kp4     -INF    4059.780     +INF       .
  U                   pepper_ext.q2.t1.c_land.ky5.kp5     -INF    3442.259     +INF       .
  Z
  ZK                  ---- VAR fertused  Amount of fertiliser applied
  sigma
  GRMARG                      LOWER     LEVEL     UPPER    MARGINAL
  GRMARG_k
  fertused            1.q1     -INF   1.9374E+7    +INF        .
  diff                1.q2     -INF   1.6642E+6    +INF        .
  techamount          2.q1     -INF   2.6212E+6    +INF        .
  X                   2.q2     -INF   7.4978E+5    +INF        .
  watreqc
  pricewat            ---- VAR diff  Difference between observed and actual cropping patttern
  varcosts
  tot_cost_wat                     LOWER     LEVEL     UPPER    MARGINAL
Execution
Display
  RES_RES
```

Note: q1, q2 are water types, defined in the model constraints (see equation definitions above) as:

- q1: freshwater
- q2: treated wastewater

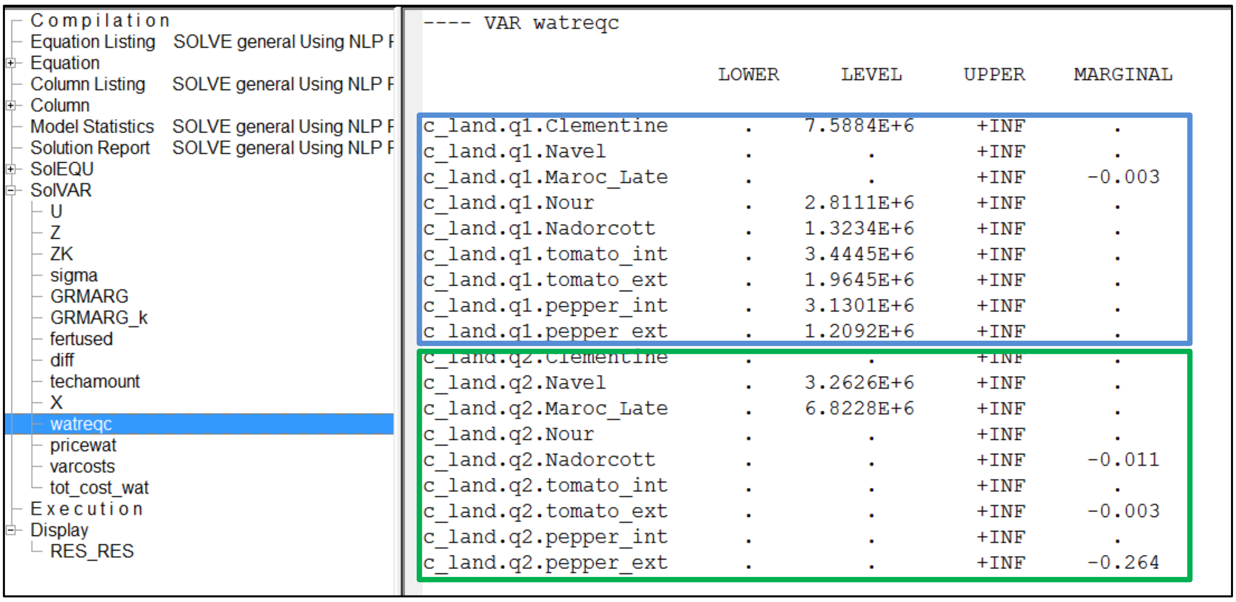
- **Crop distribution**

```
SolVAR
  U                 LANDT   .tot         .tot              47592
  Z                 LAND    .tot         .q1               33873
  ZK                LAND    .tot         .q2               13719
  sigma             crop    .Clementine.q1                 12472
  GRMARG            crop    .Navel      .q2                 4754
  GRMARG_k          crop    .Maroc_Late.q2                  8965
  fertused          crop    .Nour       .q1                 4856
  diff              crop    .Nadorcott  .q1                 1195
  techamount        crop    .tomato_int.q1                  4996
  X                 crop    .tomato_ext.q1                  3274
  watreqc           crop    .pepper_int.q1                  5040
  pricewat          crop    .pepper_ext.q1                  2040
  varcosts          WATq1   .c_land     .Clementine      7588422
  tot_cost_wat      WATq1   .c_land     .Nour            2811094
Execution           WATq1   .c_land     .Nadorcott       1323391
Display             WATq1   .c_land     .tomato_int      3444452
  RES_RES
```

The colors indicate:

- Total land
- Area irrigated with freshwater
- Area irrigated with treated wastewater
- Crop distribution

- **Water requirement**



The colors indicate:

- Amount of freshwater
- Amount of treated wastewater

As an example, the summary of the initial parameters and main outputs of the model are shown in Tables 3 and 4, relatively to the application of the model to one of the MADFORWATER case studies, the citrus farming system in Souss-Massa, Morocco.

Table 1: Integrated agro-economic model: Initial parameters

	Variables				
	Crop distribution (ha)	Yield (ton/ha)	Price (€/ton)	Variable costs (€/ha)	Cost of technology (€/ha)
Clementine	12527	30	280	3042.2	350
Navel	4750	40	380	3105.6	350
Maroc_late	8981	45	365	3105.6	350
Nour	4840	40	304	3105.6	350
Nadorcott	1194	65	404	3042.2	350
Tomato_int	5000	50	350	3200	350
Tomato_ext	3300	30	300	3100	350
Pepper_int	5000	40	380	3000	350
Pepper_ext	2000	28	360	2800	350
Total area (ha)	47592				

Table 2: Integrated agro-economic model: results

	Variables	
Crops	**Area (ha)**	**Water req (m3/ha)**
Clementine	12472	608
Navel	4754	686
Moroc_late	8965	761
Nour	4856	578
Nador_cott	1195	1107
Tomato_int	4996	689
Tomato_ext	3274	600
Pepper_int	5040	621
Pepper_ext	2040	593
Total area (ha)	47592	
Total income (euro)	421958614	
Income (euro/ha)	8866	
Crop distribution (%)