INTERNATIONAL CENTER FOR BIOSALINE AGRICULTURE

Project Completion Report

Impacts of hydrogel-based soil amendment (EVERGREEN®) on water use efficiency by date palms.

November 2022

Summary

The Green Solutions company proposed ICBA to test the product vide open call on Date Palm experiment.

ICBA, as per the agreed technical plan, tested their potassium hydrogel-based polymer called "Evergreen®". The polymer given to ICBA by Green Solutions company, is a kind of soil amendment as per the custom category of fertilizers for testing under the local environmental conditions (aridity and sandy soil) at ICBA's research station. The trial aims to evaluate hydrogel potential for improving crop yield and water productivity, and to determine its impact on water use efficiency (WUE) of date palm trees, and to identify best application methods and rates. The proposed plan of the polymer application in the field was finalsied to test the feasibility of the product under such harsh conditions. Twenty-seven date palm trees at ICBA's research station were included in the Evergreen experiment, whereby it was applied at the beginning of the growing season 2020-2021 at the top layer of the soil (50 cm). The product was added to plants at two application rates and two different distances from the tree's trunks using two application methodologies. Evapotranspiration rates have been determined since the product's application. A real-time soil water content monitoring system, including sensors and smart application, was used to determine root-zone soil moisture after the application of Raincatcher compared to the control.

Results obtained so far showed that the irrigation water quantity for the trees decreased by **82%** compared to the control group. The trees did not show any signs of dryness or damage during the season. During the last 7 months of the experiment, the saving was 85% (one-seventh) without any damage or stress to the tree. This confirms that a stabilized 85% water saving is achieved over long periods.

The installed real-time soil water content monitoring system enabled water irrigation based on soil moisture content and plant available water , which is the difference in water content between field capacity and permanent wilting point in soil.

By the end of the season after fruits harvesting, the total water savings was 82%. Indeed, the watering frequency was reduced to once every seven days for the trees with Raincatcher compared to control.

Based on a single season experiment, the technology's impact on the yield and quality of dates was positive and confirmed its efficiency when temperature and evapotranspiration are even high.

After harvest, the results obtained from the hydrogel-based soil amendment (Evergreen®) project showed that the trees' irrigation water quantity can be significantly decreased compared to the control group. Indeed, the watering was reduced to once every seven days for the trees with Raincatcher compared to control. The total water savings were equivalent to an average of 82% water saving, and fruit yield increased by 20%, especially for the application of 300 g of Evergreen per tree. Meanwhile, the application of only 1 00g per tree was not found enough for having a good fruit size. Indeed, it was decreased by 13 to 20%.

In addition to water saving with Evergreen, available soil nutrient contents are significantly higher, including nitrogen, phosphorus, calcium and magnesium. It helped to improve the environment in the root zone through better moisture availability and reduced water loss through deep filtration, which may lead to reduced nutrient loss. Also, Evergreen increased soil respiration rate after the incubation simultaneously increased the soil microbial biomass carbon. However, avoiding the risk of sodium build-up in the treated area requires attention to the importance of soil leaching after or during the growing season.

We can note that the irrigation requirement was calculated , according to ICBA's previous work (Al-Muaini et al., 2019; https://doi.org/10.1016/j.agwat.2019.05.022) with includes a factor-of-safety (25%) and the
salt leaching fraction (25%). Thus, part of the saved water comes from reducing the this added amount.
Fruit yield increased by an average of 20%, especially for applying 300 g of Evergreen per tree. This can partly be explained by enhancing the nutrition uptake and its availability for the trees for a more extended period. Indeed, the hydrogel reduced the loss of water and minerals, as per the findings.

After the end of this on-going experiment, further long-term physiological and agronomic field assessments and the product biodegradability test will be conducted to verify that there are no adverse effects on the trees.

The potassium hydrogel-based polymer is a soil amendment that promises water-saving in arid
regions with limited irrigation sources and severe salinity conditions. This study is one of the few
studies that started evaluating the hydrogel's role and improving crop yield and water productivity environments.
Therefore, the purpose of this research was to determine the impact of EVERGREEN on the water use efficiency of established date palms and determine the best
application method and rates for economical production and optimum water productivity.

The results obtained come from a natural open field trail with all scientific rigors for experimenting.
ICBA confirms all the obtained results of testing EVERGREEN hydrogel under field conditions. However, under field conditions, trial can occur with some factors that this research project does not cover.
ICBA is not responsible for any variation positively or negatively of retesting or using the product under different conditions, i.e., higher salinity alkalinity, lousy farming practices etc…

Research context/introduction

The Middle East and North Africa (MENA) region, including the United Arab Emirates (UAE), is characterized by an arid climate that constrains agricultural production and productivity due to water scarcity, high salinity, poor soil, and climate variability. The UAE is among the top water-scarce countries globally with high evapotranspiration rates (ETo), which exceed 2000mm, with an average annual precipitation of around 50 mm per year (Allen et al., 1998). As a result, most agricultural production in the country is dependent on irrigation. According to the Abu Dhabi *State of the Environment* report (2017), around 8000 farms have been abandoned due to the lack of freshwater resources. The UAE is heavily dependent on imports to reduce the gap between local production and consumption. For example, 1.7 million tons of animal feed are imported to the Emirate of Abu Dhabi annually. Such heavy reliance on imports for food and feed crops renders UAE's food security vulnerable to economic shocks and disruptions in international markets and supply chains.

Food security at the regional and local levels is threatened by lack of freshwater for irrigation and increasing drought events. Agriculture is by far the major consumer of water. The date palm (Phoenix dactylifera L) is one of the principal crops cultivated in this region. It is considered the oldest fruit tree in the Arabian Peninsula and an essential component of the local food system. It is also viewed as a symbol of prosperity in the Arab world. The UAE is one of the top 10 date palm-producing countries, accounting for 12% of the crop's global production (Jaradat and Zaid, 2004). However, date palm is one of the crops with the highest water consumption and accounts for about one-third of all groundwater utilization in the UAE (MOEW, 2015).

