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IR$_2$MA
Large Scale Irrigation Management Tools for Sustainable Water Management in Rural Areas and Protection of Receiving Aquatic Ecosystems

Subsidy Contract No: I1/2.3/27

WP#5

Deliverable 5.4.3

Recycled water DSS evaluation

Project co-funded by
European Union, European Regional Development Funds (E.R.D.F.) and by National Funds of Greece and Italy

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Deliverable 5.4.3 - Demonstration activities and applied research Recycled water DSS evaluation

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Summary

The application of a common decision support system (DSS) for water management at the end-user level (capitalization of ETCP GRIT2007-13 IRMA project) will promote the cooperation of their managing authorities to confront common problems. In this framework, a decision support system (DSS) was developed in the framework of the IR2MA project for use of non-conventional water for irrigation on a farm scale. A case study is presented running the model in the irrigation district 17, Trinitapoli, Puglia region. The input parameters used for running the model are given through a set of local climate, soil, crop, and irrigation water conditions, whereas the output parameters are given utilizing relative yields, crop evapotranspiration, irrigation requirements, drainage, number of days crops were under stress and leaching requirements. The simulations were conducted for peach and tomato crops for the three years, 2014–2016. Several different irrigation management options were tested. The model was tested for full irrigation and deficit irrigation scenarios, as well as for conditions of saline irrigation water.

Keywords: IR2MA, Decision-Support Systems(DSS), water supply, water management, treated wastewater

Sommario

L'applicazione di sistemi di supporto alle decisioni (DSS) per la gestione dell'acqua a livello di utente finale (capitalizzazione del progetto ETCP GRIT2007-13 IRMA) promuoverà la cooperazione delle loro autorità di gestione per affrontare i problemi comuni. In questo quadro, è stato sviluppato un sistema di supporto alle decisioni (DSS) nell'ambito del progetto IR2MA per l'uso dell'acqua non convenzionale per l'irrigazione su scala aziendale. Viene presentato un caso di studio che esegue il modello nel distretto irriguo 17, Trinitapoli, regione Puglia. I parametri di input utilizzati per l'esecuzione del modello sono forniti attraverso un insieme di condizioni climatiche locali, del suolo, delle colture e dell'acqua di irrigazione, mentre i parametri di output vengono forniti utilizzando i rendimenti relativi, l'evapotraspirazione delle colture, i requisiti di irrigazione, il drenaggio, il numero di giorni requisiti di stress e lisciviazione. Le simulazioni sono state condotte per le colture di albicocco e pomodoro per il triennio 2014-2016. Sono state testate diverse opzioni di gestione dell'irrigazione. Il modello è stato testato per scenari di irrigazione completa e di irrigazione deficitaria, nonché per le condizioni dell'acqua di irrigazione salina.

Parole chiave: IR2MA, Sistemi di supporto alle decisioni (DSS), approvvigionamento idrico, gestione dell'acqua, acque reflue

1. Introduction

In the framework of the IR2MA project, fruitful cooperation between scientific research and Italian and Greek policymakers will improve the water management of the irrigation-drainage systems, to reduce contamination of receiving aquatic ecosystems. The Sinistra Ofanto Irrigation Scheme, in Southeastern Italy managed by Consorzio per la Bonifica Della Capitanata (CBC), is selected as a case study. CBC is considered to run the most advanced participatory system in the program area. It applies state-of-the-art infrastructure and management systems and it also applies for years a water management DSS for end-users. This makes it an ideal partner to exchange know-how and provide valuable feedback for the relevant systems in Epirus. The overall objective of this report is to verify and validate the success of a DSS developed in the framework of the IR_2MA project. The main purpose of developing the DSS model is to support the use of non-conventional water for irrigation on the farm scale. The evaluation is important to indicate the deficiencies and to improve the DSS model in the future. The specific objectives of this study were: (1) to perform a literature review on the DSSs developed for agricultural irrigation with low-quality waters (2) to highlight the evaluation results and findings for the DSS model developed.

2. What is a Decision Support System (DSS)?

A Decision Support System (DSS) is a concept where computer-based systems are used to assist an organization and analyze information to support decision making. Their purpose is to smoothen the decision-making process for management, operations, planning, or optimal solution path recommendation. DSS offers scientific-technical tools often developed by multidisciplinary teams to combine skills and experience. In the context of agriculture developing a DSS may help local authorities to choose between alternatives of wastewater reuse, decide quickly about the risk and feasibility of a proposal and better adapt the solution to local conditions (Ganoulis 2012).

2.1 Analysis of current Wastewater DSS in the literature

This section provides a detailed review of DSS and methodologies that have been proposed for recycled wastewater. There are several decision support tools (DSTs) available for water and wastewater treatment selection and design that have been reviewed by (Hamouda et al. 2009). Most DSTs usually address planners and designers with a strong focus on technical aspects, dominating the logic of the developed systems reviewed.

Table 1. List of DSS used for wastewater application in agriculture.

Name	Objective	Reference
TechSelect 1.0	Selection of Wastewater Treatment Alternatives	(Kalbar et al. 2016)
Poseidon	Supports pre-feasibility studies and aims at promoting water reuse and building capacities in the field	(Oertlé et al. 2019)
WDB IV	Quantify problems related to wastewater reuse and identify measures to be taken to improve the situation	(De Schutter 2007)
DSS	Evaluation of wastewater reuse feasibility	(Papa et al. 2016)
DSS	Feasibility of implementing wastewater reuse in South Africa	(Adewumi et al. 2010)
DSS	Simulate best options with conjunctive use of TW and GW for scheduling seasonal irrigation	(P. W. Jayasuriya et al. 2018)

See: Decision support systems in water and wastewater treatment process selection and design: a review

2.1.1 TechSelect 1.0 DSS

TechSelect 1.0 (Kalbar et al. 2016) is a scenario-based lifecycle-based decision support tool for the selection of wastewater treatment alternatives. The tool uses Microsoft Excel to take input from the users and to display the results.

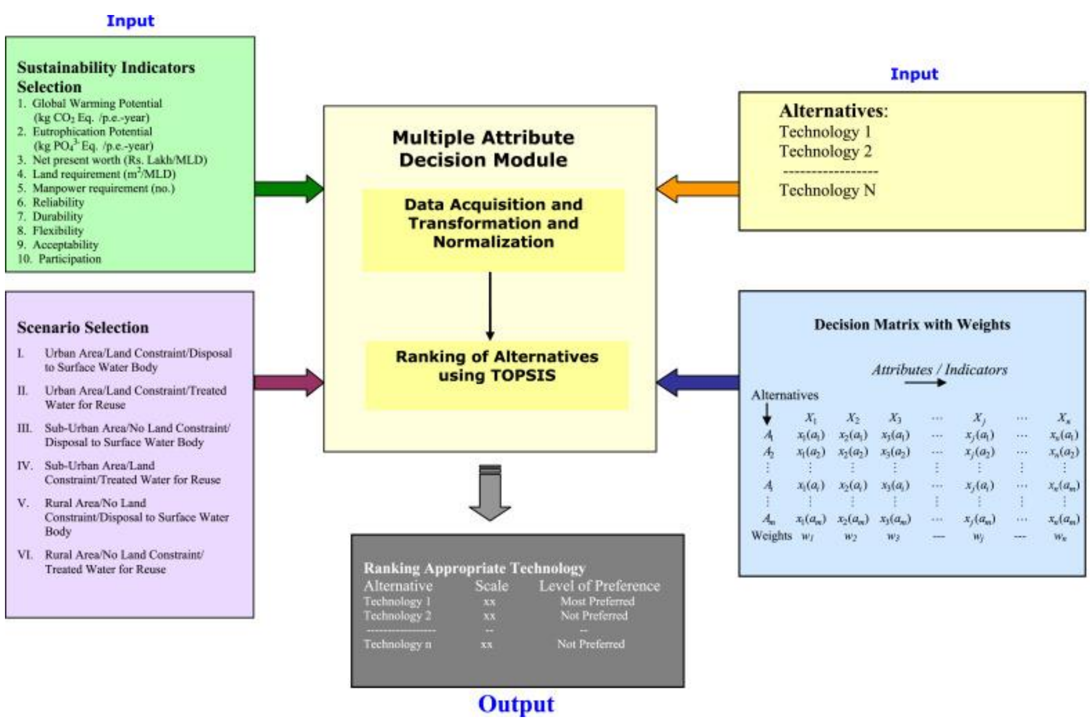

Fig. 1. The architecture of the TechSelect 1.0.

