MENAWARA

WP4. IMPROVE USE EFFICIENCY OF NON-CONVENTIONAL WATER IN AGRICULTURE

Output 4.2. Living Labs equipped with TWW Irrigation trains adapted to local contexts

A 4.2.1 Design, equipment and operationalization of the demo sites. Ramtha, Jordan

Responsible partner: NARC

30/10/2023

Menawara is a project funded by the EU unded the ENI CBC Med programme. Its total budget is €2.901.546,93 out of which €2.611.392,23 as EU funding (90% contribution).

This document has been produced with the financial assistance of the European Union under the ENI CBC Mediterranean Sea Basin Programme. The contents of this document are the sole responsibility of NARC and can under no circumstances be regarded as reflecting the position of the European Union or the Programme management structures.

The 2014-2020 ENI CBC Mediterranean Sea Basin Programme is a multilateral Cross-Border Cooperation (CBC) initiative funded by the European Neighbourhood Instrument (ENI). The Programme objective is to foster fair, equitable and sustainable economic, social and territorial development, which may advance cross-border integration and valorise participating countries' territories and values. The following 13 countries participate in the Programme: Cyprus, Egypt, France, Greece, Israel, Italy, Jordan, Lebanon, Malta, Palestine, Portugal, Spain, Tunisia. The Managing Authority (JMA) is the Autonomous Region of Sardinia (Italy). Official Programme languages are Arabic, English and French. For more information, please visit:www.enicbcmed.eu.

The European Union is made up of 28 Member States who have decided to gradually link together their know-how, resources and destinies. Together, during a period of enlargement of 50 years, they have built a zone of stability, democracy and sustainable development whilst maintaining cultural diversity, tolerance and individual freedoms. The European Union is committed to sharing its achievements and its values with countries and peoples beyond its borders.

TABLE OF CONTENT

ABBREVIATIONS AND ACRONYMS

Acronym	Description
DI	Drip Irrigation
Φ	Diameter
WUA	Water Users' Association
LL	Living Lab
MoA	Ministry of Agriculture
SDI	Surface Drip Irrigation System
SIM	Safe Irrigation Management
TWW	Treated Wastewater
VC	Village Council
WP	Work Package
WWTP	Wastewater Treatment plant
NARC	National Agricultural Researc Center

1. Background

This technical report has been written in the context of the MENAWARA project on *Non-conventional Water Re-use in Agriculture in Mediterranean countries.*

The joint challenges of the MENAWARA project consist in providing additional resources by recycling drainage and wastewater, rationalizing water use practices and setting operational governance models in line with national and international plans. The project is designed to enhance access to water through the treatment of wastewater to be re-used as complementary irrigation and to strengthen the capacity of governmental institutions, non-state actors operating in the sector, technicians, and farmers.

The report reports the activities carried out in the fourth Work Package (WP4) of the MENAWARA project and, in particular, is related to the **Output 4. 2 "Living Labs equipped with TWW Irrigation trains adapted to local contexts"** and **Activity 4.2.1 "Design, equipment and operationalization of the demo sites"** as described in infographic below (Figure 1).