Background

Hydrogel-based polymers are commercially available as a soil amendment and have been used as a water-retaining material in the arid and semi-arid regions. However, very few studies have evaluated their role and impact on improving crop yield and water productivity in arid and semi-arid areas. Therefore, this experiment is meant to check the efficiency of the Hydro retaining fertilizer developed by Green Solutions in reducing water needs for irrigation in sandy soil and arid environments. The concept is that Hydrogel stores water in its elements after filling the hydrogel with irrigation water which gradually infiltrates into the soil just to meet the vegetation's (max) evaporative requirements. added value of using the hydrogel is threefold: i) to save on water through minimizing direct evaporation and leaching, and ii) to save on irrigation monitoring cost. iii) their impact on soil properties in arid and semi-arid regions and on water consumption and water use efficiency.

About the tested product:
EVERGREEN is a Nutrient hydrogel booster assembled via a technological process with potassium acrylate copolymers. The latter excludes sodium, which is harmful, especially in salt-affected soils. EVERGREEN is manufactured by GREEN SOLUTIONS , which has requested ICBA's services for field testing of EVERGREEN® under UAE conditions.

Experimental setting

The EVERGREEN Hydrogel experiment is being conducted at the ICBA date palm farm (25°05’54"N 55°23'36"E) as per the mutually agreed technical plan. These date palm trees are about 8 years old. Twenty-seven date palm trees established at the ICBA research station were used to evaluate this hydrogel. Date palm trees are planted in rows with a plant spacing of 8 x 8 meters.

The hydrogel was applied at the beginning of the growing season 2020-2021, at 50 cm soil depth, around the tree (Figure).

The product was added at:

- ✓ ***two application rates:***
  - 1000 g/tree
  - 500 g/tree
- ✓ ***two methodologies***
  - Injection
  - Gel application
- ✓ ***two different distances from the tree's trunk.***
  - 100 cm
  - 50 cm
- ✓ ***Number of replicates: 3***

Management practices utilized during the trial period.

Fertilization

Organic compost was applied at 25 kg per tree per year during the last two weeks of October, and NPK fertilizer was applied in the first week of October as per standard agronomic practices in the UAE.

Irrigation network layout

Further, the main supply irrigation system and new drip irrigation were customarily carried out before the product application. The drip lines are installed over the EVERGREEN circles.

To ensure water supply homogeneity, irrigation was applied using a drip system, a line source with 13 emitters was installed around each tree. Emitter discharge is 2GPH (7.57LPH) at 3.5 bar operating pressure. The flowmeters were installed.

Freshwater with electrical conductivities of 0.4 dSm^{-1} is used for irrigation, and advanced chemical and biological analyses were carried out (Table 1).

Table 1: Chemical and biological water analysis

Chemical Parameters	Value in the irrigation water (mg/L)
pH at 25 °	8.07
Conductivity at 25°C	280 **µS/cm**
TSS*	<5
TDS**	156
Cl	53
SO4	<5
Ca	20.2
Mg	3.4
CaCO3	65
Total alkalinity to pH 4.5***	56
Bicarbonate	68
Na	34.8
K	1.05
Fe	<0.01
Cu	<0.01
Mn	<0.01
Zn	<0.01
Pb	<0.01
Cr	<0.01
Appearance	Clear
Odour	Acceptable

Biological Parameters	Value in the irrigation water
Aerobic Colony Count	292-397 CFU/ml ***Guideline 500Max.#***
Total Coliforms	Absent
Fecal Coliforms	Absent
Escherichia coli	Absent
Enterococci	Absent

**Total suspended Solids*
***total dissolved solids at 180°C*
**** REF: https://www.cefns.nau.edu/~teb/ambl/sop/SOP_AMBL_103A_Alkalinity.pdf*

Figure 1 shows the experiment layout for the date palm plantation at the ICBA research station and the different EVERGREEN (EG Palms) experimental design.

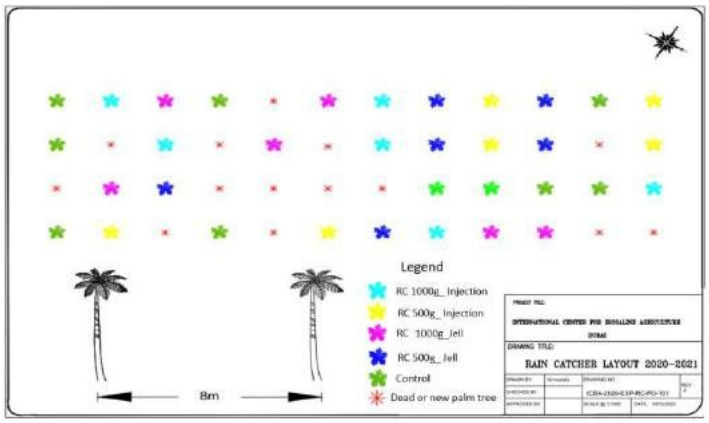


Figure 1: Irrigation network for the Evergreen subsurface irrigation system installed at ICBA station.