Sustainability criteria are incorporated into decision-making. It uses a life cycle sustainability assessment framework for assessing technologies from environmental (life cycle assessment), economic (life-cycle costing), and social (various sustainability indicators) perspectives. TechSelect 1.0 is based on the Multiple Attribute Decision-Making (MADM) algorithm (Figure 1) using a unique attribute information processing approach and mathematical principle to rank the alternative. The first step is to choose the set of criteria and indicators that will rationally prioritize alternatives. Once this set is in place, some preliminary operations such as data transformation (i.e. handling negative values) and normalization (i.e. vector normalization) are performed. The user must choose the scenario under which the decision is to be taken.

2.1.2 Poseidon DSS

Poseidon DSS (Figure 2) is a user-oriented, simple, and fast Excel-Tool which aims to compare different wastewater treatment techniques based on their removal efficiencies, their costs, and additional evaluation criteria. It is useful for pre-feasibility studies to promote water reuse in regions where it is still an emerging concept (Oertlé et al. 2019). The developed DST composes of several elements in a transparent, widely used spreadsheet software (Microsoft Excel). It combines 37 pre-selected unit processes which can lead to a series of maximum of 10 unit processes per treatment train. Different parameters can be personalized and adapted to every single user.

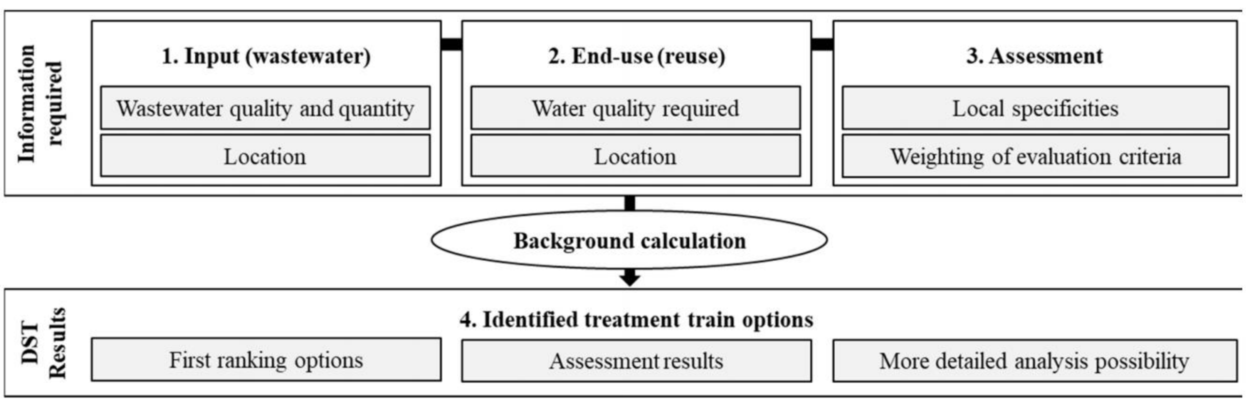

Fig. 2. The architecture of the decision support tool (DST).

2.1.3 The Aquaenvec Tool

The AQUAENVEC project developed decision-making tools (Figure 3) for optimizing the urban water cycle to achieve environmental and economic benefits, using Life Cycle Analysis (LCA) and Life Cycle Cost analysis (LCC). The AQUAENVEC is a tool for eco-efficiency assessment of urban water cycle activities helping to obtain a set of environmental, economic, and eco-efficiency indicators based on a life-cycle perspective (ISO 14045:2012). It is devoted to urban water cycle managers. The tool is available online at http://www.life-aquaenvec.eu/the-aquaenvec-tool/ or the direct link http://tool.life-aquaenvec.eu/en. There is no installation package as it is a web tool.

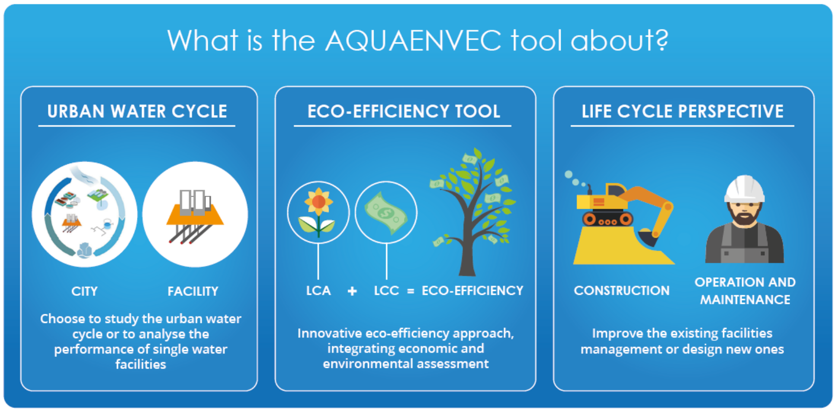

Fig. 3. The architecture of the AquanVec tool.

2.1.4 MOSTWATAR

MOSTWATAR (which stands for Model for Optimum Selection of Technologies for wAstewater treatment And Reuse) is intended to assist planners and decision-makers in the techno-economic assessment of reclamation technologies and aid in the selection of the best 5 treatment trains for given end-use and location, wastewater characteristics, and flow rate. The results from user-generated options are presented and it is shown that this model can be a very useful tool for selecting the best treatment trains for wastewater reclamation and reuse. It is a user-friendly planning tool for the evaluation and selection of the best TTs for reclamation and reuse of municipal wastewater for non-potable reuse applications (such as irrigation, groundwater recharge, and various urban uses). The user can input the site-specific aspects such as population, wastewater quality, and quantity generated, local climatic and hydrogeological conditions, and so on through a user-friendly interface. The final selection is based on 13 quantitative and qualitative criteria such as cost, land requirement, adaptability to upgrade, and ease of construction. MOSTWATAR© is a point and click model consisting of the following modules: (a) Community data, (b) Reuse criteria, (c) Form TT, (d) Design criteria, N. (e) TT performance, (f) Selection criteria, (g) GA optimization, and (h) Results. A simplified structure of the MOSTWATAR© model is shown in Figure 4.

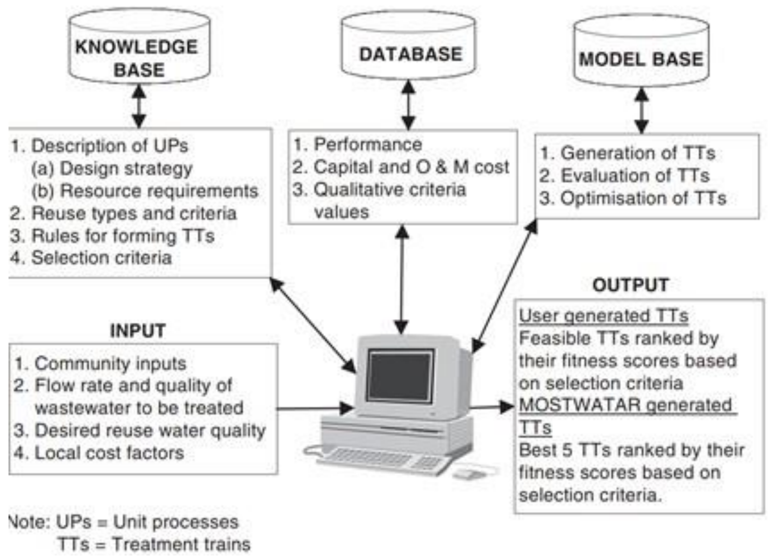

Fig. 4. The architecture of the MOSTWATAR© tool.

3.1.1 SelSys-Irrigation system tool

The SelSys Decision Support System (DSS) is a web-based tool (Figure 5) to guide the decision on the selection of suitable irrigation systems, taking into account constraints as soil characteristics, water quality, climatic conditions. The selection criteria are considering as well the crop, single crop or rotation, and the investment required. The SelSys DSS consists of a set of matrices developed by an expert panel on the ground of the available literature and know-how. The SelSys is working based on the Expert System concept. The SelSys database includes 44 irrigation methods, among the most diffused, which have been analyzed and ranked with the help of 26 indicators, then normalized and grouped in 16 input categories.