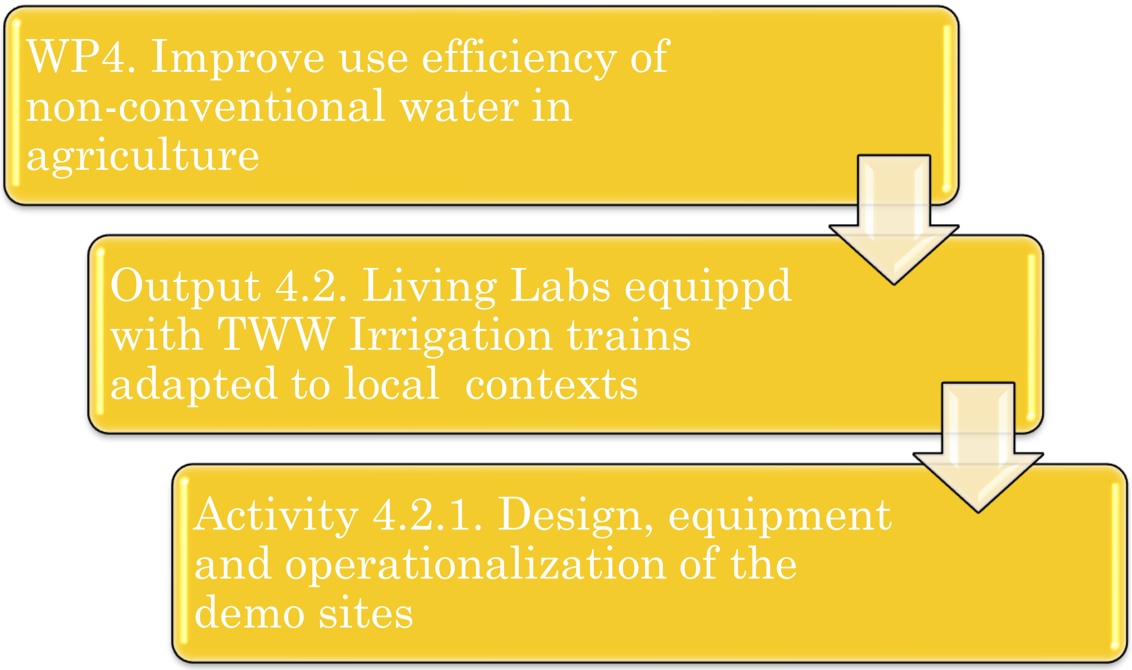

Figure 1. Infographic on the context of this technical report.

This is the second output related to the intervention in Ramtha, following the agronomic characterization and water and irrigation appraisal (Activity 4.1.1) whose report has been submitted on February 2020.

More specifically the output 4.2 is described as follows: "Based on the findings of output 4.1, the irrigation trains combining technologies and techniques are identified and implemented in the intervention areas and their operative performance and their impact on water use efficiency and productivity on health and on groundwater are monitored."

This document details the technical aspects of the irrigation trains realised in Ramtha over the period of December 2020 to May 2023 as part of Activity 4.2.1 "Design, equipment and operationalization of the demo sites".

A Living Lab's implementation document has been shared by CIHEAM BARI and NRD-UNISS to support partners in jointly developing and testing innovations within a network formed of public and private stakeholders in the framework of an open innovation process.

2. Area of intervention

Ramtha is a city located north of Jordan, in the Irbid Governorate near the border with Syria as shown in Figure 2. The city's population reached about 164 thousand with 90% of households connected to the sewer network. It covers 40 km^2 on a plain 30 km northeast of the Jordan River and Irbid. Ramtha experiences a Mediterranean climate. The summer is hot and long (four months in average), but it has cool nights.

MENAWARA has started its activity in Ramtha Experimental Station for Treated Wastewater Studies of the National Agricultural Research Center (NARC), located in Ramtha at first and later on 4.5 ha or dunums belonging to 9 farmers.

The below Table 1 shows the location coordination and the distance in between each pilot site and the treatment plant.

Table 1. Pilot sites locations

Farmer Name	**Distance to treatment unit(m)**	**Location coordination**	
		Longitude	Latitude
Ali Salim Al-Zoubi	520	35.98125	32.59204
Shibli Shiboul	220	35.98661	32.59141
Abdel Fattah Al-Wardat	470	35.98867	32.59086
Tayseer Al-Masry	750	35.98443	32.59654
Issa Khaza'leh	490	35.98895	32.59054
Ahmad Al-Khaza'leh	870	35.97978	32.58982
Ahmed El Rizk	One line with 950 m	35.98942	32.5969
Ahmed Shara		35.98909	32.59778
Khaled Karaki		35.98933	32.59573
Sum	4270		