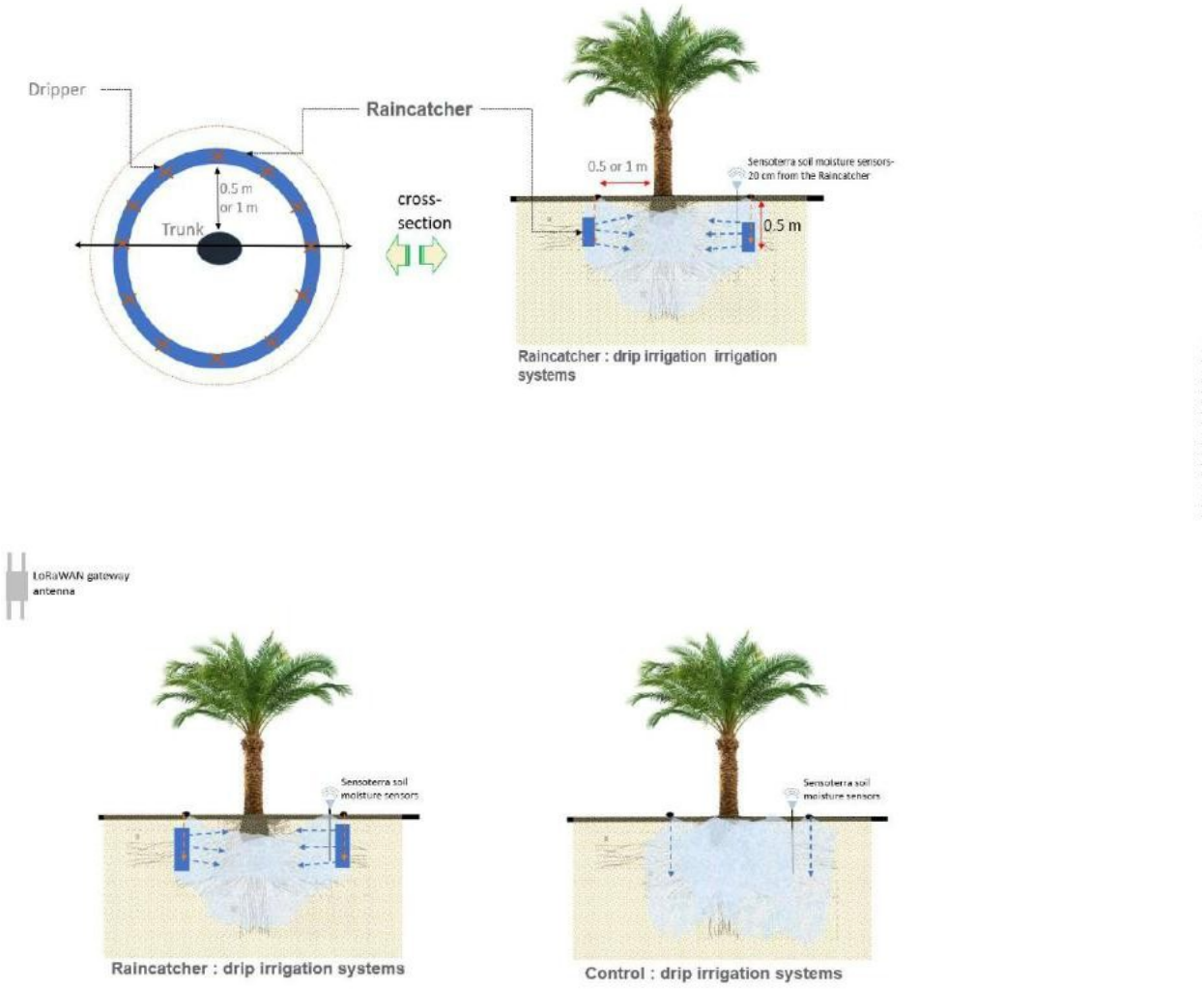


Figure 2: Description of the tested irrigation systems and the installed soil-moisture sensors at ICBA station

IRRIGATION REQUIREMENT AND SCHEDULING

Reference evapotranspiration ETo (mm/day) and irrigation practices at ICBA

Evapotranspiration rates and irrigation water requirements were determined using ICBA weather station data (Figure 2). A real-time soil water content monitoring system (AgrIOT), including soil moisture Sensoterra sensors and smart application, was used to determine root-zone soil moisture after EVERGREEN application relative to the control (Figure 2). Sensoterra soil moisture sensors were installed 20 cm inside the application area to monitor the temporal soil moisture (Figure 2).

Figure 3: Photo of the drip irrigation system installed above the Evergreen and the Sensoterra soil moisture sensor.

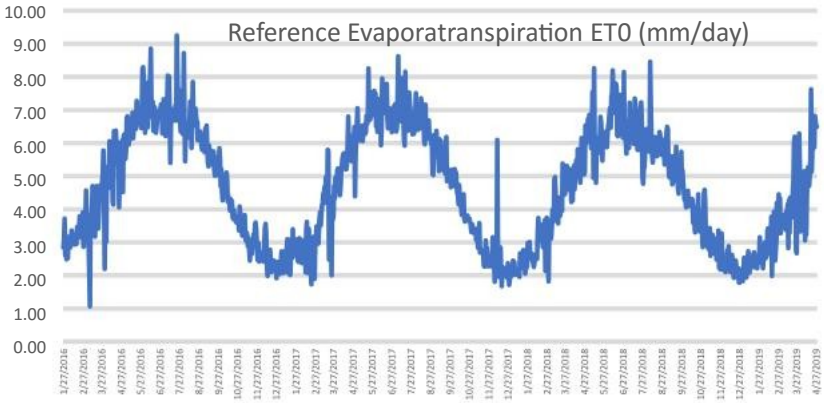


Figure 4: Reference evapotranspiration ETo (mm/day) at ICBA based on the last three year's data.

ETc is calculated to provide an average irrigation rate in liters of water/tree/day. The collected data from the site were used to estimate the reference evapotranspiration (ET) according to the Penman-Monteith Evapotranspiration FAO-56 Method, and then the total water supplied was determined to obtain the water date palm requirement.

The irrigation schedule agrees to the recommendation of Al-Muaini et al., 2019 (https://doi.org/10.1016/j.agwat.2019.05.022), which accounts for a 25% factor-of-safety and a 25% salt
leaching fraction.

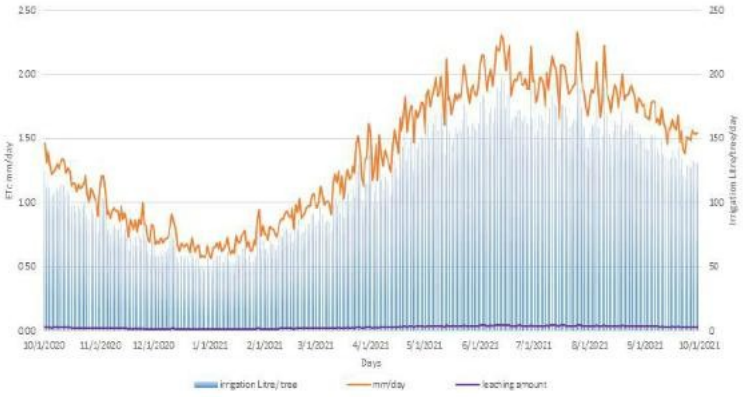


Figure 5: Estimation of irrigation water requirement at ICBA

Figure 6: Sensoterra sensors position in the trial field to determine the soil moisture in percentage and real-time data visualization by AgrIOT platform.

