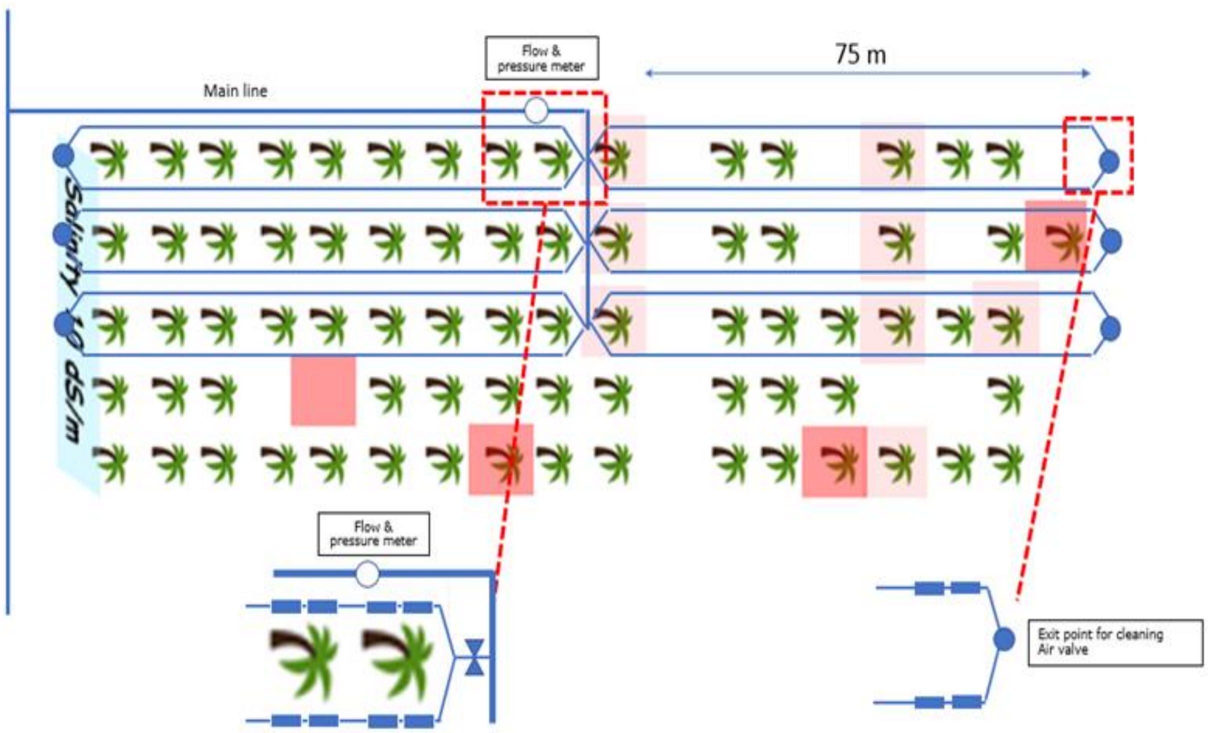
Feasibility of the HYDROROCK Subsurface Irrigation System for Water Conservation in Semi-arid Areas

Annual Progress Report

(September 2020 – August 2021)



International Center for Biosaline Agriculture (ICBA)

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Feasibility of the HYDROROCK Subsurface Irrigation System for Water Conservation in Semi-arid Areas

1. Background

This experiment is meant to evaluate the feasibility of newly developed Hydrorock subsurface irrigation for water conservation in (semi) -arid areas. This system stores water in the elements that gradually infiltrate the soil to meet the vegetation's (max) evapotranspiration demand. The idea behind this setup is twofold: 1) to save on water through avoiding direct evaporation, and 2) to save on labor and maintenance costs of the superficial elements.

Based on the properties of the Hydrorock materials, crop properties and water requirements, soil data, and water quality, Wageningen Environmental Research (WEnR) has been contracted by Hydrorock to design a system minimizing water losses (in terms of length, depth, and covering membrane of the Hydrorock elements). The design should also be 'universally applicable, such that only the irrigated crop will determine refill amounts and irrigation interval. The Hydrorock-international and Hydrorock-Australia have many demonstration plots. One of them is in the International Center for Biosaline Agriculture (ICBA), covering about 100 date palm trees. The system was installed in 2020, and monitoring has been done since then.

2. Methodology

2.1. Experimental setting

The Hydrorock sub-irrigation system experiment is being conducted at the ICBA date palm farm (25 13″N and 55 17″E). These date palm trees are about 20 years old. Eighteen local and imported date palm varieties (ten from UAE, seven from Saudi-Arabia, and one from Iraq) were grown under three irrigation water quality treatments (5, 10, 15 dSm^{-1}), with five repetitions (five trees per treatment). The experimental field was divided into three sub-plots. Each subplot was irrigated with different salinity water.

Date palm trees are planted in rows with a plant spacing of 8 x 8 meters. A gap of 20 meters is kept between each plot group of five plants. Three salinity levels (5, 10, 15 dSm^{-1}) of irrigation water were used for irrigation purposes. Irrigation treatments were arranged in a randomized complete block design, with five replicates per treatment, five rows per salinity level.

One row from each plot was used for the Hydrorock sub-irrigation system experiment; the nearest row, irrigated by the original bubbler irrigation, is taken as a reference control for comparison.

The main supply irrigation system and the mixing of water were customarily carried out. Three irrigation water salinity levels corresponded to electrical conductivities of 5, 10, and 15 dSm^{-1}. These salinity levels were obtained by mixing freshwater with highly saline-sodic groundwater (EC_w = 25 dSm^{-1}, SAR > 26 mmol/l with Na and Cl concentrations higher than 190 meq/l and pH = 7.6) in the proportions required to achieve the target salinity levels.

2.2. Irrigation network layout

Figure 1 shows the irrigation layout for the date palm plantation at the ICBA research station and part of the Hydrorock subsurface irrigation system (HR), with two blocks installed per tree, one for each side. The installation of the HR irrigation system started on 13th September and was completed on 7th October - 2020. The bubbler system was disconnected on 10th October, and the plants were connected to the newly installed HR system. The flowmeter was installed on 2nd November - 2020. The capacity of the HR is 107 L, and the porosity of the elements is 90%.

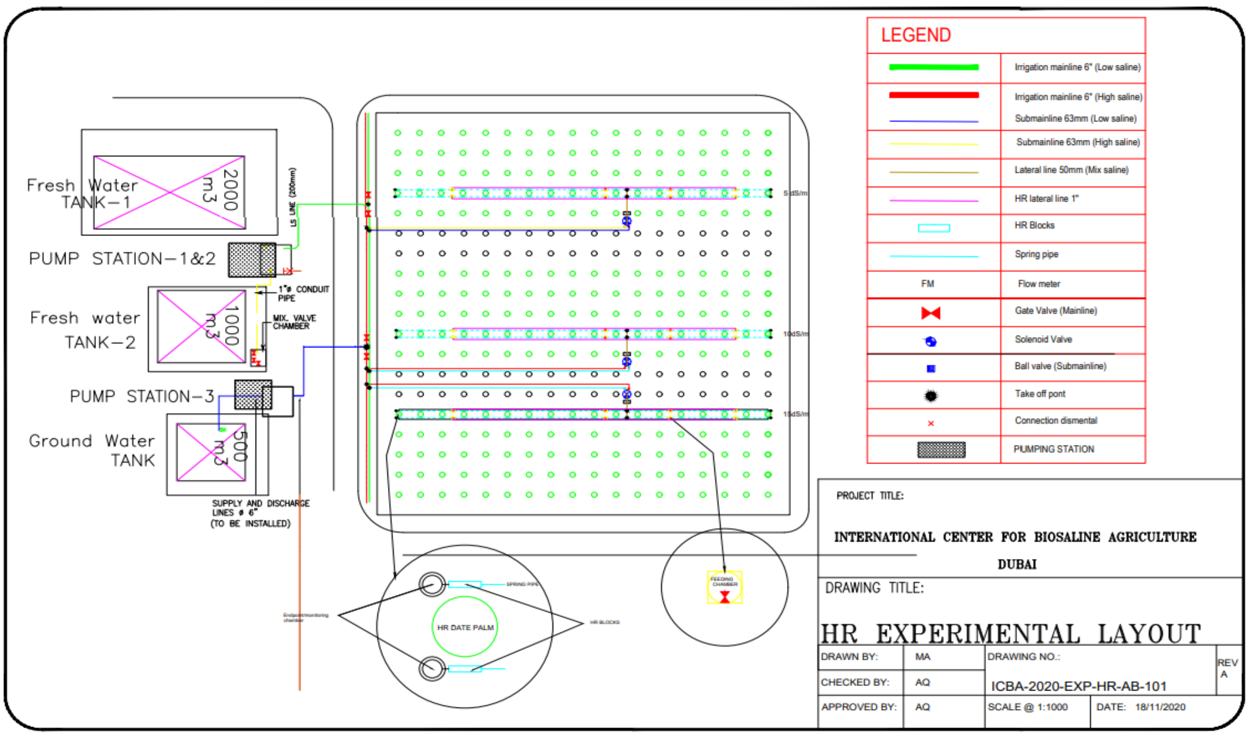

Figure 1: Hydrorock subsurface irrigation system installed at ICBA station.

The technical characteristics of ICBA pumps are given in Table 1. Freshwater is supplied by pumping stations 1 and 2, and the groundwater by pumping stations 3 & 4. Submersible pump-1 extracts high saline water from well-1 and delivers it to the groundwater tank.