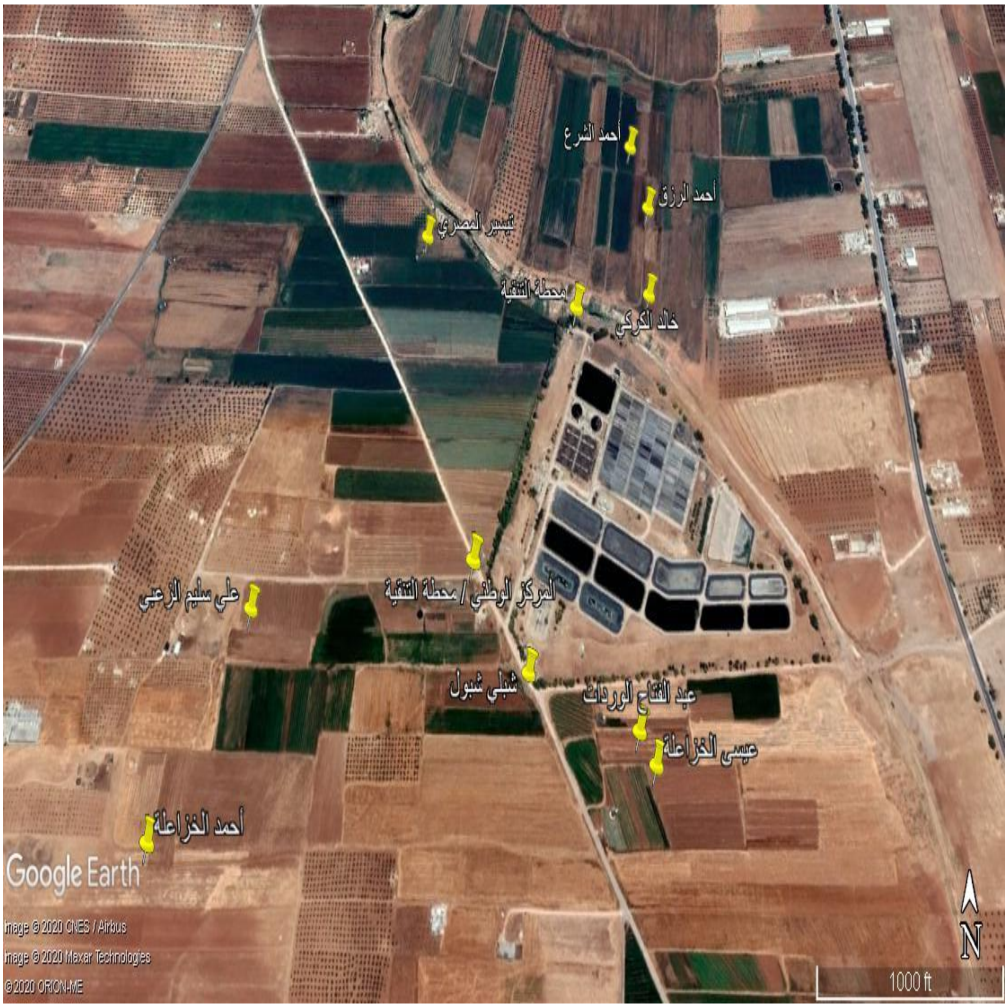

Figure 1. pilot sites locations

The area of intervention for SDI system with TWW covers comprises 9 plots cropped with Alfalfa crops. The crops, area and irrigation requirements for the plots irrigated with the TWW from the WWTP of Ramtha treatment plant are shown in **Errore. L'origine riferimento non è stata trovata.**. The location of the plots is also visualized in **Errore. L'origine riferimento non è stata trovata.**. The listed material in Table 2 were supplied to the Pilot sites by the MENAWARA project.

Table 2. The SDI system: Material and Specification supplied and installed

Item	Unite	Quantity	Specification
PE 90mm	m	7845	Original non-recycle material/ purple color 12 bar pressure
Techline DL dripline 16 mm GR inline dripper for subsurface irrigation system	m	95000	Pressure Compensated Non-Leakage (PC-NL) drippers 2Lph 30 cm between drippers/purple color
T20x16x20 mm	#	3000	Proper connection for subsurface irrigation
PE End line 16mm	#	3000	Original non-recycle material/purple color
HC Flow Meter - 3" (90 mm) BSP thread	#	7	The flow meter consists of two parts: 1. Flow meter body: The flow meter body contains an analog dial for manual readings as follows. The meter will have three wires to be connected to the sensor inputs on the controller for remote measurement. In all models, protruding from the flow meter's body. The wires need 2. Adapter: Each flow meter has an adapter to allow connection to the irrigation system
Solenoid valve	#	7	24 VAC solenoid: 350 mA inrush, 190mA holding, 60 HZ -Size (50 mm) External and internal manual bleed allows quick and easy "at the valve" activation, Double-beaded diaphragm seal design for superior leak free performance Encapsulated 24 VAC solenoid with captive plunger for hassle-free service
Pressure regulated valve 3"	#	9	
Air relief valves	#	18	
Water Pump		2	Min Q 12 lps at 120m Head

3. Establishment and operationalization of the living lab

Since 1993, NARC has been engaging with key stakeholders of Ramtha around the perceptions and value of treated wastewater in the location with the aim of identifying and establishing a living lab (LL) for the MENAWARA project. Through MENAWARA, the living lab was operationalized in Ramtha to design, through interactions and debates, the best solution for the water scarcity problem of the area including the design of the irrigation network of Ramtha. The living lab of Ramtha including various stakeholders such as 9 farmers and the Ministry of Water and Irrigation (MoWI), were organized (Figure 4) to discuss and share knowledge, raise awareness about the need to use TWW, the design of the network, technical considerations, and analyses to be performed, capacity building needs, governance issues and the operation and maintenance aspects.

A focus group meeting (Fig. 2) with farmers who are irrigating their forage crops by the treated wastewater was conducted at NARC's Ramtha Station in order to discuss the main opportunities and challenges while using the treated waste water.