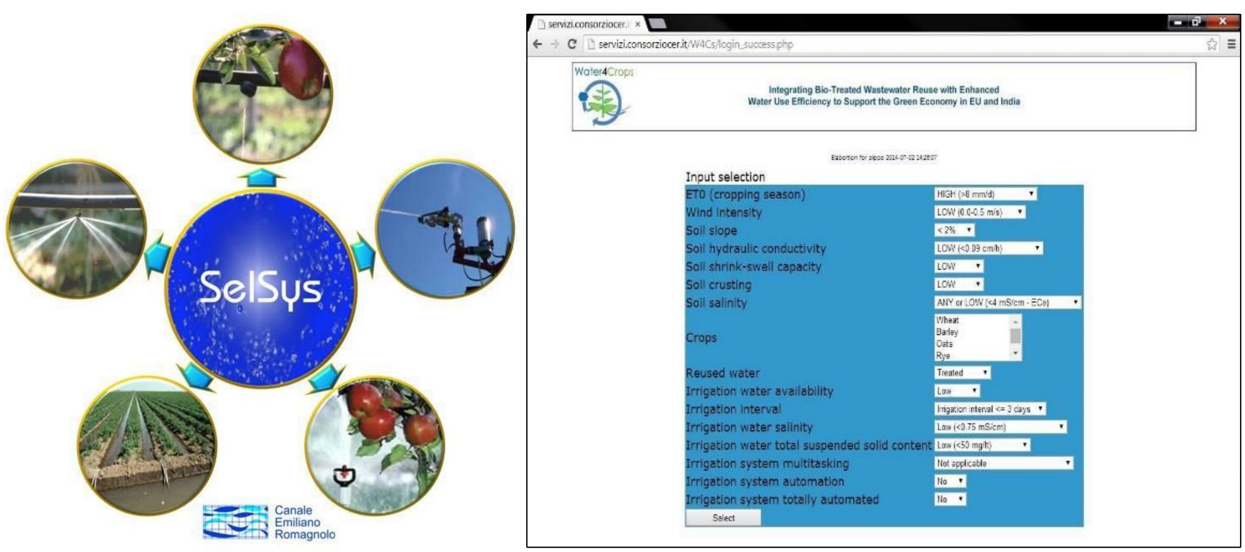

Fig. 5. Screenshot of SelSys webpage application.

3.1.2 DSS 1 - Papa et al. 2016

The proposed DSS (Papa et al. 2016) is aimed at judging the feasibility of wastewater reuse, and it is founded on an integrated assessment of the entire "reuse chain". A large set of input factors is assessed related to each "actor" of the reclamation process: (1) the wastewater treatment plant (WWTP); (2) the hydraulic system, required to transport water from the plant to the user; (3) the final user (e.g. crops irrigation). For WWTP, DSS input factors are represented by the chemical, physical, and microbiological parameters, chosen according to the final destination of reused wastewater. The hydraulic system is related to a system for water transportation. For the final user, water quality and availability and supplementary parameters (a type of crops, soil properties, etc.) are the milestones. This tool represents useful technical support for decision-makers whenever a judgment on reuse feasibility is required.

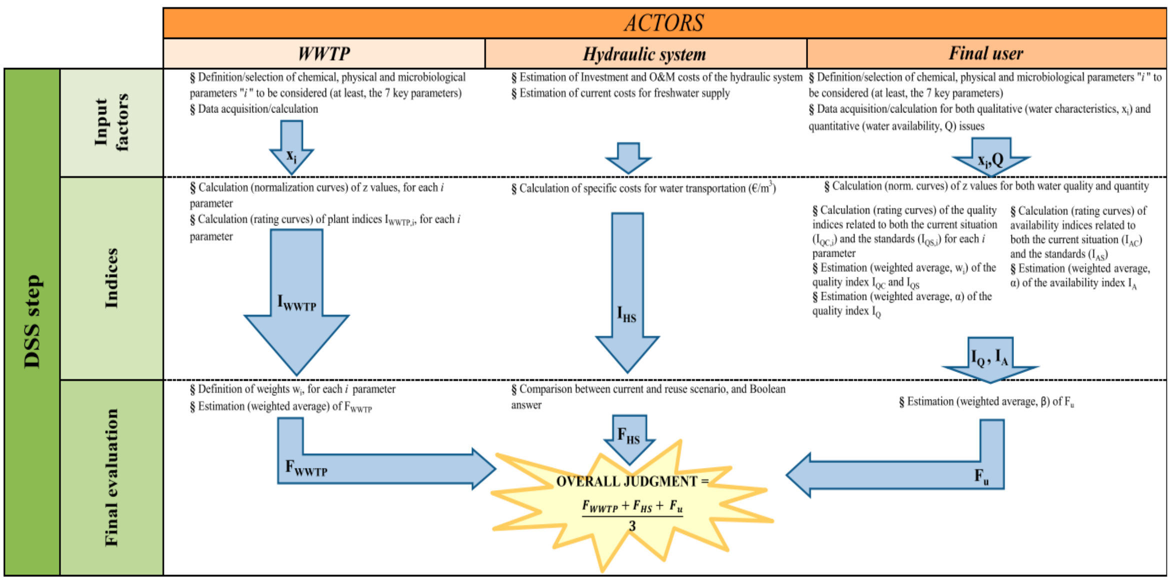

Fig. 6. DSS conceptual framework.

3.1.3 DSS 2 - (Adewumi et al. 2010)

The DSS (Adewumi et al. 2010) is classified into quantitative and qualitative modules (Figure 7). The quantitative modules consist of technical and economic assessment criteria while qualitative modules consist of environmental and social assessment criteria. Under quantitative assessment, technical assessment starts with the estimation of the volume of non-potable water needed for agricultural irrigation, urban, domestic, mining, and industry, and in other uses. This module, therefore, provides the basis to justify a reuse project economically by quantitative estimation of the volume of recycled water needed for various activities. Other quantitative assessments include pollutant removal efficiency to meet reuse water quality, capital, and O&M costs of the 33 unit processes from which the DSS can form a diversity of wastewater treatment trains. Treatment train qualitative is classified into technical (i.e. reliability, adaptability to upgrade, varying flow rate, change in water quality, ease of O&M, and ease of construction) and environmental (i.e. power and chemical requirements, odor generation, and impact on groundwater) criteria.