Table 1: Technical characteristics of ICBA Pumping Stations

No.	Description	Pump type	Power (hp)	Flow rate (m^3/hr)	Head (m)	OPERATION
1	Fresh water pumping station (1&2)	Booster	15	30	57	SET OF 4 PUMPS = 2D+1A+1S
2	High saline water pumping station (3&4)	Booster	15	27	53	SET OF 2 PUMPS = 1D+1A
3	Submersible pump for well-1	Submersible	7.5	25	75	
4	Submersible pump for well-2	Submersible	7.5	25	80	

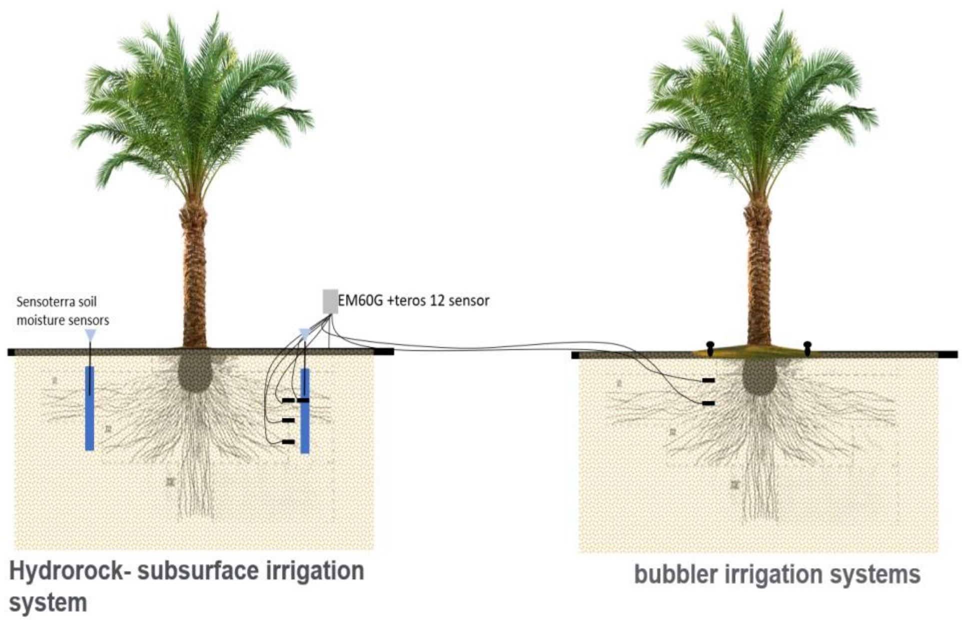

Figure 2. Schematic view of HydroRock and Bubbler irrigation systems installed at ICBA station.

2.3. Management practices utilized

Organic compost was applied @ 35 kg per tree per year during the last two weeks of October, and NPK fertilizer was used in the first week of October as per standard agronomic practices in the UAE.

Organic fertilization

Organic fertilizer was added in the trenches below the edge of the wet area away from the palm trunk. The sulfur was added at a rate of 0.5 kg per palm.

Nitrogen fertilization

Ammonium nitrate fertilizer is used in the drip irrigation system @ 800 grams of nitrogen per fruit palm annually and divided into equal weekly batches from March to August. Considering the general recommendation, the concentration of the fertilizer salts in the solution should not exceed 0.5 g per liter.

Potassium fertilizer

Potassium sulfate is added in the fertigation system @ 1.0 – 1.5 kg per palm annually along with the nitrogen fertilizer. Potassium fertilizer can be added with magnesium, alternating with nitrogen fertilizer, at a rate of 1.0 – 1.5 kg potassium sulfate and from 0.5 – 1.0 kg of magnesium sulfate per palm per year depending on the condition of the trees, and they are dissolved together. Potassium and magnesium fertilizer may be added directly (not through the irrigation system) under the drippers in two batches (March and May).

Phosphorous fertilization

Phosphorus fertilizer was added @150 gm for one palm in weekly batches in the fertilizer alone or dissolved with nitrogen fertilizer. The acid concentration should not exceed 0.2 g per liter of irrigation water, and the fertilizer salts in the solution are not more than 0.5 g per liter.

2.4. Soil analysis of the experimental site

The soil at the experimental site is sandy (around 98% sand, 1% silt, and 1% clay), calcareous, porous, and neutral to moderately alkaline, with organic matter of 1% with EC_e ranges from 4.4 to 7.5 dSm^{-1}.

Table 2. Soil properties in field trial site of the collected samples according to sensor positions.

Sample ID	pH	EC_e dSm^{-1}	Organic matter (%)	C (%)	Clay (%)	Silt (%)	Sand (%)
ICBA-P1 HR-M40+ICBA1-P2 HR-block	7.52	6.03	1.18	0.68	0.79	0.32	98.89
ICBA1-P3 HR-L 60	7.59	5.76	1.09	0.63	0.79	0.52	98.69
ICBA1-P4 HR-R 90	7.37	6.65	1.19	0.69	1.03	0.52	98.45
ICBA2-P1 HR-block+ICBA2-P2 HR-M 40	7.52	7.50	1.22	0.71	0.59	0.36	99.05
ICBA2-P3 HR-L 60	7.60	5.54	1.03	0.60	0.87	0.44	98.69
ICBA2-P4 HR-L 90	7.73	4.46	1.17	0.68	0.95	0.56	98.49
ICBA1-P5 BU-30	7.54	5.03	1.64	0.95	0.79	0.60	98.61
ICBA2-P5 BU-30	7.74	7.04	1.50	0.87	0.07	0.32	99.61
ICBA1-P6 BU-60	7.53	5.61	1.13	0.66	1.19	0.68	98.13
ICBA2-P6 BU-60	7.66	5.48	0.98	0.57	0.71	0.16	99.13

2.5 Irrigation scheduling and water applied

Irrigation was applied according to the calculated ET_c (Figure 3) following the installation of the Hydrorock subsurface irrigation system. In the beginning of the experiment, blocks were daily, considering the HR capacity of 214 L. This practice continued until 18th November (Figure 4) and then was reduced to once every two to three days. During the winter season, HydroRock blocks were filled twice a week on average until the end of March. From the beginning of April as the ET_c increased, the blocks were filled every two days as one on, one-off (Figure 4).

For the bubbler system, water was applied daily throughout the experiment (Figure 5).

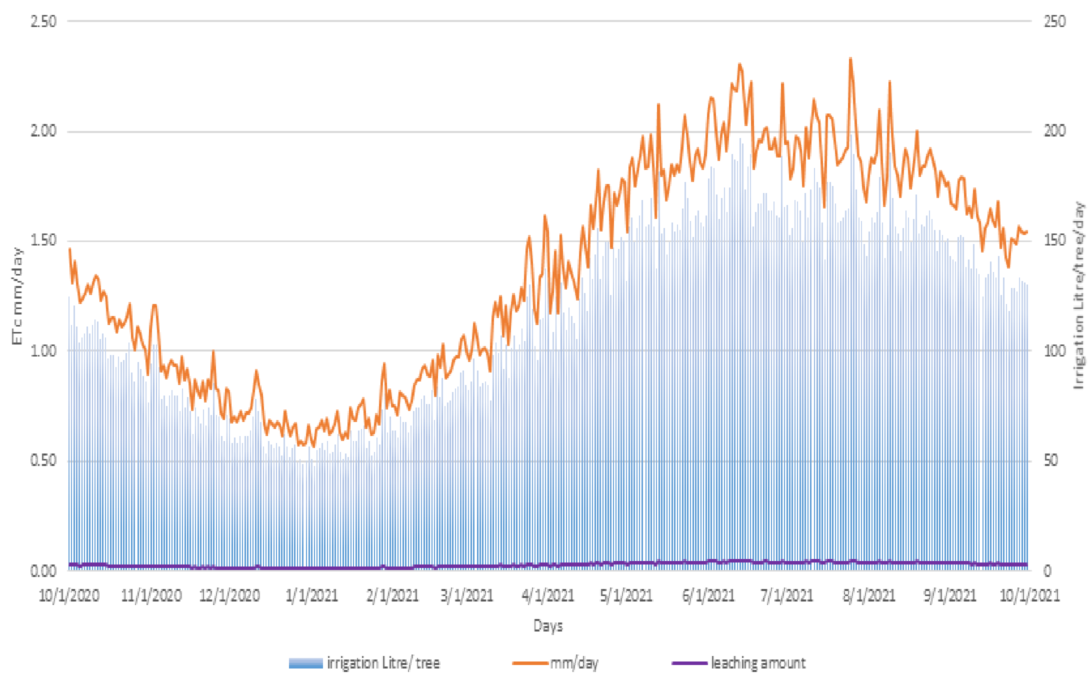

Figure 3. Estimation of irrigation water requirement at ICBA

3. Results

3.1. Water conservation and soil moisture content

TEROS-12 soil moisture sensors were installed in the soil at the bubbler system and the HR system to measure the volumetric soil water content and Sensoterra sensors were installed in the HR-block to measure the water content of the block. The data are accessible online through the AgrIOT platform. These sensors were installed in the subplot of 5.0 dSm^{-1}. However, no sensors were installed in the subplots of 10 dSm^{-1} and 15 dSm^{-1}. Therefore, no data on soil water content was collected from these subplots.

The total amount of water consumed by the HR system was estimated at 674 m^3, 34% less than the bubbler system (1024 m^3), as shown in Figures 4 and 5. This irrigation practice kept the moisture level in the Hydrorock-block above 50% during the hot summer periods, according to data collected from the Sensoterra sensor via the AgrIOT Platform (Figure 6). The Hydrorock-block moisture data indicated no excess water loss, and the moisture content remained between 50% and 90%.