Figure 2. Focus group meeting with stakeholders at NARC's Ramtha Research Station

The meeting's main results can be summarized as follows:

- All the farmers are used to adopt the surface irrigation system to irrigate forage crops, whose figures are listed in Table 7, and they are suffering from the following:
- They did a contract with water authority to get the TWW from Ramtha WWTP according to a weekly schedule (water turn). The supplied TWW is not sufficient to irrigate all their land mainly because they are using surface flood irrigation.
- Management of TWW is a problem: TWW demands occur at the same time for all the farmers, and there are no storage facilities for the TWW and they don't have a water meter in each farm.

- The water authority is responsible to do TWW management and distributing water among farmers according to their own land surface area.
- They don't have on-farm water collection pools or tanks, they consider helping them in initiating that water collection structures is a huge benefit to solve one of the main water problems.

The farmers would have liked and would have been very enthusiastic to replace the surface irrigation by sprinkler or subsurface irrigation system. However, the Jordanian standard prevents from using the sprinkler for TWW irrigation. Farmers think that using sprinkler irrigation will enable them to irrigate all their rented land, enhance the efficiency of fertilizers, facilitate some management practices such as drying the land before harvesting as they stop the surface irrigation two weeks before Alfalfa crops harvest.

It is worth to mention that, according to the official numbers, only 1 ha from the irrigated area could be irrigated with TWW, while according to farmers, out of the total area around Ramtha' WWTP contracted to the water authority to irrigate with TWW, equal to 120 ha, 75 ha are actually irrigated with TWW (Table 3).

Till 2001, Alyarmouk Agricultural Association was responsible for the management of water distribution among farmers. That association stopped and was canceled in 2001. Currently, there are no water users' associations or agricultural associations. At the end of the meeting, farmers were informed that the MENAWARA project would have carried out experiments to test the efficiency of different irrigation systems inside the NARC's Research Station in the first year. In the second year, the activities would have been carried out with the active participation of the farmers in their own plot. All the farmers welcomed the project.

Table 3. list of figures according to the farmers

The total area around Ramtha WWTP that has a contract with water authority in order to use the TWW.	About 120 ha
The total area cultivated with Forages around Ramtha WWTP that is actually irrigated by TWW	About 75 ha
Over all the 120 ha around Ramtha WWTP	7 ha in owned by farmer 113 ha are rented from other "private"
TWW cost	570 JD/ha/year
Currant TWW price	0.05 JD/m³
Old TWW price	0.02 JD/m³
Land rent cost	300-500 JD/ha
Forage price :	
Dried clover	200 JD/ton
Green clover	35 JD/ton
Forage corn	35 JD/ton

During the project, different activities have been carried out in order to operationalize the living lab described in the below table.

Table 4. Overview of performed works to operationalize the living lab

Performed work	Description
Design of the irrigation network	After multiple meetings with the key stakeholders of the living lab of NARC, an irrigation network design was finalized by CIHEAM Bari and NARC team
First experiment at the NARC's research center	Assessment of the impact of different irrigation methods on alfalfa yield quantity and quality to identify the most appropriate to be further installed in farmers' plots.
Design and developed a machine for installing sub-surface drip irrigation lateral at 205 cm below soil surface level	This machine can install and bury 4 laterals under the soil surface in the same time at different depths and spacing
Installation of SUB- Surface drip irrigation systems of 9 plots including installation of flowmeters, fertilizers injectors sand and disc filters	The details of the installed materials can be seen in Table 2.

For a proper functioning and sustainability of the irrigation scheme and operationalization of the Living Lab, a Memorandum of Understanding was signed between NARC and each selected farmer identifying the responsibilities of each part as follows:

- NARC committed itself in providing farmers with the subsurface irrigation systems including the irrigation pipe, a subsurface irrigation network with sand filter, screen filter, and a water meter, fertilizer injector as well as 50 kg/ha alfalfa seeds. Farmers will be supported as well with ad hoc training.
- Farmers committed themselves in maintaining the irrigation network and its accessories, as well as to continue cultivating the land for a further 5 years.

Before the installation and operationalization of the irrigation network at each plot, a baseline assessment of the soil analysis was done.

Along the project duration, multiple visits to the farmers were conducted, as well as exchange visits with the farmers abroad and multiple training sessions as part of operationalizing the living lab, as described under Output 5.1 'Capacity building plan and training sessions".

Farmers' Capacity building sessions have been conducted and covered topics such as optimal water management of growing forage crops under TWW conditions, agricultural best practices, as well as maintenance of the irrigation system.

These training sessions have positively impacted on the knowledge of people and has raised discussions that are crucial to strengthen the knowledge of farmers. The Ramtha's farmers are developing their professional knowledge and effective WWTP management system, as well as the usage of TWW in agriculture.