General soil description of the experimental site

The soil at the experimental plots 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 5.4 to 7 dSm^{-1}.

Irrigation scheduling and water use

A step-by-step application of irrigation water was adopted as follows:
Phase 1: After installing the Evergreen Hydrogel, the first exercise (the irrigation practice) consisted of "filling up the hydrogel" and assessing the required time to fill it up. The watering was supplied daily. Considering an absorption capacity of approximately 300 ml per g of dry preparation, (0.3L x 1000g = 300 L). The date-palm requirement in summer (220 L/palm), irrigation of EG happened one time per day at the beginning of each irrigation interval.
Irrigation allows moisture retention between minimum target soil water (safely higher than permanent wilting point) and field capacity. The data was collected from a Sensoterra sensor via the AgrIOT Platform for monitoring purposes.

Phase 1: On 17 October 2020, the watering of palms fitted with EVERGREEN (EG Palms) has been reduced by two-third **(-66%)** compared with the control (reference palms). EG Palms received 160 L of water every three days, compared to every day for the reference palms (control), until the end of October.

⇨ The RC Palms did not show any signs of dryness or damage.

Phase 2: On 1 November 2020, reference palms were irrigated with 120 L per day.. Meanwhile, EG Palms received 120 L of water every three days, until 10 November.

⇨ The RC Palms did not show any sign of dryness or damage.

Phase 3: On 10 November 2020, the watering of EG Palms was reduced by three-quarters (-75%), i.e. they received 120 L of water every four days compared to 120 L every day for the reference palms.

⇨ The RC Palms did not show any sign of dryness or damage.

Phase 4: On 8 December 2020: watering was reduced to once every five days.

Phase 5: On 28 December 2020: watering was reduced to once every six days.

Phase 6: On 28 January 2021: watering was reduced to once every seven days.

Phase 7: from 28 January 2021 to 30 August 2021 (the harvest day) watering was continued as once every seven days.

This step-by-step way of experimentation was deployed as to reduce the risk of permanently damaging the trees

So far, no sign of dryness or damage has been noticed after six months.

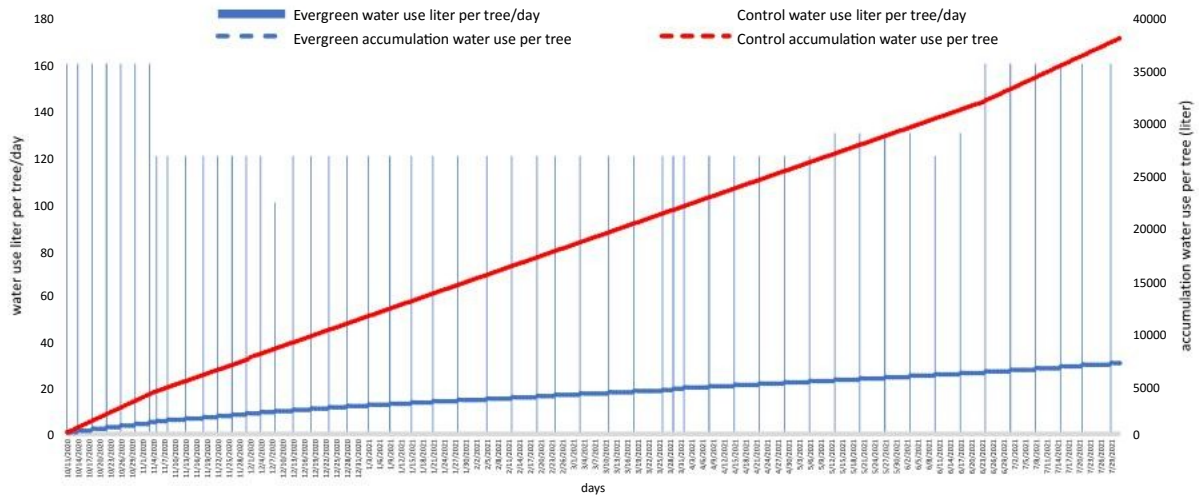


Figure 7: Irrigation scheduling and cumulative water use per tree for Evergreen relative to control between 11 Oct 2020 and 29 July 2021.

The water meter reading results show that EVERGREEN used an average of 82% less water than the control During the first project phase (Figure 7). An average of 37.92 m^3 of water was used to irrigate one tree's control.

(reference tree) for 294 days. Meanwhile, only 6.79 m^3 of water was used to irrigate one RC tree, which means 82% saving. The amount of water applied to the RC system since the trials stated was given in the Excel file.

The impact of RAINCATCHER soil amendment on water use efficiency and soil properties.

Figure 8: Laboratory measurements of Raincatcher chemical parameters (to the left, the acid digestions of Raincatcher and to the right, the determination of moisture and ash content)

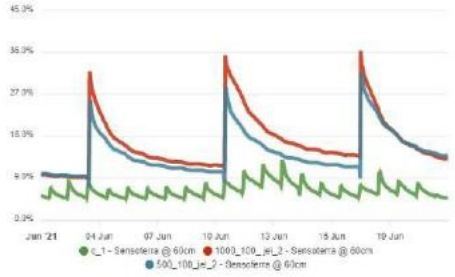
Table 2: summarizes some of the selected chemical properties of the raincatcher soil amendments

Parameter	Ash content	Moisture content	C	N as NO_3	Total N	P-PO_4
	%	%	%	$g.Kg^{-1}$	$g.Kg^{-1}$	$g.Kg^{-1}$
Average value	43.04	11.02	25.6	2.2	1.20	34
SD	0.31	1.11	2.11	0.50	1.2	5.3

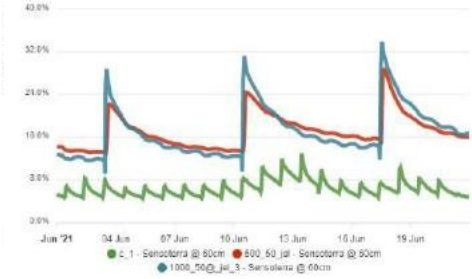
The impact of RAINCATCHER soil amendment on water use efficiency and soil properties.