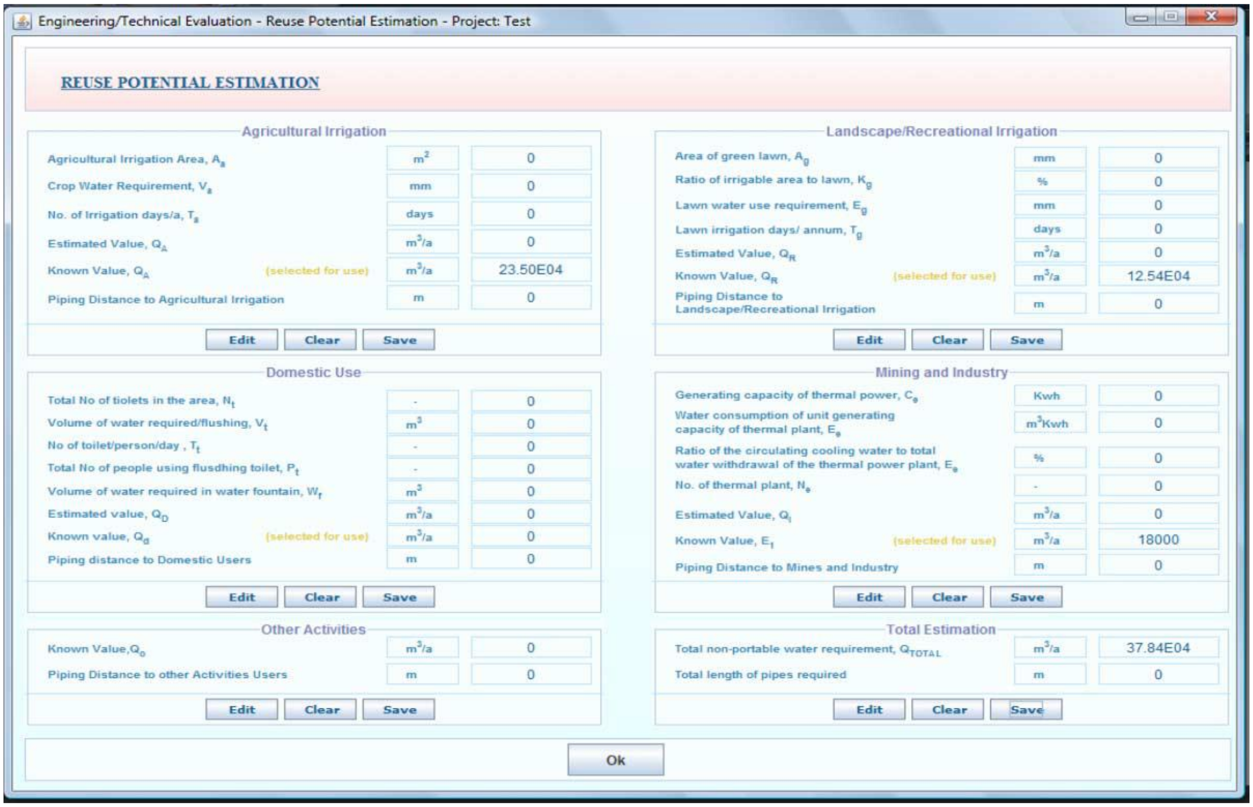

Fig. 7. Adewumi et al. 2010 DSS conceptual framework.

3. IR2MA DSS evaluation

A case study is presented running the model in the irrigation district 17, Trinitapoli, Puglia region. The input parameters used for running the model are given through a set of local climate, soil, crop, and irrigation water conditions, whereas the output parameters are given utilizing relative yields, crop evapotranspiration, irrigation requirements, drainage, number of days crops were under stress and leaching requirements. The simulations were conducted for peach and tomato crops for the three years, 2014–2016. Several different irrigation management options were tested. The model was tested for full irrigation and deficit irrigation scenarios, as well as for conditions of saline irrigation water.

3.1 Climate input parameters

Climate data for the model are obtained from agro-meteorological station in Trinitapoli (Latitude Nord 41° 19' 16.22'''; Longitude East 16° 07' 45.25''; elevation: 16 m a.s.l.), South Italy (Puglia region), for the period 2014-2016. The agrometeorological station provides daily measurements of minimum, mean and maximum temperature, precipitation, and minimum, maximum, and means relative humidity, incoming solar radiation, and wind speed. These measurements are used to estimate daily reference evapotranspiration (ET_0). The model offers several possibilities in estimating ET_0, and in this case, the original Penman-Monteith equation was used. Figure 8 and Figure 9 present monthly averages of reference evapotranspiration and the sum of monthly rainfalls for the three observed years.

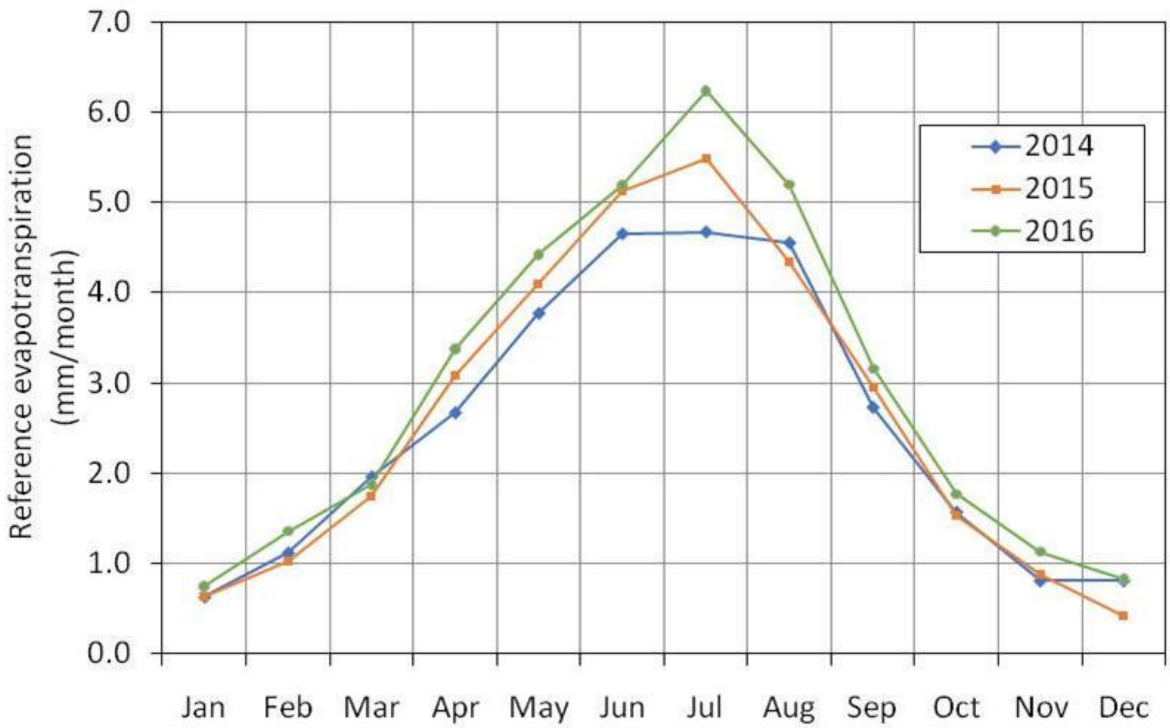

Fig. 8. Mean monthly reference evapotranspiration at Trinitapoli agro-meteorological station for the period 2014-2016.

In the year 2016, the mean summer months reference evapotranspiration was higher compared with the other two years. Nevertheless, in the year 2015, reference evapotranspiration during May, June, and July was also much higher compared with the year 2014. Therefore, regarding the demand of the atmosphere, the year 2016 was much demanding, followed by 2015, whereas the year 204 was much less demanding. Total annual rainfall in the years 2016 and 2015 were similar (540.6 mm and 544.4 mm respectively), whereas the amount of rainfall in the year 2014 was almost 100 mm lower (447.6 mm). In the vegetation period (March-October) the amount of rainfall was the highest in the year 2016 (403.0 mm), and a bit lower in the year 2015 (379.4 mm). In the year 2014, the amount of rainfall recorded in the vegetation period was significantly lower, 293.8 mm.

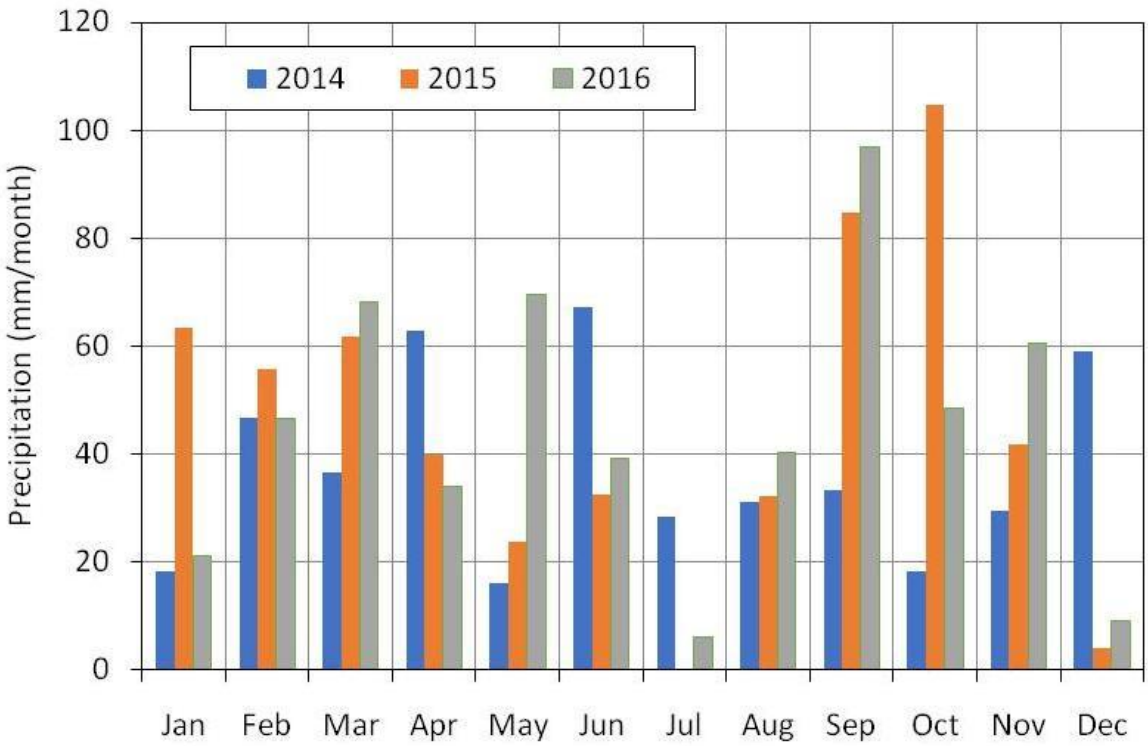

Fig. 9. Monthly rainfalls at Trinitapoli agro-meteorological station for the period 2014-2016.