4. Design of the irrigation systems at the Demo site

The first activity was carried out from December 2020 to October 2021 at Ramtha's Experimental Station for Treated Wastewater Studies of the National Agricultural Research Center (NARC), located at Ramtha area, 88 km north of Amman, Jordan. Ramtha.

The objective of the activity was to investigate the impact of different irrigation methods on alfalfa yield quantity and quality using the treated wastewater under the semi-arid condition. The Complete Randomized Plot Design was used to investigate using four different irrigation methods namely sprinkler, surface (Basin), drip and subsurface. Each plot had a size of 5×5 m with 3m intra spacing and the four irrigation methods were replicated four times in randomly distribution. Applied irrigation water were calculated based on Penman-Monteith equation using CropWat software considering the used irrigation system efficiency.

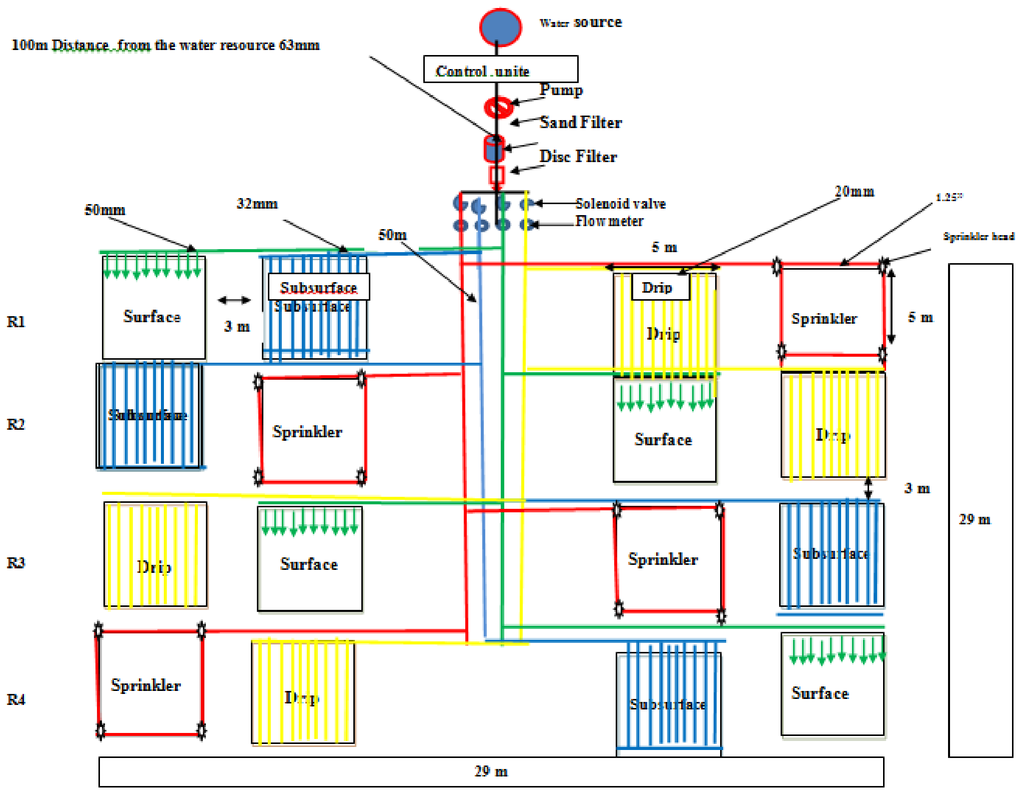

Figure 3. Experiment at the NARC's plot

Results indicated that surface irrigation gave the highest alfalfa fresh yield without a significant difference in comparison with the subsurface irrigation. The average alfalfa fresh productivity was 123, 120, 109 and 91 ton h-1 for surface, subsurface, drip and sprinkler irrigation methods, respectively. The average increases in the alfalfa fresh weight obtained from subsurface irrigation were 32% and 10% compared to sprinkler and drip irrigation, respectively. The subsurface and drip irrigation methods significantly increased the dry yield compared to surface and sprinkler irrigation. The average increases in the alfalfa dry weight obtained from subsurface irrigation were 10%, 21% and 47% compared to drip, surface and sprinkler irrigation, respectively. Na, Cl and Fe of alfalfa leaves content were significantly higher in alfalfa leaves irrigated by sprinkler irrigation, compared to other irrigation methods. Moreover, N percentage was significantly lower in alfalfa leaves irrigated by subsurface irrigation method in comparison with the other three irrigation methods. Neither *E.coli* nor FC were detected on the alfalfa leaves when using subsurface irrigation. However, *E.coli* and FC counts were highly presents on the leaves irrigated by sprinkler, and it is also highly presents in the lower part of the plant when surface irrigation is adopted. The results prove the presence of high risk of pathogens in sprinkler and surface irrigation methods with this quality of water. Subsurface irrigation might be adapted as an efficient irrigation methods when using non-conventional water resources under the semi-arid condition. (Further information about results could be found in D.4.3).