The Sensoterra sensor readings of different Raincatcher treatments relative to the control result are depicted in the graphs (Figure 8). Overall, the results show that the soil moisture levels of the RC trees are higher than the control.

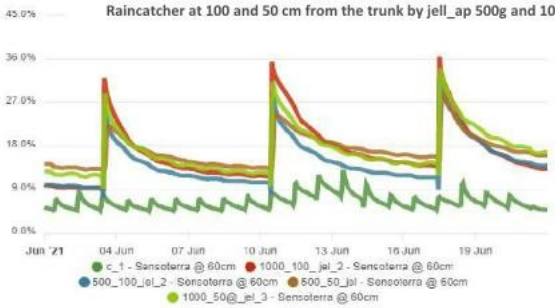
Raincatcher at 100 cm from the trunk by jell_ap 500g and 1000g Vs. control



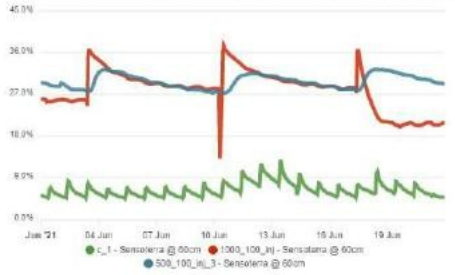
Raincatcher at 50 cm from the trunk by jell_ap 500g and 1000g Vs. control



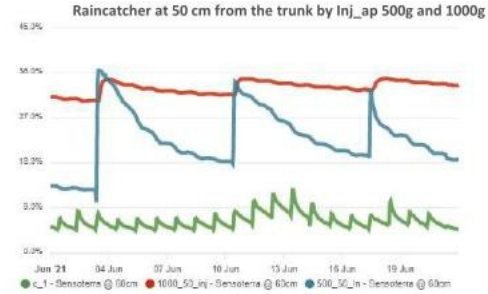
Raincatcher at 100 and 50 cm from the trunk by jell_ap 500g and 1000g Vs. control



Raincatcher at 100 cm from the trunk by Inj_ap 500g and 1000g Vs. control



Raincatcher at 50 cm from the trunk by Inj_ap 500g and 1000g Vs. control



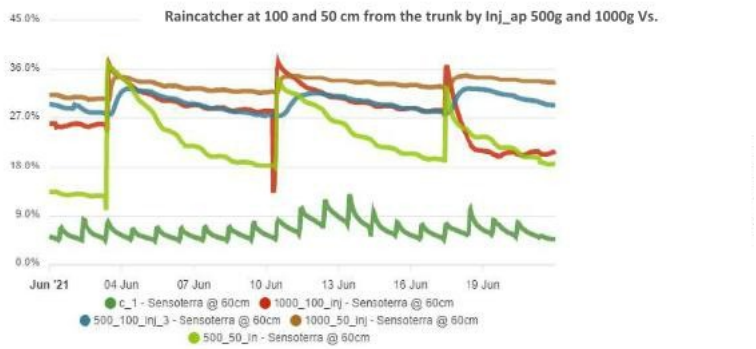


Figure 9: The behavior of soil water content (moisture %) for the different EG treatment Vs. the control estimated by Sensoterra sensors and illustrated and visualized by smart farm app, during the summer period.

Recommendation

Plant available water is a useful concept for irrigation because it communicates the size of the water reservoir in the soil available for the plant to use. This can be monitored using the soil moisture sensor readings as well as in-field assessment. Based on these observations, we can decide the number of days after which EG trees should be irrigated. This practice will help in water conservation through better irrigation scheduling. sensor can provide continuous soil water content data that can guide irrigation management decisions to increase crop yield and water use efficiency.

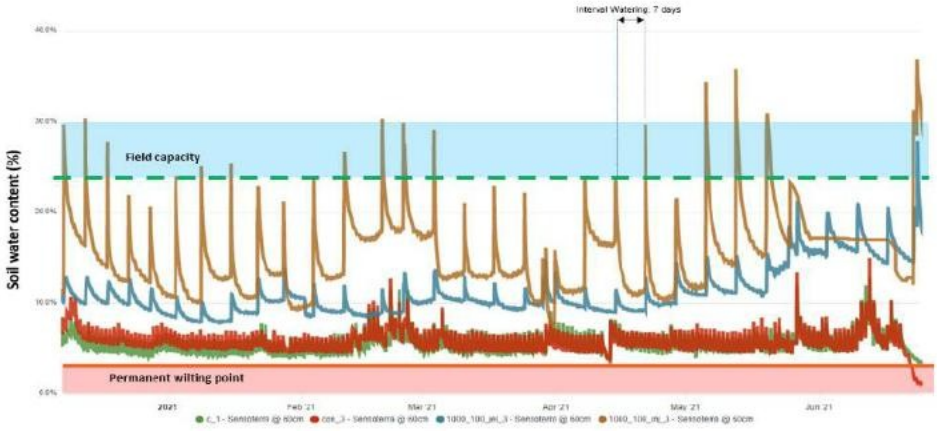


Figure 10: Example for soil water content sensor reading for EVERGREEN treatment from 10 December 2020 to 21 July 2021: controls (c-1 and c-2) Vs. Soil amended by 500g Raincatcher by injection and gel application. *Note that the controls were irrigated every day and EVERGREEN one per week*

Impact of Evergreen on the chemical, physical and biological properties of treated soils during the season

Evergreen showed higher soil moisture conservation in the field. The laboratory water holding capacity for the soil samples collected from the field did not significantly differ in soil saturation percent, field capacity or wilting point. The soil texture (Sand) did not change due to the treatment (Table 4)) and so the soil color (7/6 10YR)