3.2 Soil input parameters

The typical soils of the region are Eutric Fluvisols. Soil is very thick, deeper than 100 cm. It contains 140 mm of water per 1 m depth of soil. It has a loamy texture according to the USDA classification. It contains 39% sand, 40% silt, and 21% clay, in the 0-30 cm depth, whereas the particle size distribution does not change a lot in the subsoil. Soil bulk density along the soil profile has values around 1.40 g cm^{-3}. Gravel content in the topsoil and subsoil is 4 and 7%, respectively. Soil is slightly calcaric, 0.5 to 2.5% of $CaCO_3$ in the topsoil and subsoil, and rich in exchangeable bases. It has a neutral to slightly alkaline reaction with topsoil pH in the water of 7.2, and 7.5 in the subsoil, respectively. Cation exchange capacity in the topsoil and subsoil is moderate to low, 16, and 14 cmol kg^{-1}, respectively. Soil is poor with total organic carbon in topsoil and subsoil, 0.86 and 0.38%, respectively. The electrical conductivity of soil saturation extract is 3 dS/m throughout the entire thickness of the profile for the tomato crop, and 2 dS/m for peach, respectively. Soil water-holding characteristics are presented in Table 2..

Table 2. Soil water characteristics.

Soil Layers (top-down)	Depth [cm]	Soil texture	Field capacity [vol%]	Wilting point [vol%]	Soil water content [mm/m]
1st	0–50	loam	40	26	140
2nd	50–100	loam	37	23	140
3rd	100–120	loam	37	23	140

3.3 Crop input parameters

Simulations were conducted on two chosen crops: tomato and peach. The input parameters for the two crops are given in Tables 3, 4, 5, and 6. Tomato is known as a moderately sensitive crop to soil salinity whereas peach is a sensitive crop to salinity.

Table 3. Tomato crop and management input.

	Crop stage	Initial	Crop development	Mid-season	Late season	Harvesting	Total length
Growing days	Length	30	40	45	30	145	145
	Starting day	April-1	May-1	June-10	July-25	August-24	
Crop coefficients	K_c values	0.60	1.15	1.15	0.80	0.80	
	K_y values					1.10[3]	
	K_c basal	0.15	1.10	1.10	0.70		
Rainfall	Rainfall coefficient[1]	0.90	0.90	0.90	0.90	0.90	
	Rainfall minimum (mm)[2]	1.00					
Depletion fraction threshold		0.40	0.40	0.40	0.40		
Irrigation	Irrigation threshold[4]	0.40	0.40	0.40	0.40		
	Irr_supply_1	1.00	1.00	1.00	1.00		
	Irr_supply_2	0.00	0.00	0.00	0.00		
	Irr_efficiency	0.85	0.85	0.85	0.85		
	Irr_wet_coef	1.00	1.00	1.00	1.00		

[1]To be multiplied with rainfall to obtain effective rainfall

[2]minimum amount of rainfall to be included in the calculation; lower than 1 mm is considered no rainfall

[3]whole season value

[4]under deficit irrigation scenarios, irrigation threshold during the entire season was set to be 0.6 and irrigation amount should be fulfilled field capacity water content

Table 4. Additional tomato crop input.

Additional input parameters	
Number of days to stop irrigation before harvesting	10
$EC_{e,\ threshold}$ [dS m^{-1}] – mean electrical conductivity of the saturation extract for the root zone when crop yield first reduces below maximum	2.5
b [%/(dS m-1)] – reduction in yield per increase in EC_e	9.0
ECw [dS m^{-1}] – electrical conductivity of irrigation water above which the yield starts to reduce below maximum	1.7
Crop height [cm]	60
Initial root depth [cm]	20
Maximum root depth [cm]	60
Base temperature [°C]	10
Cutoff temperature [°C]	35

Table 5. Peach crop and management input.

Parameter	Crop stage	Initial	Crop development	Mid-season	Late season	Harvesting	Total length
Growing days	Length	30	60	100	30	145	220
	Starting day	Mar-1	Mar-31	May-30	Sept-7	Oct-7	
Crop coefficients	K_c values	0.50	0.90	0.90	0.70	0.70	
	K_y values					1.10[3]	
	K_c basal	0.15	0.85	0.85	0.50		
Rainfall	Rainfall coefficient[1]	0.90	0.90	0.90	0.90	0.90	
	Rainfall minimum (mm)[2]	1.00					
Depletion fraction threshold		0.40	0.50	0.50	0.50	0.50	
Irrigation	Irrigation threshold[4]	0.50	0.50	0.50	0.50		
	Irr_supply_1	1.00	1.00	1.00	1.00		
	Irr_supply_2	0.00	0.00	0.00	0.00		
	Irr_efficiency	0.85	0.85	0.85	0.85		
	Irr_wet_coef	1.00	1.00	1.00	1.00		

[1]To be multiplied with rainfall to obtain effective rainfall

[2]minimum amount of rainfall to be included in the calculation; lower than 1 mm is considered no rainfall

[3]whole season value

[4]under deficit irrigation scenarios irrigation threshold during the entire season was set to be 0.7 and irrigation amount should fulfill field capacity water content

Table 6. Additional peach crop input.

Additional input parameters	
Number of days to stop irrigation before harvesting	15
$EC_{e,\ threshold}$ [dS m^{-1}] – mean electrical conductivity of the saturation extract for the root zone when crop yield first reduces below maximum	1.7
b [%/(dS m-1)] – reduction in yield per increase in EC_e	21.0
ECw [dS m^{-1}] – electrical conductivity of irrigation water above which the yield starts to reduce below maximum	1.1
Crop height [cm]	180
Initial root depth [cm]	100
Maximum root depth [cm]	100
Base temperature [°C]	10
Cutoff temperature [°C]	35

3.4 Simulation results

3.4.1 Scenario 1 (The year 2014) – Tomato

The results of Scenario 1 demonstrate the ability of the model to run with different irrigation water salinity scenarios. Input parameters are given in the Table below.

Table 7. Scenario 1 input for tomato crop.

Input parameters	Full	Deficit
ECw [dS m^{-1}] – electrical conductivity of irrigation water	1, 2, 3, 4, 5	1, 2, 3, 4, 5
ECw [dS m^{-1}] – electrical conductivity of the saturation extract	1.5, 3, 4.5, 6, 7.5	1.5, 3, 4.5, 6, 7.5
Irrigation threshold = depletion threshold	0.4	0.6

The results of simulations for tomato crops are presented in Table 8.

- **Full irrigation:** For full irrigation, the obtained results indicate the maximum obtained yield in the scenario with the electrical conductivity of irrigation water below the threshold value of EC_w for tomato crop. The increase in ECw resulted in a relative yield decrease, reaching almost 50% reduction at ECw = 5 dS/m. After every irrigation event, the model is set to apply water up to field capacity water content. Consequently, the net irrigation requirement is the lowest at no salinity stress treatment, whereas in the stress treatments net irrigation requirement is 423.2 mm for all treatments. Anyway, due to salinity stress, one portion of this water is part of the leaching fraction (15%, or 65.1 mm), whereas the other part is drainage water. Leaching fraction remains the same in salinity stress treatments, whereas the drainage water increases with irrigation water salinity increase.
- **Deficit irrigation:** For deficit irrigation, the obtained results indicate the maximum obtained yield in the scenario with the electrical conductivity of irrigation water below the threshold value of EC_w for tomato crop. Anyway, a reduction of more than 10% was obtained. The increase in ECw resulted in a relative yield decrease, reaching a 50% reduction at ECw = 5 dS/m. After every

irrigation event, the model is set to apply water up to field capacity water content. Consequently, the net irrigation requirement is the lowest at no salinity stress treatment, whereas in the stress treatments net irrigation requirement is 364.5 mm for all the treatments. Anyway, due to salinity stress, one portion of this water is part of the leaching fraction (15%, or 56.1 mm), whereas the other part is drainage water. Leaching fraction remains the same in salinity stress treatments, whereas the drainage water increases with irrigation water salinity increase.