5. Decision support system: TWW irrigation plan

The study area in Ramtha was assessed to design proper irrigation plan to alfalfa cultivation by comparing 4 irrigation systems, in synergy with the Master Science in Sustainable Water and Land Management in Agriculture at the Mediterranean Agronomic Institute of Bari within a Master thesis entitled: Combining Field Experiments and Modelling for a No Harm Irrigation Management with Treated Wastewater: Case Studies from Jordan And Palestine.

The research sought to harmonizing field-collected data in 2021 and calibrating the Safe Irrigation Management (SIM), a one-dimensional, daily water balance model in Ramtha (Jordan), on alfalfa, ii) simulating with SIM scenarios with TWW accounting for water quantity and quality inputs; iii) identifying the best/no harm irrigation management practice tailored to TWW. With this regard, two scenarios were identified to run SIM model 1) farmer planning, referring to the model calibration FARMOD; 2) ON-DEMAND referring to the irrigation schedule suggested by SIM.

Furthermore, to assess whether generated outputs by the model using current inputs reflects proper TWW irrigation management, an optimal scenario was also set up since current inputs referring to long TWW management may imply a reduction in the model accuracy. Further scenario was thus considered as optimal considering water and soil input data referring to better quality condition (proper soil and water quality), and gathered by assuming agro hydrological practices as strategy to tackle long term TWW management as Jordan context.

By integrating the monitoring with a modelling, it was thus predicted proper TWW requirements being the computation based on not only initial soil conditions, and soil properties, but also on the water quality.

In detail, the methodology was set up as follows: by considering -) a monitoring phase which considers a data set regarding crop, water, and soil quality parameters; -) a modelling phase where used the data set collected as input in the SIM model to perform the first run to generate the calibration of the model, called FARMOD scenario. By performing the calibration, the accuracy of the model is tested, and the same farmer behaviour is reproduced through the model. Yet, the input and output of the first run are extended to identify appropriate irrigation management by optimizing water quality and quantity parameters and by running different scenarios, the best output scenario selected, called ON-DEMAND scenario, where irrigation management is identified by selecting threshold values in the model to not be exceed. Sensitivity analysis was performed on the model output to choose the most sensitive parameters that require long-term monitoring.

SIM is a one-dimensional daily water balance model that employs the single crop coefficient method (single Kc) (Daccache,2020). The model may create irrigation scheduling options, assist with farm irrigation scheduling, and evaluate the impact of variable water quality on water balance. SIM has four modules (figure 4) that are suitable to various meteorological, agricultural, soil, water quality, and irrigation methods situations.

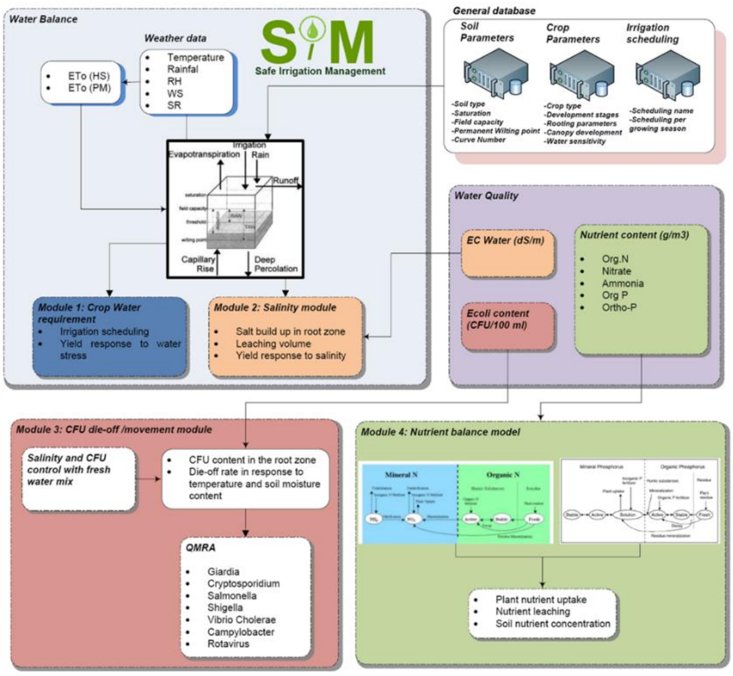

Figure 4. SIM model layout (Source: Dacchache,2020).

Before testing the methodology above described, a technical visit to Jordan's experimental field was also carried out in July 2022 (figures 5).