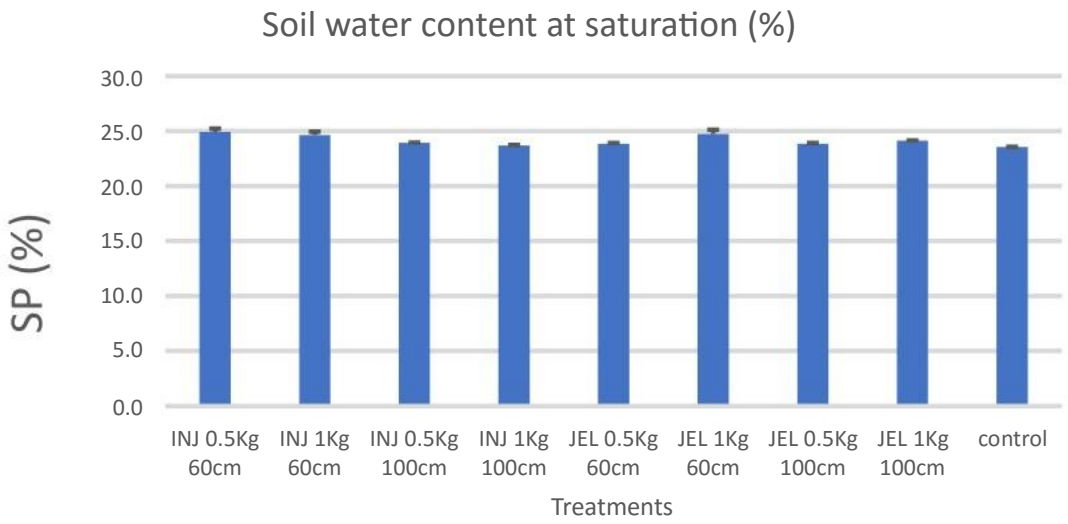


Table 3. Soil texture

Sample	Clay %	Silt %	Sand %	Texture
INJ 0.5Kg 50cm	1.19	0.28	98.53	Sandy
INJ 1Kg 50cm	0.79	0.52	98.69	Sandy
INJ 0.5Kg 100cm	1.03	0.52	98.45	Sandy
INJ 1Kg 100cm	0.71	0.16	99.13	Sandy
JEL 0.5Kg 60cm	0.87	0.44	98.69	Sandy
JEL 1Kg 50cm	0.95	0.56	98.49	Sandy
JEL 0.5Kg 100cm	0.79	0.76	98.45	Sandy
JEL 1Kg 100cm	0.11	1.12	98.77	Sandy
control	0.27	0.76	98.97	Sandy

Impact of Evergreen on Soil biological properties

Soil respiration (CO_2) emissions was determined in (100 g) soil mixed with one g of Evergreen in a closed glass vessel (250 mL) under lab temperature (25C °). CO_2 was trapped using 10 mL of 1 mol L −1 NaOH solution according to (Black, 1965) ultrapure water was added to adjust each soil mixture to 70% of field capacity before incubation. A soil without addition of Evergreen was also incubated as the control. The

excess NaOH was titrated with 0.1 mol L−1 HCl after the addition of $BaCl_2$ (Black, 1965). CO2-C emission rate (µg C g−1 soil d−1) was determined periodically during 45 days of incubation

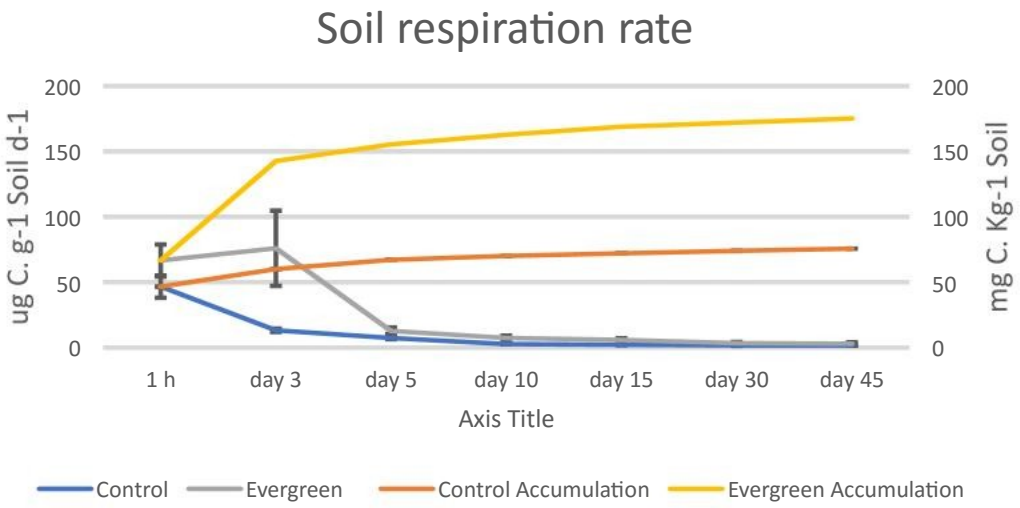


Figure 10: Effect of Evergreen (1g per 100g of sandy soils) on the cumulative and daily rates of CO_2 emissions during 45 days of incubation

Soil MBC was measured by the fumigation-extraction technique (Vance et al., 1987). soil samples (5 g) of each treatment were fumigated with ethanol-free chloroform. Then, the soil samples were extracted with 0.5 mol L^{-1} K_2SO_4 for 30 min. The non-fumigated soil samples were extracted similarly. Microbial biomass C was calculated as follow:

MBC = (OC extracted from fumigated soils − OC extracted from non-fumigated soils) ÷K_{EC}

where the k_{EC} (k_{EC} = 0.38) is a calibration factor

Applying Evergreen resulted in higher significant increases in CO_2-C emission rate compared to the control. Moreover, cumulative CO_2-C emission showed higher increases of more than 130% (from 75.7 to 175.2) mg C. kg^{-1} soil. The addition of Evergreen increased soil CO -C emission rate and cumulative CO - C emission because the added carbon, nitrogen, and other nutrients induced intense microbial activation and degradation of labile C fractions of the soil organic matter.