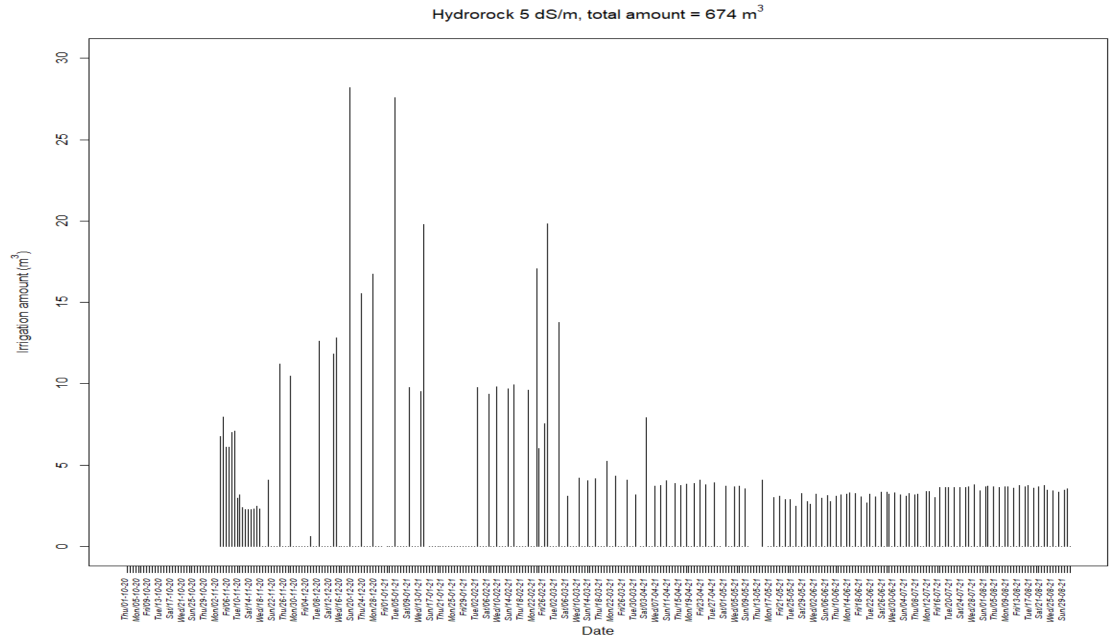

Figure 4. Amount of water applied by the Hydrorock system.

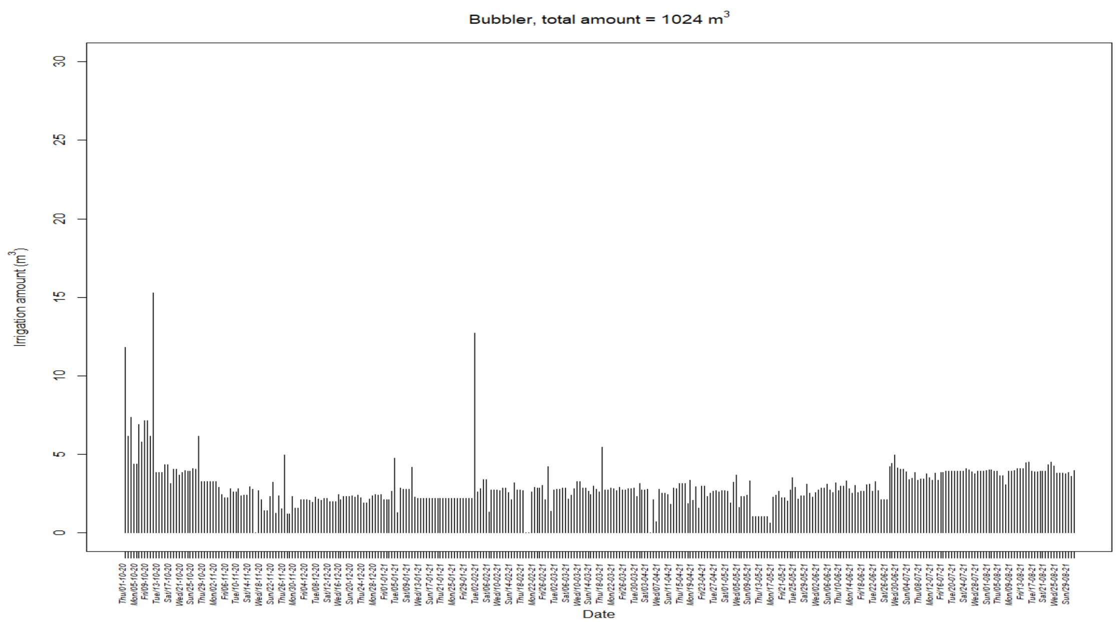

Figure 5. Amount of water applied by the bubbler system.

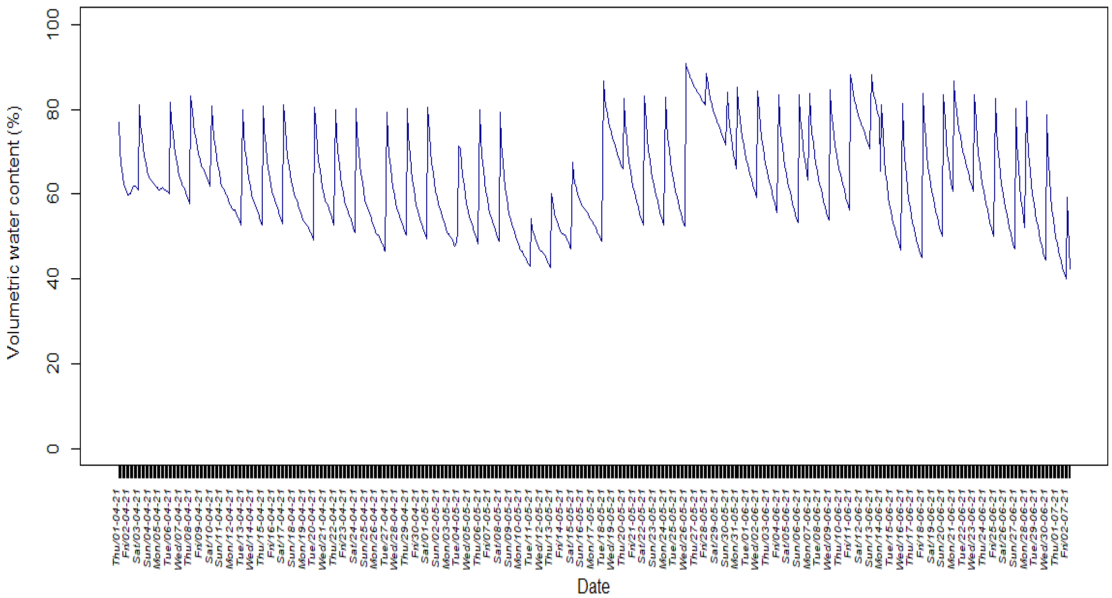

Figure 6. Hydrorock-block moisture recorded by the Sensoterra sensor via the AgrIOT Platform.

The Teros soil moisture-sensors data installed at the beginning of the line show a stabilization of the volumetric soil moisture content (m^3/m^3) around the block at 60-cm soil depth (Figure 7, ICBA2.1.4.60cm) and 35-cm soil depth (Figure 7, ICBA2.1.4.35cm). The volumetric soil moisture content in the HR system was comparable to the bubbler system (Figure 7, ICBA2.5.6.60cm) and ICBA2.5.6.35cm), indicating the efficiency of the Hydrorock system to keep an acceptable level of volumetric soil moisture content for plants uptake. This was also the case at the end of the line (Figure 8), even though the bubbler system showed slightly higher volumetric water content at 60-cm soil depth (Figure 8, ICBA1.5.6.60 cm). Nevertheless, the Teros soil moisture-sensors data installed at the end of the line show a stabilization volumetric soil moisture content (m^3/m^3) around the block (Figure 8).

As no moisture sensors were installed in the date palm trees of 10 and 15 dSm^{-1}, we could not get any data from these lines. The above data is for the date palm line of 5.0 dSm^{-1}.

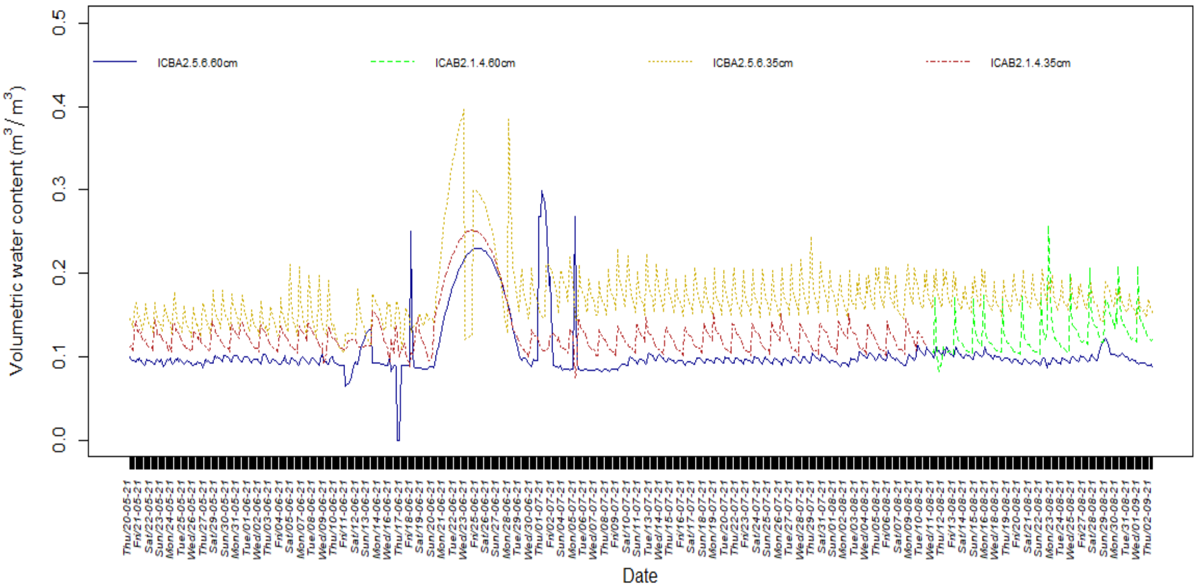

Figure 7. Volumetric water content (m^3/m^3) at the beginning of the line at 60cm and 35cm soil depths.