Table 8. Scenario 1 results for full and deficit irrigation for tomato crop, the year 2014.

Parameter	ECw = 1 dS/m	ECw = 2 dS/m	ECw = 3 dS/m	ECw = 4 dS/m	ECw = 5dS/m
Full irrigation					
Relative yield (%)	99.7	95.3	81.8	68.4	54.9
Number of days under stress	8	143	143	143	143
ET_c (mm)	564.3	541.6	472.3	403	333.7
ET_{max} (mm)	565.7	565.7	565.7	565.7	565.7
NIR (mm)	367.0	423.2	423.2	423.2	423.2
Rainfall (mm)	176.4	176.4	176.4	176.4	176.4
Drainage (mm)	28.7	86.3	148.7	212.9	279.4
Leaching fraction (-)	0.00	0.15	0.15	0.15	0.15
Leaching fraction (mm)	0.0	65.1	65.1	65.1	65.1
Depletion at harvest (mm)	51.6	30.2	23.1	17.7	14.7
WUE (kg/m^3)	10.6	10.6	10.4	10.2	9.9
IWUE(kg/m^3)	16.3	13.5	11.6	9.7	7.8
Deficit irrigation					
Relative yield (%)	89.8	86.5	74.2	61.8	49.5
Number of days under stress	66	143	143	143	143
ET_c (mm)	513.1	496.5	433	369.4	305.9
ET_{max} (mm)	565.7	565.7	565.7	565.7	565.7
NIR + LF (mm)	315.9	364.5	364.5	364.5	364.5
Rainfall (mm)	176.4	176.4	176.4	176.4	176.4
Drainage (mm)	56.1	112.8	164.3	215.9	267.5
Leaching fraction (-)	0.00	0.15	0.15	0.15	0.15
Leaching fraction (mm)	0.0	47.5	47.5	47.5	47.5
Depletion at harvest (mm)	78.9	70.3	58.1	45.9	33.6
WUE (kg/m^3)	10.5	10.5	10.3	10.0	9.7
IWUE (kg/m^3)	17.1	14.2	12.2	10.2	8.1

The comparison of water use efficiency and irrigation water use efficiency for full irrigation and deficit irrigation treatments is given in Figures 10 and Figure 11. Water use efficiency is always higher in a respectful full irrigation scenario compared with deficit irrigation scenarios. Water use efficiency decreases with an irrigation water EC increase, but the difference of less than 10% between the highest and the lowest values was observed.

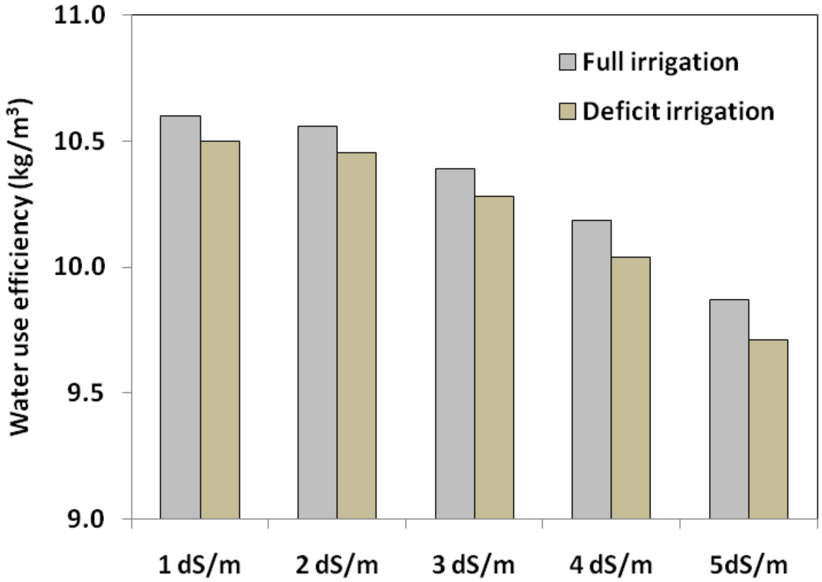

Fig. 10. Water use efficiency of tomato crop grown under full and deficit irrigation practices and different irrigation water quality.

The results of irrigation water use efficiency are much different. The values of IWUE decrease with an increase in ECw but too much compared with WUE. The lowest IWUE (8.1 kg/m^3) is more than twice lower compared with the highest IWUE (17.1 kg/m^3). On contrary to WUE, IWUE is always higher in deficit irrigation treatment compared with full irrigation treatment.

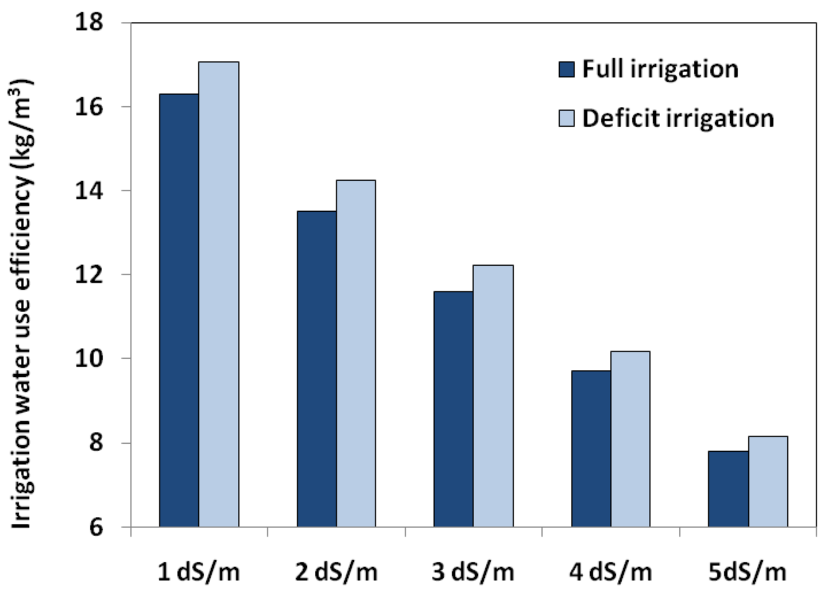

Fig. 11. Irrigation water use efficiency of tomato crop grown under full and deficit irrigation practices and different irrigation water quality.

3.4.2 Scenario 1 (The year 2014) – Peach

The results of Scenario 1 demonstrate the ability of the model to run with different irrigation water salinity scenarios. Input parameters are given in box 1 below.

Table 9. Scenario 1 input for the peach crop.

Input parameters	Full	Deficit
ECw [dS m^{-1}] – electrical conductivity of irrigation water	1, 2, 3, 4, 5	1, 2, 3, 4, 5
ECw [dS m^{-1}] – electrical conductivity of the saturation extract	1.5, 3, 4.5, 6, 7.5	1.5, 3, 4.5, 6, 7.5
Irrigation threshold = depletion threshold	0.5	0.7

The results of simulations for peach are presented in Table 10.

- **Full irrigation:** The obtained results indicate the maximum obtained yield in the scenario with the electrical conductivity of irrigation water below the threshold value of EC_w for tomato crop. The increase in ECw resulted in a relative yield decrease, reaching more than 50% reduction at ECw = 3 dS/m. After every irrigation event, the model is set to apply water up to field capacity water content. Consequently, the net irrigation requirement is the lowest at no salinity stress treatment, whereas in the stress treatments net irrigation requirement is 497.3 mm for all treatments. One portion of this water is part of the leaching fraction (64.9 mm), whereas the other part is drainage water. Leaching fraction remains the same in salinity stress treatments, whereas the drainage water increases with irrigation water salinity increase.
- **Deficit irrigation:** The obtained results indicate the maximum obtained yield in the scenario with the electrical conductivity of irrigation water below the threshold value of EC_w for tomato crop. Anyway, a reduction of 6.1% was obtained. The increase in ECw resulted in a relative yield decrease, reaching a 50% reduction of yield at ECw 2.7 dS/m. After every irrigation event, the model is set to apply water up to field capacity water content. Consequently, the net irrigation requirement is the lowest at no salinity stress treatment, whereas in the stress treatments net irrigation requirement is 343.8 mm for all treatments. One portion of this water is part of the leaching fraction (44.8 mm), whereas the other part is drainage water. Leaching fraction remains the same in salinity stress treatments, whereas the drainage water increases with irrigation water salinity increase.