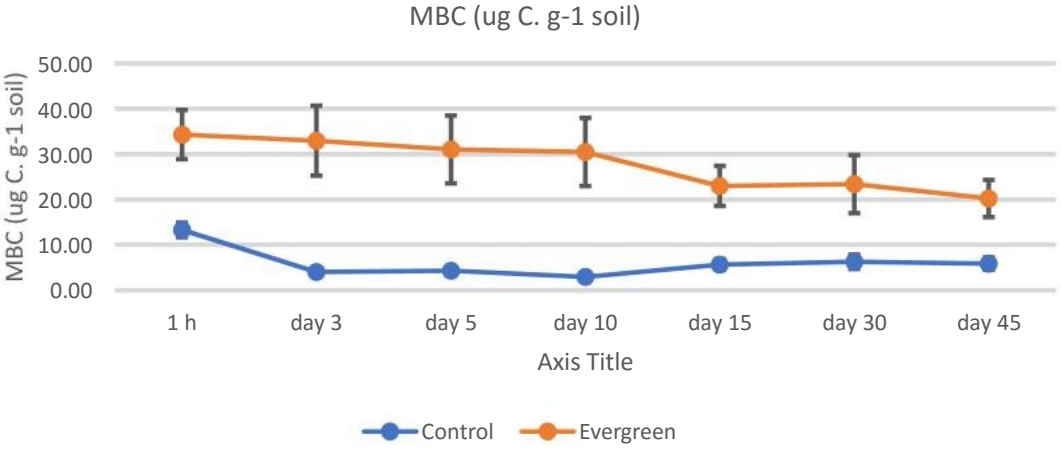


Figure 11: Effect of Evergreen treatment on the soil microbial biomass C (MBC)

The soil amended with Evergreen showed a significant increase in MBC throughout incubation. The values of soil MBC for the control, ranged between 5.8 and 13.3 for the control while Evergreen treated soils showed MBC ranging between 20.2 to 34.3 µg C g^{-1} soil. the increase in microbial biomass due to the application of organic additives is mainly due to the addition of substrate C, which can be responsible for the increased number of microorganisms in the organically amended soil and the subsequently stimulated microbial activity.

Soil Chemical and physical properties during the season

Table 4 summarizes the impact of Evergreen on the chemical properties of the treated soils. Evergreen did not show any significant impact on the soil pH. However, soil electrical conductivity significantly increased for both gel and injection treatment. Evergreen significantly increased the soil content of the measured elements. Soil available nitrogen was significantly increased by most of the Evergreen treatments. Phosphorus concentration is almost doubled for all the Raincatcher treatments.

Evergreen significantly increased soil organic matter content from 0.9 % to more than 1.4 % in case of injection and gel application at a 65 cm application distance from the trunk. Soil soluble and Calcium content significantly increased from 3.1 and 2.9 to 16 and 9 meql-1 respectively. Soluble Sodium was significantly increased from 126 to more than 600 ppm for the application of 1Kg of Evergreen gel.

Table 4. Average values and standard error of selected soil parameters for samples collected Evergreen treatment experimental location.

Treatment	pH	EC	N (ppm)	K (ppm)	P (ppm)	OM	%C	Ca (meq)	Mg (meq)	Na (ppm)
INJ 0.5Kg 50cm	7.4 ±0	3.3 ±1	16.2 ±5.4	96.3 ±21	11.8 ±4.8	1.1 ±0.3	0.7 ±0.1	13.1 ±3.5	7.4±1.1	498.5±54.4
INJ 1Kg 50cm	7.5 ±0.1	3.8 ±0.9	8.4 ±4.6	158.9 ±13.7	28.6± 6.7	1.6 ±0.1	0.9 ±0.1	14.2 ±3.2	8.0±1.1	629.3±55.2
INJ 0.5Kg 100cm	7.3 ±0.1	3.8 ±0.6	3.9 ±1.2	125.5 ±22.8	10.4± 2.6	1.1 ±0.1	0.7 ±0	14.3 ±1.8	9.1±0.8	577.9±41.5
INJ 1Kg 100cm	7.4 ±0	3.3 ±0.6	6.7 ±4.6	135.6 ±2.6	5.5± 1	1.1 ±0	0.7 ±0	11.8 ±1.4	7.4±0.5	495.3±43
JEL 0.5Kg 60cm	7.4 ±0	3.9 ±1.3	10.3 ±3.8	124.5 ±24.9	18.6± 7	1.4 ±0.3	0.8 ±0.2	14.4 ±3.9	8.6±1.2	594.8±86.1
JEL 1Kg 50cm	7.4 ±0.1	4.0 ±0.4	1.9 ±0.4	144.7 ±28.3	21.7± 6.8	1.2 ±0.2	0.7 ±0.1	16.8 ±2	8.4±0.6	566.9±19.5
JEL 0.5Kg 100cm	7.4 ±0	3.1 ±0.4	2.7 ±0.7	114.4 ±13.2	4.1± 1.5	0.9 ±0	0.5 ±0	11.4 ±1.7	7.5 ±0.8	452.2±20.2
JEL 1Kg 100cm	7.5 ±0	2.3 ±0.5	6.7 ±03.5	120.5 ±8.4	9.3± 0.6	1.1±0.1	0.6±0	7.9±0.7	6.1 ±0.50.2	356.4 ±48
control	7.4 ±0	1.0 ±0.4	2.4 ±0.1	58.9 ±7.2	4.2± 1.7	0.9± 0	0.5± 0	3.1± 0.1	2.9 ±	126.0 ±7.4

Changes in soil chemical properties after harvesting relative to the mid-season: nutrient uptake by date palm after applying the hydrogel compared to the control group.

Agricultural soil is a very complex and dynamic system. Therefore, changes in the chemical properties like nutrient availability and soluble nutrient content after a growing season are expected. Nutrient availability and balances in soil solution is a function of many different factors, including but not limited to: Soil fertilization and nutrient inputs, nutrient uptakes or removal by plant, nutrient losses and leaching, nutrient fixation etc. Therefore, nutrient availability cannot be used as a sole indicator to judge soil health or estimate nutrient uptake by plants. For example, decreased nutrient availability could be due to higher plant uptake of available nutrients or higher increased nutrient fixation and decreased solubility due to changes in soil solution chemistry. Hence the interpretation of soils chemical parameters should be combined with other system data, including crop, irrigation, and climate. Table 5 shows the changes in selected soil chemical parameters after dates harvest relative to the same parameters at ***the midseason***. The soil of the control treatment (non-treated trees) showed a significant increase in soil salinity and pH

due to alkaline irrigation water with some concentrations of sodium cations. On the other hand, many EVERGREEN treatments resulted in reduced soil salinity (Compared to the initial salinity).