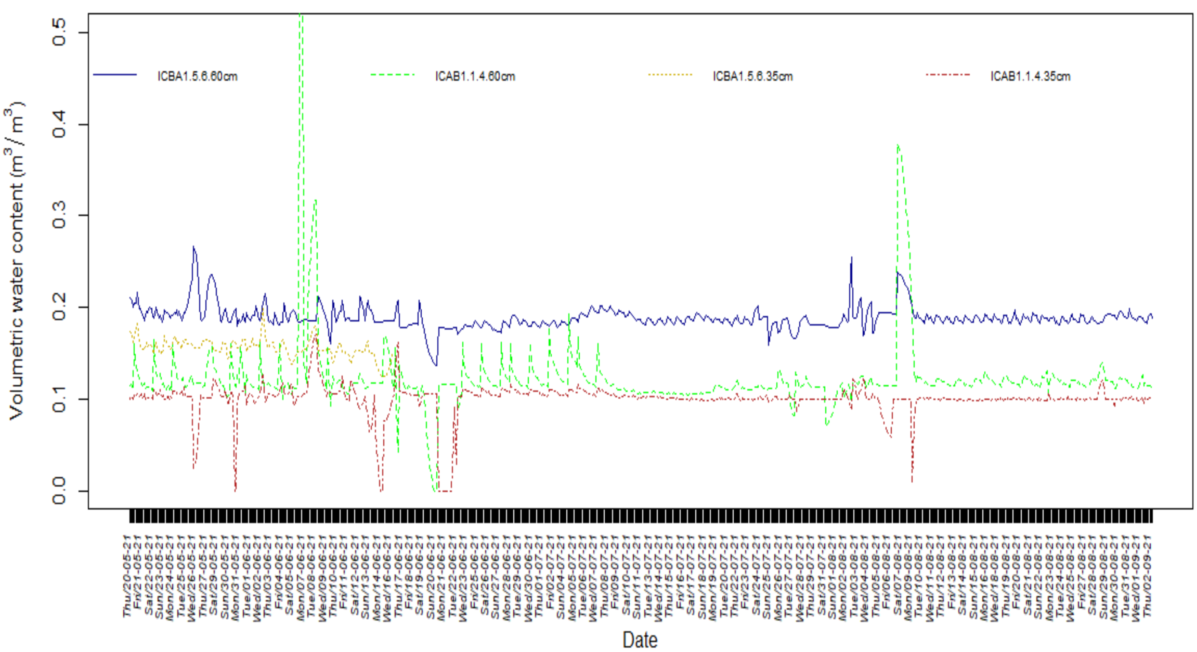

Figure 8. Volumetric water content (m^3/m^3) at the end of the line at 60 cm and 35 cm soil depths.

3.2. Fruit yield of different varieties

The fruit yield of different date palm varieties responds inversely to different salinity levels. Figure 9 illustrates the fruit yield (kg/tree) by the bubbler and Hydrorock systems under three salinity levels for FARAD variety and LULU varieties. For FARAD variety, the Hydrorock system had a 23.8% higher yield than the bubbler system at 5.0 dSm^{-1} salinity level. However, this was not the case at higher salinity levels. The HR system produces 61% less yield than the bubbler system at 10.0 dSm^{-1} salinity level (Figure 9A). The FARAD variety did not produce any product with the Hydrorock system at 15.0 dSm^{-1} salinity level. However, the Hydrorock system had a comparable yield with the bubbler system for the LULU variety under 5.0 and 15 dSm^{-1} salinity levels. Also, it showed an advantage over the bubbler system under the 10.0 dSm^{-1} level (Figure 9B). These results indicate that the LULU variety is more salt-tolerant.

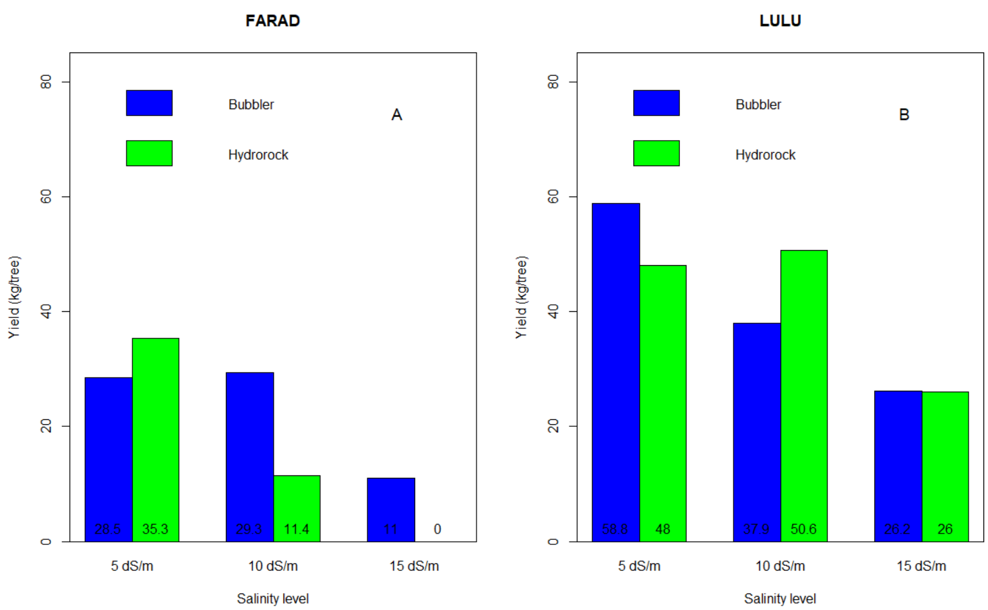

Figure 9. Fruit yield (kg/tree) by the bubbler and Hydrorock systems at three salinity levels for (A) FARAD variety and (B) LULU variety.

Results of fruit yield for BARHI and KHALAS varieties are shown in Figure 10. BARHI variety is a salt-sensitive variety and did not produce any output at 10 and 15 dSm^{-1} salinity levels. The yields under the Hydrorock system were higher than the bubbler system at 5.0 dSm^{-1} (Figure 10A). The KHALAS variety showed 48.7% higher yield increase under the HR system at 5.0 dSm^{-1} (Figure 10B). However, when salinity increased to 10 and 15 dSm^{-1}, the HR system did not yield any output (Figure 10B). Similar results were obtained for SHAHLAH and ABU-MAAN date palm varieties (Figure 11). The HR system had a comparable yield with the bubbler system for SHAHLAH and ABU-MAAN varieties under 5.0 dSm^{-1} salinity levels (Figure 11). However, more than 50% yield reduction for both varieties was observed under the HR system at 10-15 dSm^{-1} salinity levels compared with the bubbler system (Figure 11).

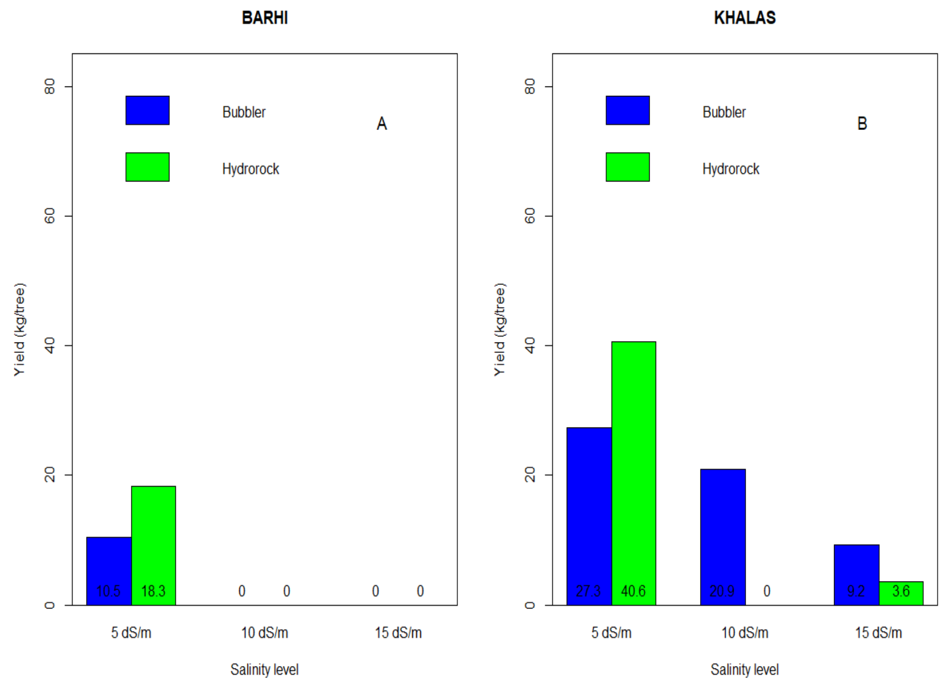

Figure 10. Fruit yield (kg/tree) by the bubbler and Hydrorock systems in three salinity levels for (A) BARHI variety and (B) KHALAS variety.