Figure 5. Field experiment and NARC

The experimental field concerned four irrigation schedules according to irrigation type: surface, sprinkler, sub-surface, and drip irrigation. Each system is connected by a separated pipe coming directly from the treatment station (Figure 6).

Figure 6. Types of irrigation system.

During the field visit, it was highlighted such aspects related to the soil status. From a quality point view, it was observed, since it is Vertisol soil, cracks due to salt accumulation and low soil aeration. This might be owing to the low infiltration rate and salt accumulation in sites that have been induced with low-quality treated wastewater for an extended length of time, resulting in a high percentage of cracks not allowing the water to move through the soil, especially using a surface irrigation system.

In detail, the study was carried out as follows: 4 scenarios were set up by using SIM model in order to rebuild the soil and nutrient behaviour under famer irrigation management (FARMOD). The same simulations were run again but based on the model scheduling (ON-DEMAND). To FARMOD scenario was considered a biweekly irrigation schedule with an average volume of 3 to 4 mm.

Overall, a yearly irrigation volume was provided: 1044 mm with the surface irrigation, 969.7 mm for sprinkler irrigation,798.6mm for drip irrigation and 754.1 mm for subsurface irrigation.

The results highlight as remains a challenge identifying an irrigation management plan to adopt when TWW is being used continuously. In this framework, this study aimed at shedding light on the importance of selecting appropriate irrigation scheduling tailored for TWW relied on a methodology that coupled monitoring and modelling.

Four different irrigation systems (drip, surface, sprinkler, and subsurface) tested through all the simulations shown that when alfa-alfa was sub-surface irrigated, 17 250 kg/ha yield was produced according to the ON-DEMAND scenario, as compared to 15 600 kg/ha in the FARMOD scenario. Regarding salinity, ECe for alfa-alfa differs along the four irrigation systems, the ON-DEMAND showed lower values of ECe compared to the FARMOD scenario.

Improving water quality and implementing agro-hydrological practices are critical points in ensuring the sustainability of TWW reuse. In this regard, an optimal scenario assuming optimal input soil and water quality data coming from the application of these practices was run through SIM.

These results demonstrated that modelling and monitoring form a robust approach to identifying appropriate irrigation management since higher yield, enhanced nitrogen and phosphorus uptake, and lower salinity and E. coli values can be achieved.

Based on the results observed, it can be deduced as there shouldn't be only a proper irrigation system to irrigate, particularly to forage and orchards, but rather such irrigation systems shall be combined to improve water use efficiency (e.g. subsurface and sprinkler). The combined use of drip and sprinkler, for example, could allow to balance the risks between the soil the crop status overtime, rather than merely establish a priori to neglect the risks induced by irrigation events on the soils as: salinization, root asphyxia and sodicity, since they are not a direct risk to the human beings compared to those may occur eating the crops.

Yet, to reduce the risks in the soil and ensure the long-lasting functionality of the subsurface irrigation system, it could be also relevant to consider higher dripper discharges than the current 2.1l/h, because the high discharge could reduce the time of irrigation, thus the persistence of TWW within of the irrigation system, and likely improve the irrigation efficiency. In addition, this alternative design of the subsurface irrigation systems could further decrease the moistened zone below the irrigation line, which on the contrary could be a favourable condition to trigger such soil microbial and chemical processes.

Finally, to reassess the value of the agricultural productivity with TWW irrigation should also increase the awareness to do not benchmark against crop yield achieved with conventional water.

A series of good practices that could be applied and implemented in future work for sustainable TWW reuse as follows: farm filtration techniques; better management of salinity, toxicity, and health hazards; selection of the irrigation methods; agronomic practices.

6. SDI SYSTEM IMPLEMENTATION AT PILOT SITES

Following the experiment at NARC's Research Station, the most appropriate irrigation network was installed in Ramtha's Living Lab. 9 plots of 0.5 hectares each are currently irrigated with the potential to be extended. The design of the irrigation network is described here below. In Figure 7, the part of the existing network and the part that was extended (around 300 m with 90 mm diameter of main pipelines for each pilot) is shown. In all 9 plots SDI irrigation systems were installed.

drip irrigation (SDI) system.