Table 10. Scenario 1 results for full and deficit irrigation for a peach crop, the year 2014.

Parameter	ECw = 1 dS/m	ECw = 2 dS/m	ECw = 3 dS/m	ECw = 4 dS/m	ECw = 5dS/m
Full irrigation					
Relative yield (%)	99.9	72.6	41.1	9.7	No yield
Number of days under stress	5	196	196	196	
ET_c (mm)	630.9	474.4	293.7	113	
ET_{max} (mm)	631.6	631.6	631.6	631.6	
NIR (mm)	430.7	497.3	497.3	497.3	
Rainfall (mm)	239.6	239.6	239.6	239.6	
Drainage (mm)	69	264	444.1	624.2	
Leaching fraction (-)	0	0.15	0.15	0.15	
Leaching fraction (mm)	0	64.9	64.9	64.9	
Depletion at harvest (mm)	30.2	1.9	1.2	0.5	
WUE (kg/m^3)	15.8	15.3	14.0	8.6	
IWUE (kg/m^3)	23.2	14.6	8.3	2.0	
Deficit irrigation					
Relative yield (%)	93.9	68.0	38.3	8.6	No yield
Number of days under stress	29	196	196	196	
ET_c (mm)	596.4	447.8	277.3	106.7	
ET_{max} (mm)	631.6	631.6	631.6	631.6	
NIR + LF (mm)	295.9	343.8	343.8	343.8	
Rainfall (mm)	239.6	239.6	239.6	239.6	
Drainage (mm)	32.3	197.9	332.9	481.4	
Leaching fraction (-)	0	0.15	0.15	0.15	
Leaching fraction (mm)	0	44.8	44.8	44.8	
Depletion at harvest (mm)	93.8	62.8	27	4.8	
WUE (kg/m^3)	15.7	15.2	13.8	8.1	
IWUE (kg/m^3)	31.7	19.8	11.1	2.5	

The comparison of water use efficiency and irrigation water use efficiency for full irrigation and deficit irrigation treatments is given in Figure 12 and Figure 13. Water use efficiency is always higher in respectful full irrigation scenarios compared with deficit irrigation scenarios. Water use efficiency decreases with an irrigation water EC increase. The highest ECw treatment (4 dS/m) has very low water use efficiency compared with other treatments.

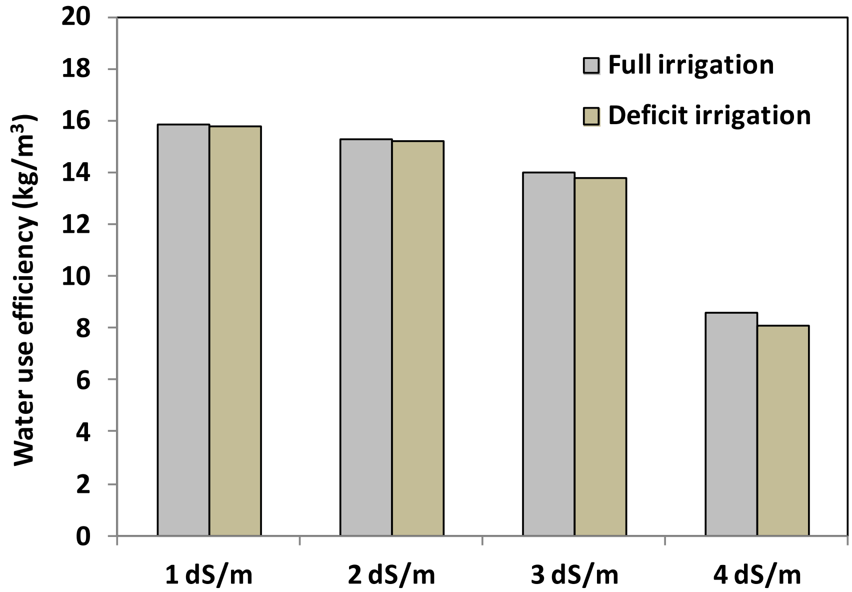

Fig. 12. Water use efficiency of peach grown under full and deficit irrigation practices and different irrigation water quality.

The values of IWUE decrease with an increase in ECw but to a higher extent compared with WUE. The difference between IWUE between the treatments is very high for both full and deficit irrigation. IWUE is always higher in deficit irrigation treatment compared with full irrigation treatment.

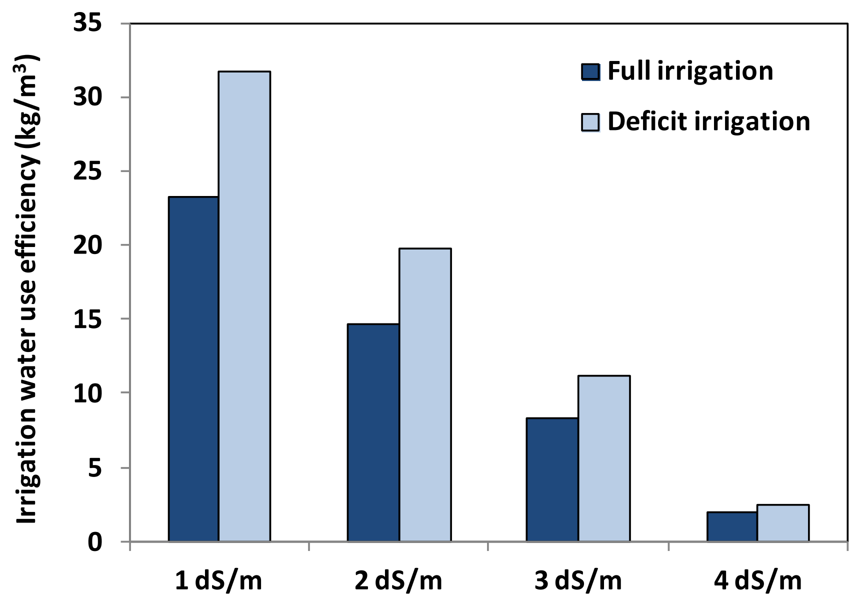

Fig. 13. Irrigation water use efficiency of peach grown under full and deficit irrigation practices and different irrigation water quality.

3.4.3 Scenario 1 (The year 2015) – Tomato

The results for scenario 1, tomato crop, fully irrigated, are presented in Table 11.

Table 11. Scenario 1 results for full and deficit irrigation for tomato crop, the year 2015.

Parameter	ECw = 1 dS/m	ECw = 2 dS/m	ECw = 3 dS/m	ECw = 4 dS/m	ECw = 5dS/m
Full irrigation					
Relative yield (%)	99.6	95.2	81.8	68.3	54.8
Number of days under stress	12	143	143	143	143
ET_c (mm)	615.3	590.8	515.2	439.6	364
ET_{max} (mm)	617.6	617.6	617.6	617.6	617.6
NIR (mm)	491.1	569.9	569.9	569.9	569.9
Rainfall (mm)	112.9	112.9	112.9	112.9	112.9
Drainage (mm)	20.7	96.3	171.3	246.4	321.4
Leaching fraction (-)	0.00	0.15	0.15	0.15	0.15
Leaching fraction (mm)	0.0	74.3	74.3	74.3	74.3
Depletion at harvest (mm)	34.3	6.4	5.6	4.8	4
WUE (kg/m^3)	9.7	9.7	9.5	9.3	9.0
IWUE (kg/m^3)	12.2	10.0	8.6	7.2	5.8
Deficit irrigation					
Relative yield (%)	89.8	86.5	74.2	61.8	49.5
Number of days under stress	66	143	143	143	143
ET_c (mm)	513.1	496.5	433	369.4	305.9
ET_{max} (mm)	565.7	565.7	565.7	565.7	565.7
NIR + LF (mm)	315.9	364.5	364.5	364.5	364.5
Rainfall (mm)	176.4	176.4	176.4	176.4	176.4
Drainage (mm)	56.1	112.8	164.3	215.9	267.5
Leaching fraction (-)	0.00	0.15	0.15	0.15	0.15
Leaching fraction (mm)	0.0	47.5	47.5	47.5	47.5
Depletion at harvest (mm)	78.9	70.3	58.1	45.9	33.6
WUE (kg/m^3)	10.5	10.5	10.3	10.0	9.7
IWUE (kg/m^3)	17.1	14.2	12.2	10.2	8.1

- Full irrigation: The obtained results indicate the maximum obtained yield in the scenario with the electrical conductivity of irrigation water below the threshold value of EC_w for tomato crop. The increase in ECw resulted in a relative yield decrease, reaching almost 50% reduction at ECw = 5 dS/m. The obtained results indicate the higher crop water requirements in the year 2015 compared with the year 2014. This was partially due to lower amounts of rainfall during the vegetative season, 63.5 mm less. Consequently, net irrigation applied was 146.1 mm higher in the more saline water treatments. Leaching amounts are also higher in the year 2015, as well as drainage water. This has resulted in lower WUE and IWUE compared with the year 2014. The trend in WUE and IWUE decrease with irrigation water quality deterioration was present as in the year 2014.