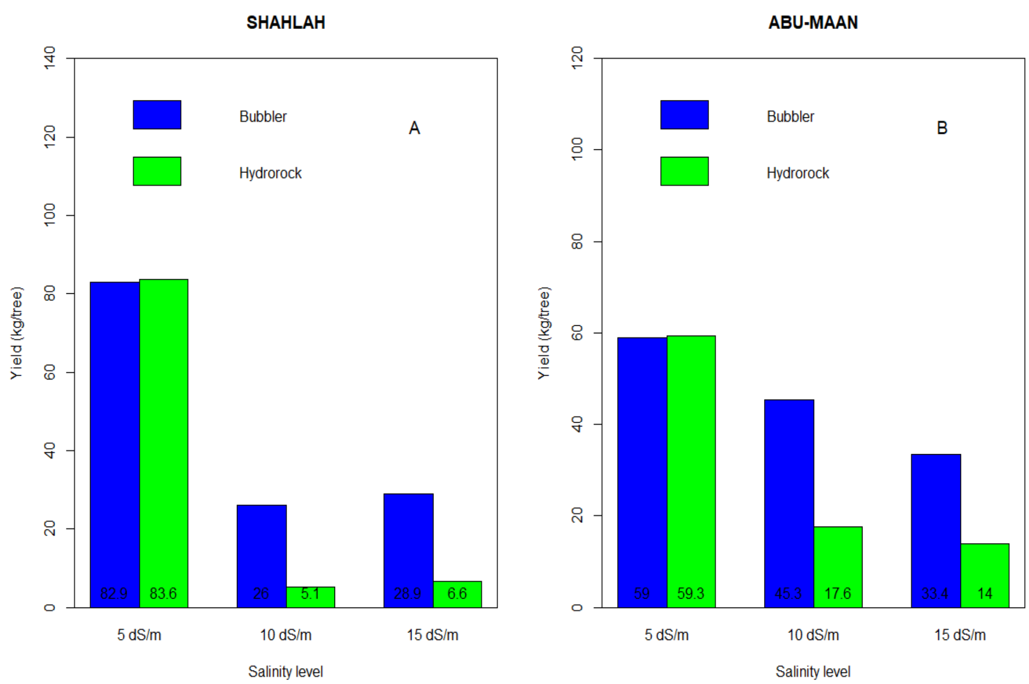

Figure 11. Fruit yield (kg/tree) by the bubbler and Hydrorock systems in three salinity levels for (A) SHAHLAH variety and (B) ABU-MAAN variety.

Other varieties did not perform well for both systems under the high salinity levels, such as AMAL HAMAM and RHOTHAN (Figure 12). The Hydrorock system produced a comparable yield with the bubbler system under 5.0 dSm^{-1} salinity level for RHOTHAN, SUKKARI, and SHAGRI varieties (Figures 12B, 13A, 13B). However, considerable yield loss was observed under the HR system at higher salinity levels (10-15 dSm^{-1}). The last three varieties AJWA, MAKHTOUMI, and NARTAT SAIF are considered salt-sensitive and did not perform well at higher salinity levels (Figures 14 and 15). The HR system showed better results for AJWA and MAKHTOUMI varieties at 5.0 dS/m and comparable yield for AJWA (Figure 14A) and higher yield for MAKHTOUMI compared with the bubbler system (Figure 14B).

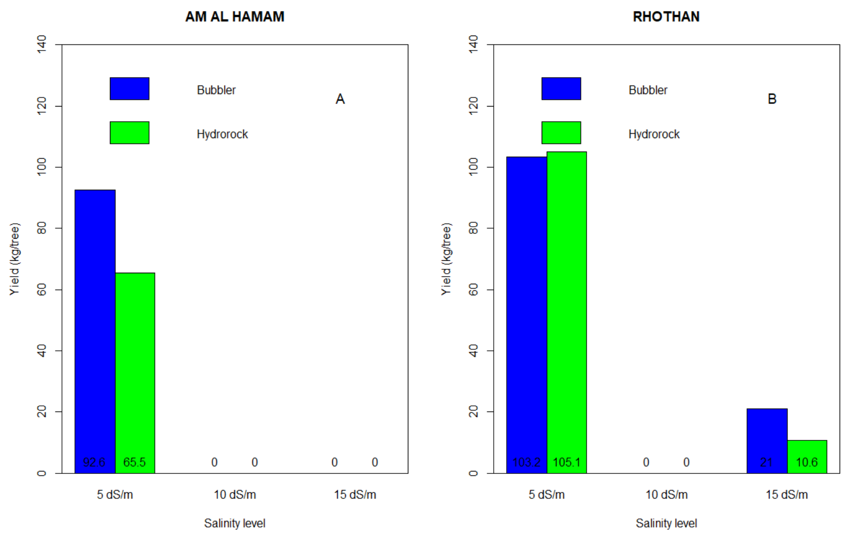

Figure 12. Fruit yield (kg/tree) by the bubbler and Hydrorock systems in three salinity levels for (A) AM AL HAMAM variety and (B) RHOTHAN variety.

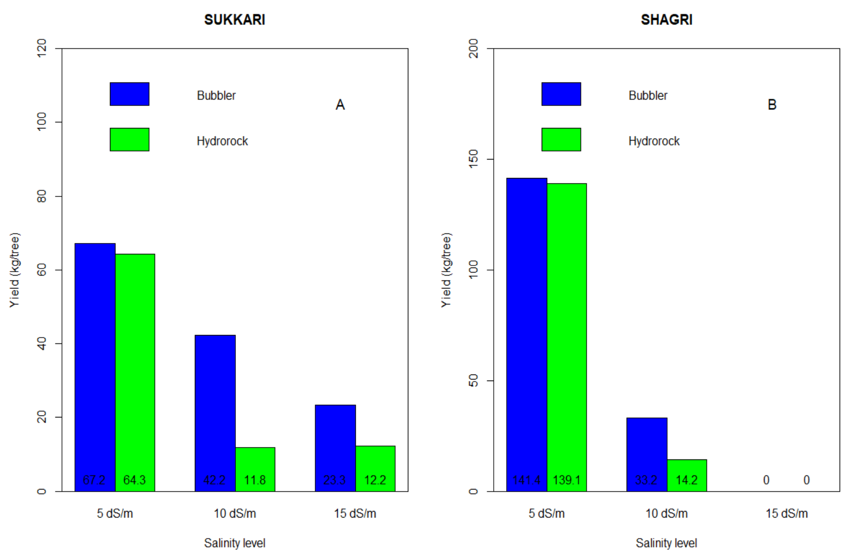

Figure 13. Fruit yield (kg/tree) by the bubbler and Hydrorock systems in three salinity levels for (A) SUKKARI variety and (B) SHAGRI variety.

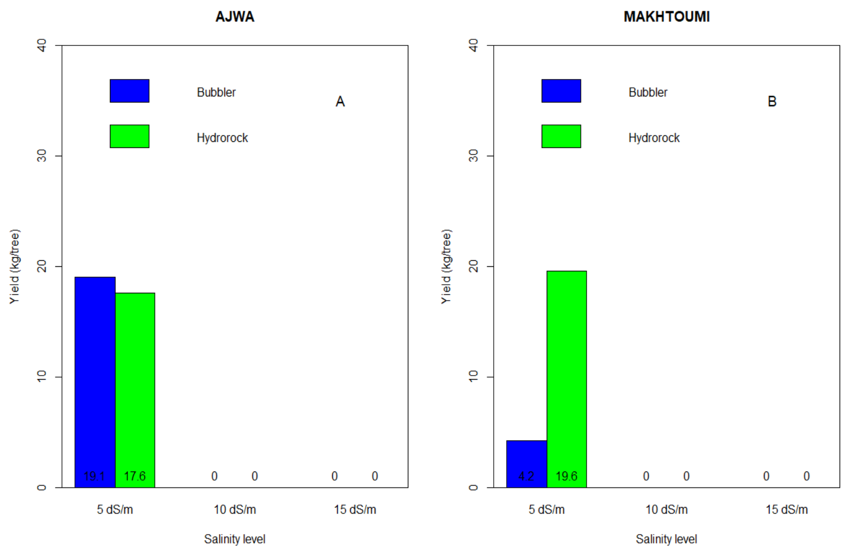

Figure 14. Fruit yield (kg/tree) by the bubbler and Hydrorock systems in three salinity levels for (A) AJWA variety and (B) MAKHTOUMI variety.

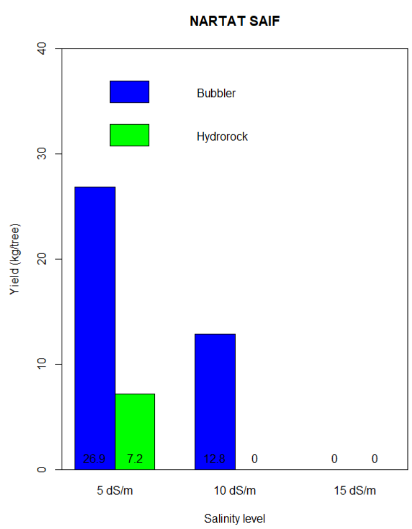

Figure 15. Fruit yield (kg/tree) by the bubbler and Hydrorock systems in three salinity levels for NARTAT SAIF variety.