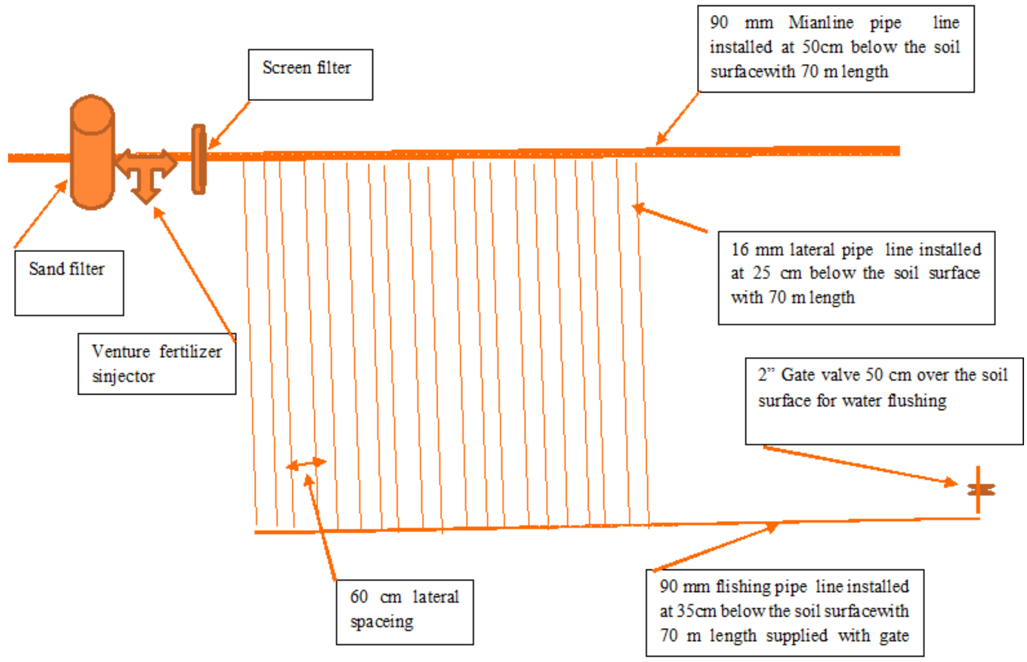

Figure 7. Each Pilot irrigation network design connected to the WWTP of Ramtha illustrating the different pipelines' lengths and diameters to grow alfalfa crops.

The protocol of operation of demo sites was prepared by CIHAM BARI and NARC team as follows:

I. Demo sites at Farmers field

- Collect the primary information about each farmer and each farm specifications.
- Draw the irrigation system layout for 0.5ha for each selected farm
- Document the specifications for the subsurface irrigation system for each farm.
- Collect the bi-weekly data from farmers about their management practices.
- Collect the flow meter weekly reading for each farm.
- Collect the farmer's observation notes about the subsurface drip irrigation system.
- Collect the production data (harvesting time, fresh and dry weight, selling price)
- Collect the farmer's perception and opinion about their experiment with MENAWARA project.

II. WW Treatment unit at NARC station

- Water monitoring for the treatment unit's influent and effluent water quality. Through collecting bimonthly water samples for the chemical and biological key elements analysis.
- Collect the weekly treatment unit's influent and effluent water flow reading.
- Removal efficiency calculation upon the results of water quality.

- Daily monitoring for treatment unit to ensure smooth treatment process.

III. Safety measure and capacity building procedure

- Implement a training course for the NARC's technicians and farmers before starting the field experiment. Training topics will include: safety measures and procedure while using TWW, Jordanian standard of using TWW in irrigation, importance and challenges of TWW reuse, principles of water treatment, introduce the MENAWARA project, irrigation systems features, design, maintenance and implementation.
- Nominate one technician from NARC staff for daily follow up of the proper implementation of the safety measure and procedures at NARC field experiments and conducting a weekly visit for farmers for the same purpose.
- Purchasing a safety stuff (cloves, special boots ...) for the NARC's technicians and farmers.

Due to delays with calls for tenders, equipment was finally received and installed in May 2023. A local machine has been designed and developed by the NARC team to install the system and several evaluation performance tests have been done to be sure that all pipes were installed at the proposed distance and depth as well as the emission uniformity distribution for the inline drippers.

Figure 8. NARC designed and developed a local machine for sub-surface drip irrigation system installation

Figure 9. Alfa alfa crop harvesting at one of the pilot farms irrigated with subsurface irrigation

5. Conclusion

In conclusion, the SDI irrigation network installed and extended in Ramtha can be considered a valuable intervention as based on feedback from the living lab's stakeholders. The SDI irrigation system with TWW is a technical solution, which could be replicated in other rural areas in Jordan where water sources are also scarce or not accessible. From the start, there was a high demand from the farmers to use the TWW and this intervention made it possible for them to tap onto this needed resource and support the farmers Ramtha in increasing their productivity to 2.5 ton/ha in comparison with traditional flood irrigation which was about 1 to 1.5 ton/ha. Moreover, the intervention also decreased the pressure on freshwater resources which are increasingly needed for drinking or vegetables under protected conditions. The results of SDI emission uniformity evaluation at pilot sites reached more than 92%.