- Deficit irrigation: The obtained results indicate the maximum obtained yield in the scenario with the electrical conductivity of irrigation water below the threshold value of EC_w for tomato crop. A reduction in yield of more than 10% was obtained. The increase in ECw resulted in a relative yield decrease, reaching a 50% reduction at ECw = 5 dS/m. Net irrigation requirement is the lowest at no salinity stress treatment, whereas in the stress treatments net irrigation requirement is 423.2 mm for all the treatments, and it is 58.7 mm higher compared with the same treatments in the year 2014. The leaching fraction is consequently lower compared with full irrigation treatment.

The trends in WUE and IWUE are the same. They both decrease with lower irrigation water quality. Both WUE and IWUE are always higher in deficit irrigation treatments compared with respectful full irrigation scenarios. Compared with the year 2014, IWUE and WUE are lower which can be contributed to a lower amount of rainfall, higher crop water requirements, and consequently higher net irrigation requirements.

3.4.4 Scenario 1 (The year 2015) – Peach

The results for scenario 1, peach, fully irrigated, are presented in Table 12. The increase in ECw resulted in a relative yield decrease, reaching almost 50% reduction at ECw = 2.7 dS/m. The obtained results indicate around 50 mm higher crop water requirements in the year 2015 compared with the year 2014. This was due to higher evaporative demand in the year 2015. Consequently, net irrigation applied was around 50 mm higher in the more saline water treatments. Leaching amounts are also higher in the year 2015, as well as drainage water. This has resulted in lower WUE compared with the year 2014, whereas the IWUE was very similar. The trend in WUE and IWUE decrease with irrigation water quality deterioration was present as in the year 2014. The reduction in yield for deficit irrigation treatment was almost 10% compared with the respectful fully irrigated treatment. The increase in ECw resulted in a relative yield decrease, reaching a 50% reduction at ECw = 5 dS/m. Net irrigation requirement is the lowest at no salinity stress treatment, whereas in the stress treatments net irrigation requirement is 459.6 mm for all the treatments, and it is 115.8 mm higher compared with the same treatments in the year 2014. The leaching fraction is consequently higher in the year 2015 compared with the year 2014.

The trends in WUE and IWUE are the same. They both decrease with lower irrigation water quality. Both WUE and IWUE have similarly valued in deficit and full irrigation treatments. Compared with the year 2014, IWUE and WUE are lower which can be contributed to higher net irrigation requirements, and a lower number of irrigation events in the year 2014.

Table 12. Scenario 1 results for full and deficit irrigation for a peach crop, the year 2015.

Parameter	ECw = 1 dS/m	ECw = 2 dS/m	ECw = 3 dS/m	ECw = 4 dS/m	ECw = 5dS/m
Full irrigation					
Relative yield (%)	99.9	72.6	41.1	9.7	No yield
Number of days under stress	6	196	196	196	
ET_c (mm)	680.5	511.5	316.7	121.8	
ET_{max} (mm)	681.3	681.3	681.3	681.3	
NIR (mm)	432.9	501.8	501.8	501.8	
Rainfall (mm)	242.8	242.8	242.8	242.8	
Drainage (mm)	49.3	243.4	433.4	624.6	
Leaching fraction (-)	0.00	0.15	0.15	0.15	
Leaching fraction (mm)	0.0	65.5	65.5	65.5	
Depletion at harvest (mm)	54.8	10.9	5.8	2.0	
WUE (kg/m^3)	14.7	14.2	13.0	8.0	
IWUE (kg/m^3)	23.1	14.5	8.2	1.9	
Deficit irrigation					
Relative yield (%)	91.5	65.8	36.9	8.0	No yield
Number of days under stress	52	196	196	196	
ET_c (mm)	628.8	469.2	290.5	111.8	
ET_{max} (mm)	681.3	681.3	681.3	681.3	
NIR + LF (mm)	395.6	459.6	459.6	459.6	
Rainfall (mm)	242.8	242.8	242.8	242.8	
Drainage (mm)	55.6	243.5	417.5	592.6	
Leaching fraction (-)	0.00	0.15	0.15	0.15	
Leaching fraction (mm)	0.0	59.9	59.9	59.9	
Depletion at harvest (mm)	46.8	10.9	5.8	2.0	
WUE (kg/m^3)	14.6	14.0	12.7	7.2	
IWUE (kg/m^3)	23.1	14.3	8.0	1.7	

3.4.5 Relative yield vs. irrigation water quality

The model computes the relative yield of crops. Figure 14 present the variety of tomato and peach relative yields for full and deficit irrigation treatments concerning irrigation water quality. On one side, the results of simulations indicate that tomato crops can be grown with electrical conductivity of irrigation water near 5 dS/m, with a double reduction in yield compared to fully irrigated treatment. On the other side, peach yield reduced by 50% is obtained already at the electrical conductivity of irrigation water at 2.7 dS/m. To mention again, tomato is a moderately sensitive crop to irrigation water salinity, whereas peach is a sensitive crop.

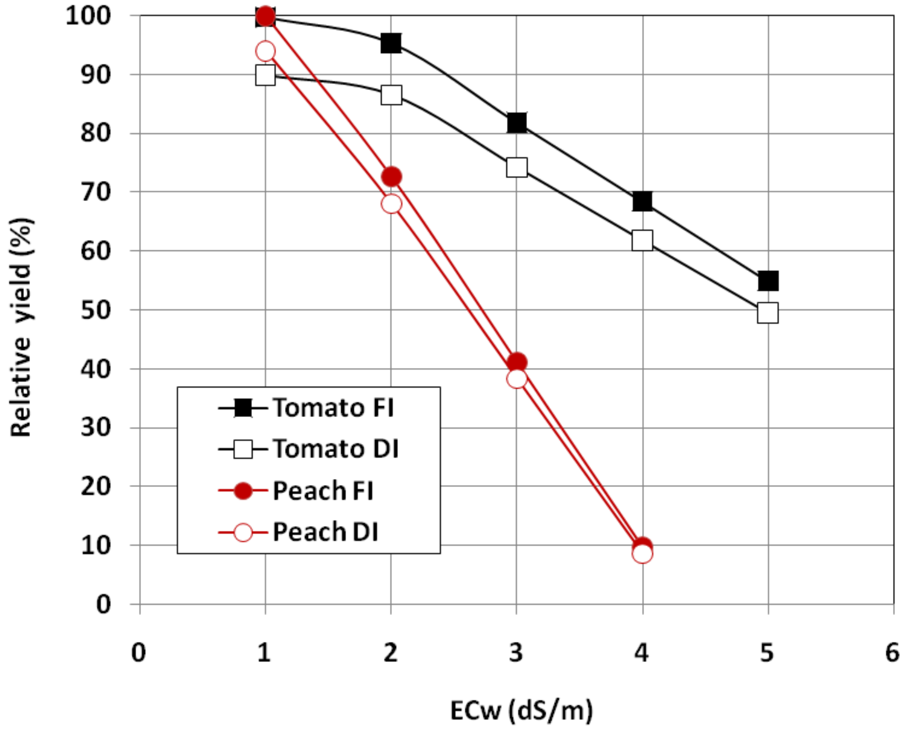

Fig. 14. Relative yields of tomato and peach under different management regimes and different irrigation water quality.

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