Figure 16 shows averaged fruit yield across all varieties. The Hydrorock system produced a comparable yield to the bubbler system (Figure 16) at 5.0 dSm^{-1}. However, under the medium and high salinity levels of 10 and 15 dSm^{-1}, the HR system showed about 50% yield reduction compared with the bubbler system.

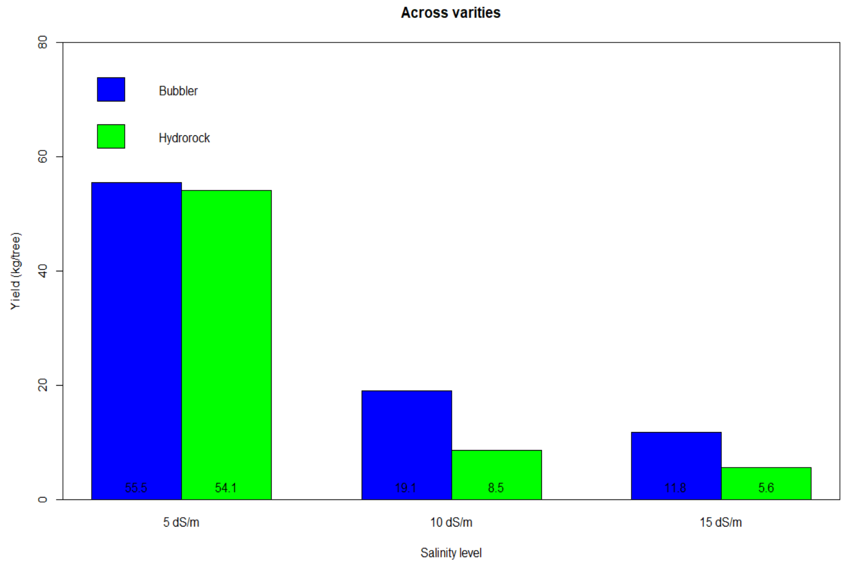

Figure 16. Average fruit yield (kg/tree) for all varieties by the bubbler and Hydrorock systems at three salinity levels.

3.3. Water use efficiency (WUE)

The water productivity (WUE) was calculated by dividing the amount of fruit produced by water consumed for each tree (kg/m^3). For FARAD variety, the WUE was 0.3 kg/m^3, which was higher for the Hydrorock system than the bubbler system under 5.0 dSm^{-1} salinity level. However, the WUE of the bubbler system was higher than the HR system at higher salinity levels (Figure 17A). The Hydrorock system performed well for LULU variety and produced higher WUE under all salinity levels (Figure. 17B). The average increase ranged from 10 to 50% higher WUE. Similar results were obtained for BARHI, KHALAS, SHAHLAH, and ABU-MAAN varieties (Figure 18-19).

Figure 20 shows higher WUE by the HR system for BARHI and KHALAS varieties at 5.0 dSm^{-1} salinity levels. Similar results were produced for SHAHLAH and ABU-MAAN varieties. The Hydrorock system had 40 to 50% higher WUE at 5.0 dSm^{-1} salinity level but much less WUE than the bubbler system at higher salinity levels (Figure 20). For AM AL HAMAM, the WUE was about the same for both systems regardless of the salinity level (Figure 21A). In contrast, the Hydrorock system showed an advantage for RHTHAN under 5.0 dSm^{-1} salinity level (Figure 21B). This was also the case for SUKKARI, SHAGRI, AJWA, and MAKHTOUMI varieties with about 50% WUE increase under the Hydrorock system compared with the bubbler system at low salinity levels (Figures 21 & 22). However, the Hydrorock system did not show any advantage at higher salinity levels. The WUE of BARTAT SAIF variety was generally low and did not show an advantage of the Hydrorock system regardless of the salinity level (Figure 23).

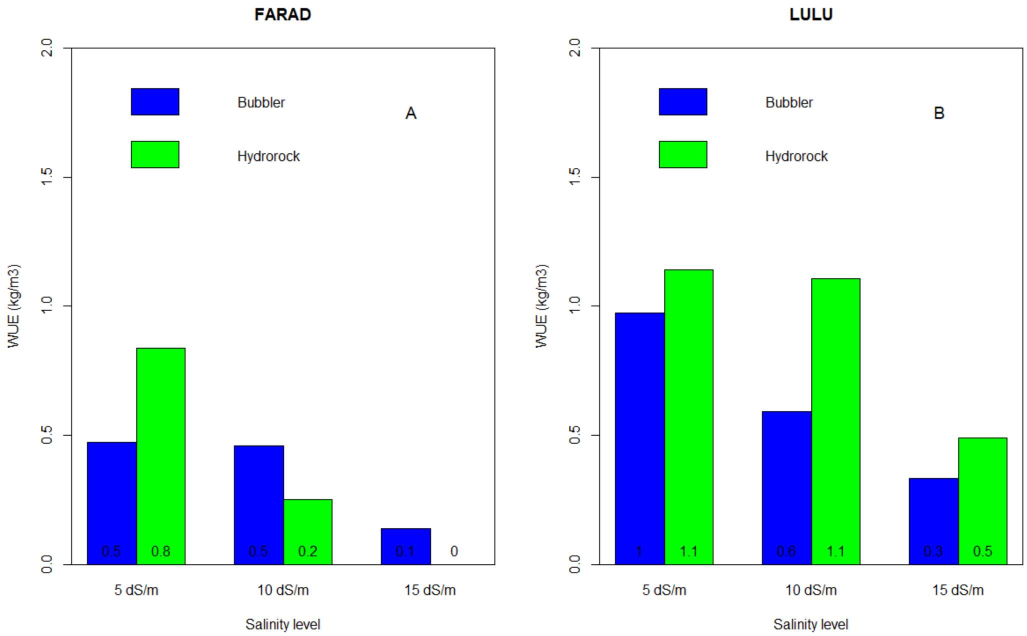

Figure 17. Water productivity (WUE, kg/m^3) by the bubbler and Hydrorock systems in three salinity levels for (A) FARAD variety and (B) LULU variety.

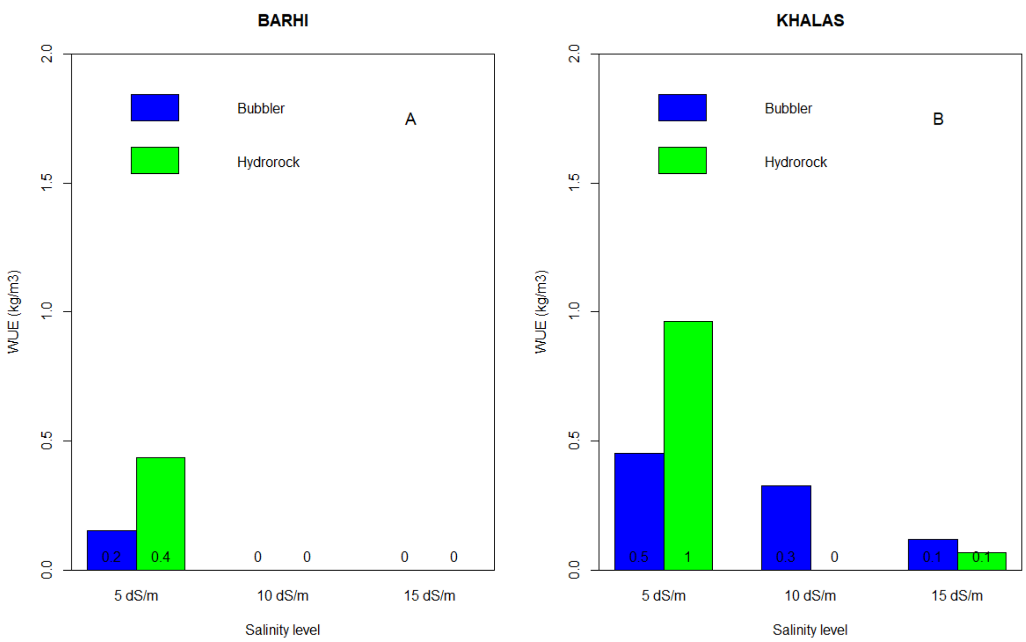

Figure 18. Water productivity (WUE, kg/m^3) by the bubbler and Hydrorock systems in three salinity levels for (A) BARHI variety and (B) KHALAS variety.

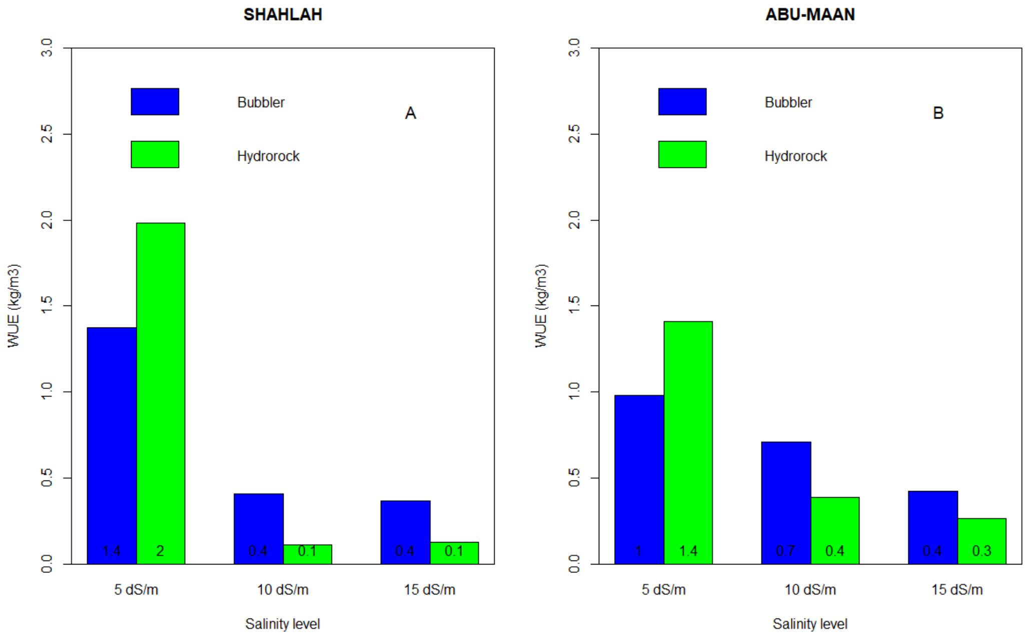

Figure 19. Water productivity (WUE, kg/m^3) by the bubbler and Hydrorock systems in three salinity levels for (A) SHAHLAH variety and (B) ABU-MAAN variety.

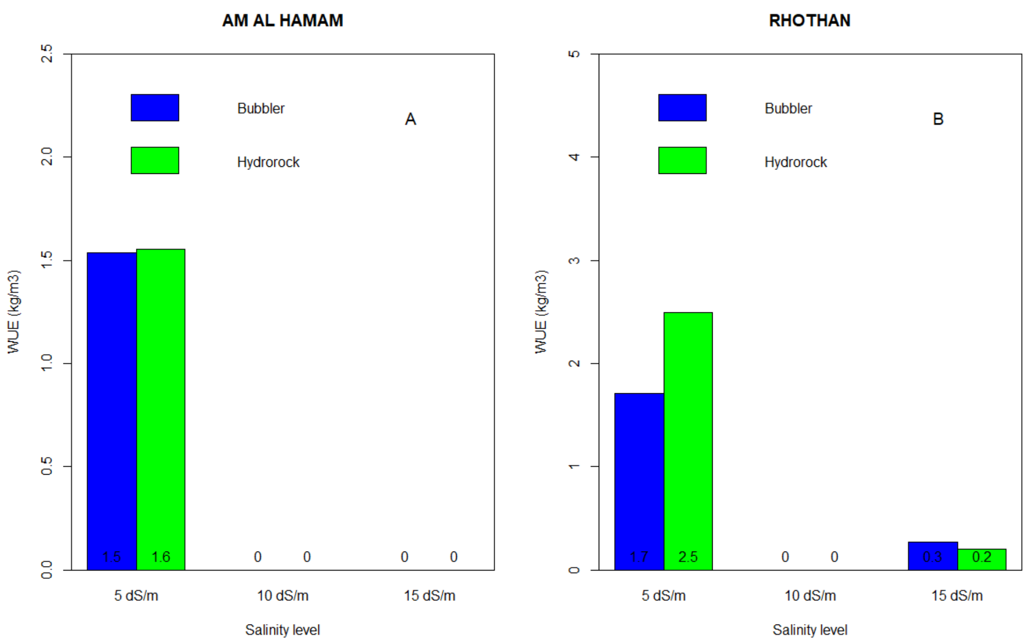

Figure 20. Water productivity (WUE, kg/m^3) by the bubbler and Hydrorock systems in three salinity levels for (A) AM AL HAMAM variety and (B) RHOTHAN variety.

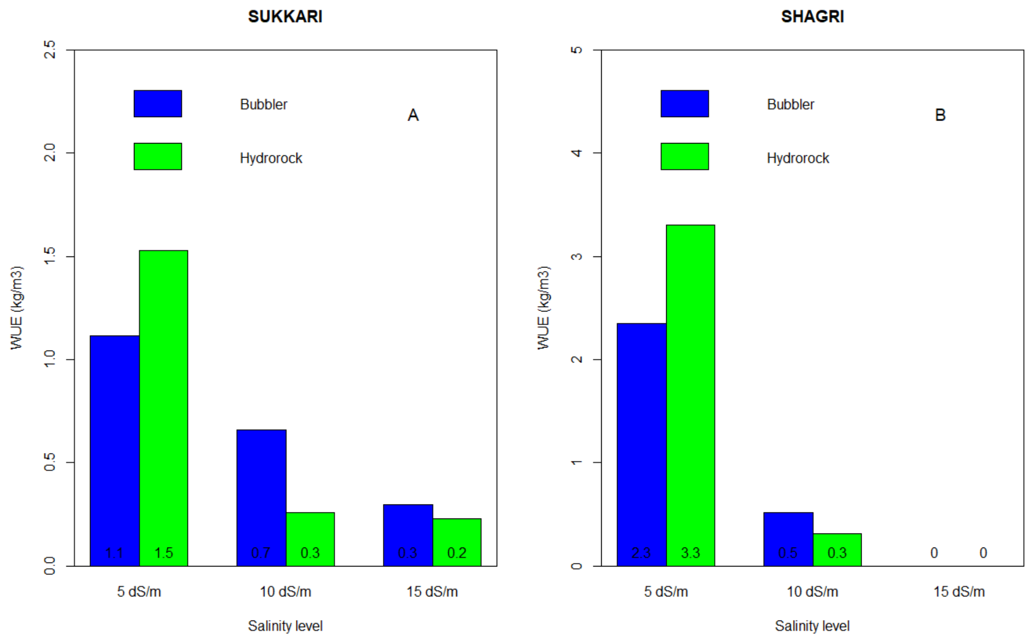

Figure 21. Water productivity (WUE, kg/m^3) by the bubbler and Hydrorock systems in three salinity levels for (A) SUKKARI variety and (B) SHAGRI variety.

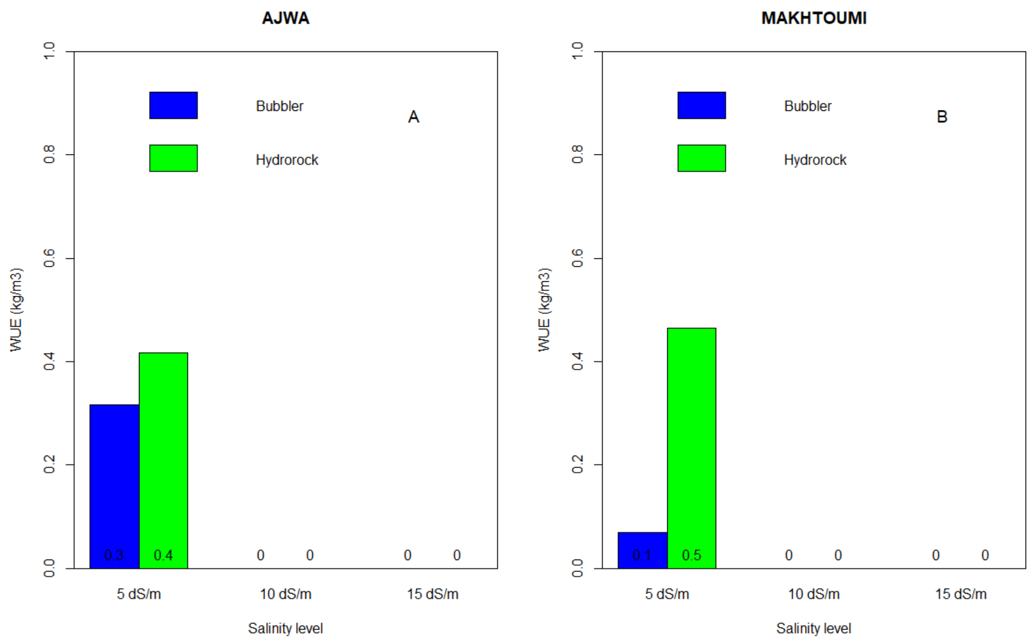

Figure 22. Water productivity (WUE, kg/m^3) by the bubbler and Hydrorock systems in three salinity levels for (A) AJWA variety and (B) MAKHTOUMI variety.

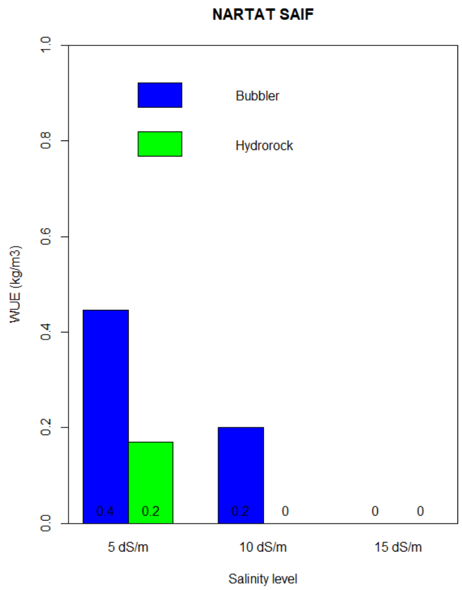

Figure 23. Water productivity (WUE, kg/m^3) by the bubbler and Hydrorock systems in three salinity levels for NARTAT SAIF variety.

Across all varieties, the WUE was 45% higher under the Hydrorock system than the bubbler system at a low salinity level (Figure 24). However, WUE under the HR system was slightly lower than the bubbler system at higher salinity levels. In general, the results indicate a water-saving potential in the Hydrorock system compared with the bubbler system when the salinity of the irrigation water is <= 5.0 dS/m. However, considerable yield reductions can be expected at high salinity levels.

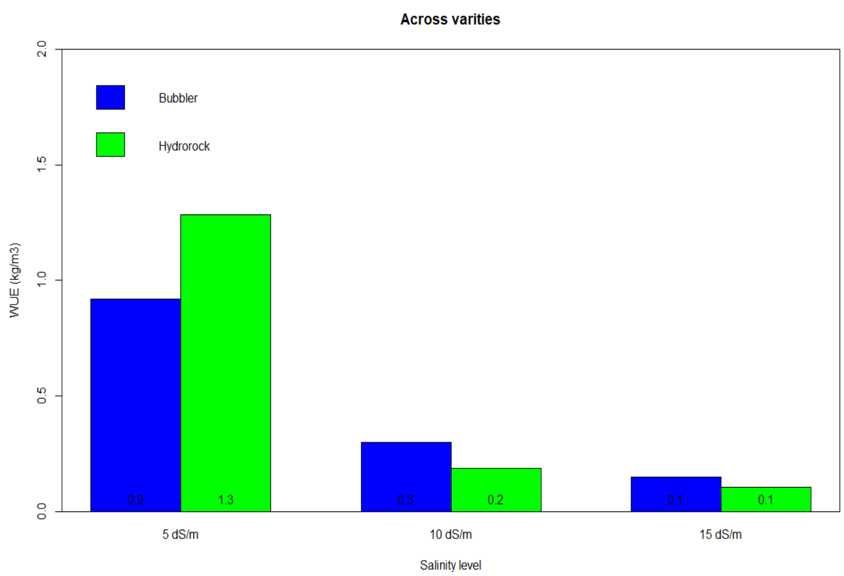

Figure 24. Water productivity (WUE, kg/m^3) by the bubbler and Hydrorock systems in three salinity levels across verities.

3.4 Soil salinity build-up

Soil samples were collected around the Hydrorock-block and the bubbler system for the control at the beginning of the experiment from the topsoil (10 cm soil depth) and at the end of the season in September 2021 from three different 20, 40, and 60 cm soil depths. The samples were analyzed to determine the soil salinity EC_e based on the soil paste extract. Results indicated an increase in salinity in lines irrigated with high saline water at the beginning of the experiment (Figure 25), which was confirmed by the data collected at the end of the season (Figure 26). Under the high salinity level of 15 dSm^{-1}, the soil salinity showed an increase regardless of the irrigation system used. However, the salt build-up was higher under the HR system than the bubbler system (Figure 26). This was proved at soil salinity > 10 dSm^{-1} by the Hydrorock system irrespective of the irrigation water salinity level or the soil depth of the sample.

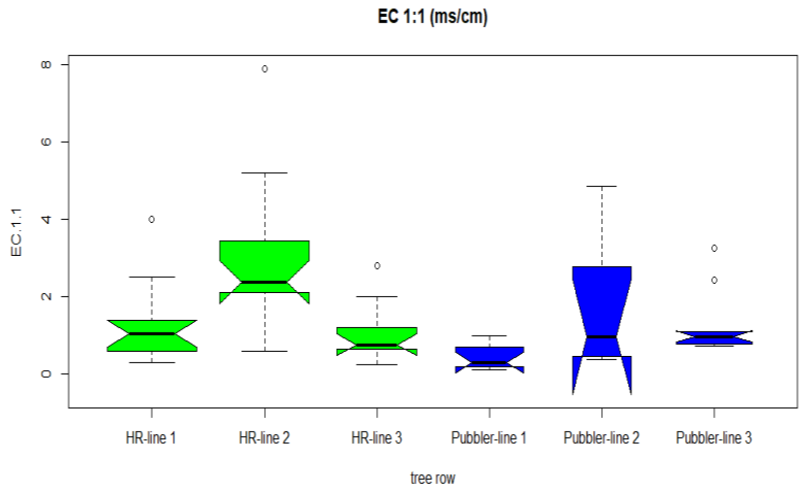

Figure 25. Soil-salinity (0-10 cm depth) above the blocks and near the bubbler (Sept. 17, 2020).

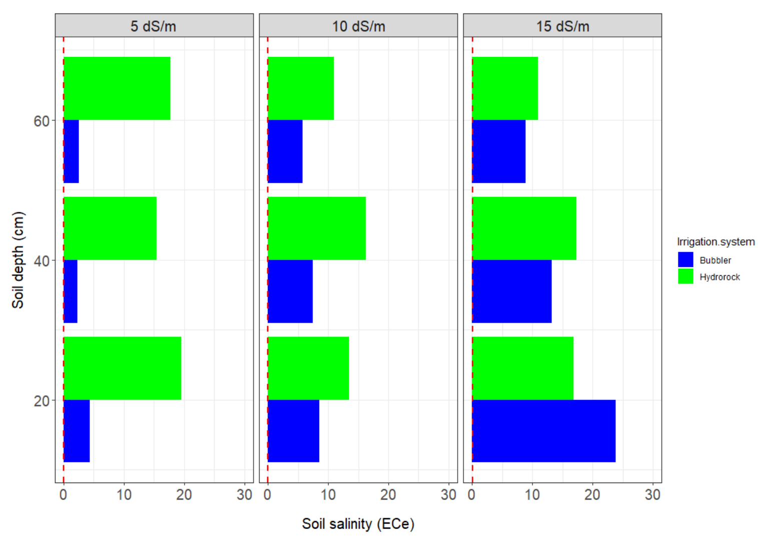

Fig. 26. Soil salinity for bubbler and Hydrorock systems at three soil depths (Sept. 20, 2021).

Figure 26 shows higher salt build-up at low salinity levels at all depths (especially in the topsoil). This may be because the amount of water applied through the HR system is sufficient to meet the crop water demand and does not provide any leaching. The situation is more difficult under higher salinity levels as the increase in salinity is much higher than the bubbler method. This situation can threaten the sustainability of crop production under the HR system. To avoid this situation, one option could be to do a periodical salt leaching using freshwater.

Since no sensors were installed in the subplots of higher salinity treatments, the dynamics of water movement in the soil profile for bubbler and HR systems could not be studied. It would have been better to install sensors in these fields to understand water movement and its impact on salinity development and crop yields.

3.5. Weed control and drought damage

The on-field assessment showed no weed pressure by the Hydrorock system compared with the bubbler system (Figure 27). The Hydrorock system did not show any stress damage on trees based on visual scoring and was comparable to the bubbler system for most of the planted varieties (Figure 27).

More weeds by the Bubbler

Less weeds by the Hydrorock

Trees irrigated with bubbler system

Trees irrigated with HR system

4. Conclusions and recommendations

- The Hydrorock system has 35 to 45% water-saving potential compared to the traditional bubbler system without compromising crop yields.
- Irrigating the HR system once every two days under low salinity irrigation water (0-5 dSm^{-1}) gave the best results in terms of water-saving as indicated by WUE of 1.3 kg m^{-3} compared with 0.9 kg m^{-3} by the bubbler system.
- The performance of the HR system is better under low salinity irrigation water (0-5 dSm^{-1}). Under higher salinity levels of the irrigation water, considerable yield reductions can be expected due to salt build-up in the root zone. The salt build-up is high as HR system does not provide any additional water for leaching purposes. To ensure sustainability, periodic salt leaching can be done using freshwater.
- The leaching requirements are calculated considering the conductivity of irrigation water (EC_w) and the conductivity of the soil (EC_e) in the root zone. As the existing HR system provides no leaching, it is highly recommended that the irrigation water used with the Hydrorock system have no or low salinity.
- It is recommended to install sensors in the higher salinity subplots to understand the water dynamics, salinity development, and reduction in crop yields. This might help in developing some workable strategies for leaching excess salts. One option could be to do periodic leaching of salts using freshwater. During the visit of Laurens last month, we discussed the possibility of installing four sensors (two in each line of 10 and 15 dSm^{-1}). He was supportive of the idea and promised to consult with colleagues in the Netherlands. We can do it now as the new date palm season has just started. This investigation would be necessary to make the HR system more acceptable for local conditions.

About the International Center for Biosaline Agriculture (ICBA)

ICBA is a not-for-profit, international Center of excellence for research and development in marginal environments. It was established in 1999 through the visionary leadership of the Islamic Development Bank (IDB), the Organization of Petroleum Exporting Countries (OPEC) Fund, the Arab Fund for Economic and Social Development (AFESD), and the Government of United Arab Emirates. Through the Ministry of Climate Change and Environment and the Environment Agency – Abu Dhabi extended the agreement with IDB in 2010 and increased their financial support to the Center.

ICBA initially focused on the problems of salinity and using saline water for irrigated agriculture. Over the last 15 years, ICBA has evolved into a world-class modern research facility with a team of international scientists conducting applied research to improve the well-being of poor farmers in marginal environments. In 2013, the Center developed a new strategic direction addressing the closely linked income, water, nutrition, and food security challenges. The new Strategy takes innovation as a core principle and identifies five innovations that form the core research agenda: assessing natural resources, climate change adaptation; crop productivity and diversification; aquaculture and bioenergy, and policy analysis. ICBA is working on several technological developments, including conventional and non-conventional water (such as saline, treated wastewater, industrial water, and seawater), water and land management technologies, remote sensing, and modeling for climate change adaptation.

ICBA is a unique institute with a clear mandate and capacity to work on rehabilitating salt-affected lands. ICBA is the custodian of the world’s largest collections of genetic resources of crops and forages suitable for salt-affected lands with a proven capacity of seed development and seed multiplication for a variety of environments. In addition, ICBA’s long history of working in Africa with local partners makes it fully qualified and eligible to lead this project.