It should be noted that the highest soil salinity (ECe) and sodium concentrations were observed in soils treated with 1000 g of EVERGREEN at 0.65 m from the tree's trunk. Thus, indicating a soil enrichment with sodium when EVERGREEN is nearby the trunk, i.e., in the middle of the roots zoon. On the other hand, most of the soil available nutrients showed a significant decrease. This result is in match with the increase of the crop yield, indicating that EVERGREEN probably increased nutrient removal from the soil through the enhanced plant uptake. This conclusion requires further investigation to study the potential impact of EVERGREEN on nutrient retention and fixation.

Table 5. Average values and standard error values of selected soil parameters for samples collected Evergreen treatment experimental location after harvest.

Application Method	Application rate	Distance from tree	pH	ECe	Ca	Mg	Na	Available Potassium	Available Phosphorus	Available Nitrogen
	g	m		(dS/m)	meq/l			ppm		
Injection	500	0.65	7.6 — 0.2	3.3 — 2.4	7.2 ↘ 7.6	4.3 ↘ 3.9	26.1 ↗ 18.2	76.0 ↘ 24.5	3.5 ↘ 2.8	25.2 ↗ 36.48
		1	7.6 ↗ 0.3	1.9 ↘ 0.8	3.0 ↘ 1.0	2.4 ↘ 0.7	15.2 ↘ 7.5	60.8 ↘ 9.27	4.3 ↘ 2.3	32.2 ↗ 23.13
	1000	0.65	7.6 — 0.3	5.2 ↗ 3.6	14.0 — 17.4	6.4 ↘ 5.9	40.7 ↗ 21.6	96.2 ↘ 30.9	5.7 ↘ 3.3	7 — 6.1
		1	7.7 ↗ 0.1	2.4 ↘ 2.7	9.5 — 13.9	3.6 ↘ 4.4	17.6 — 18.7	61.8 ↘ 22.9	5.4 — 3.1	23.8 ↗ 31.5
Gel application	500	0.65	7.5 — 0.3	2.5 ↘ 2.7	7.5 ↘ 10.5	2.9 ↘ 3.4	19.7 ↘ 20.2	96.2 ↘ 83.3	3.4 ↘ 3.6	4.2 ↘ 3.7
		1	7.7 ↗ 0.2	2.1 ↘ 0.2	3.2 ↘ 0.5	2.5 ↘ 1.0	18.2 — 1.74	51.7 ↘ 3.5	3.9 — 3.6	10.2 ↗ 9.3
	1000	0.65	7.6 ↗ 0.3	5.6 ↗ 5.4	14.7 ↘ 18.8	7.3 — 7.8	44.7 ↗ 39.3	30.1 ↘ 26.4	2.7 ↘ 3.6	5.13 ↗ 6.6
		1	7.7 ↗ 0.0	1.7 ↘ 0.8	2.9 ↘ 1.9	2.2 — 1.5	13.7 — 6.23	54.8 ↘ 4.63	5.5 ↘ 2.9	8.4 ↗ 3.7
Control			7.6 ↗ 0.1	2.2 ↗ 1.7	3.4 — 1.61	2.8 — 1.6	18.6 ↗ 17.6	56.8 — 6.32	3.9 — 2.4	27.5 ↗ 44.1

* ↗ : Significant increase, ↘ : Significant decrease — : No Change

In-field assessment of the impact of EVERGREEN soil amendment on plant water status.

Stomatal conductance

Under water stress conditions, stomatal conductance decreases due to the stomata's closure to maintain the leaves' hydric state. The results of three, four, and five days after irrigation show that the leaves were not stressed with 500g of Evergreen. Instead, their water status appeared to be better.

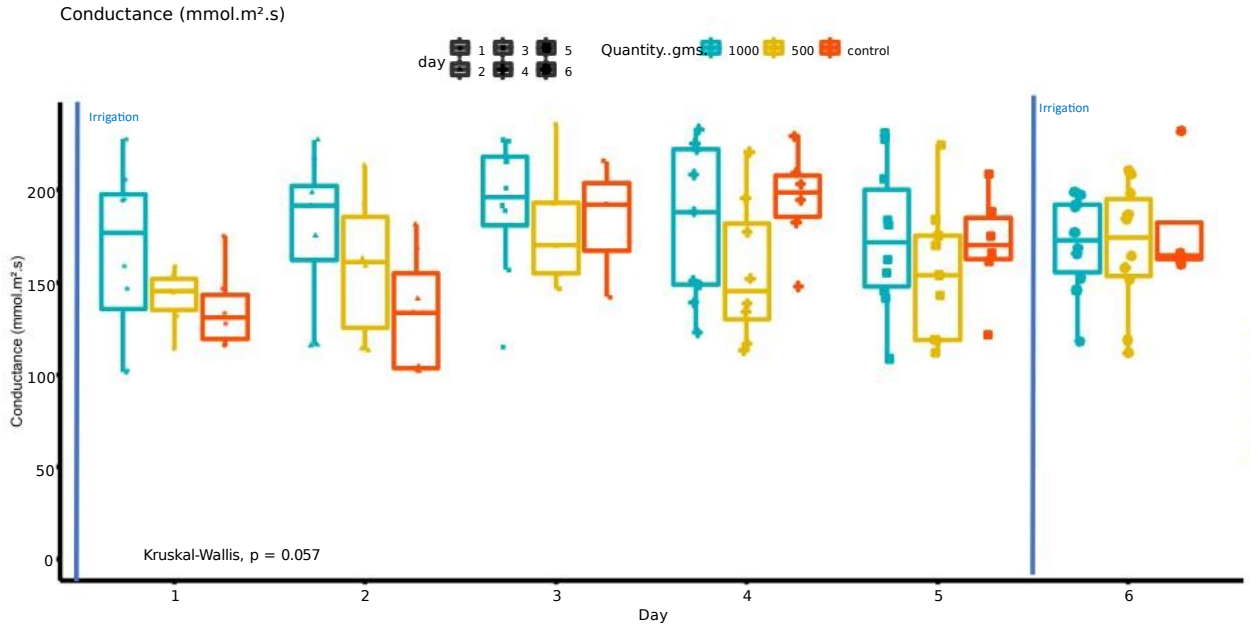


Figure 12: Daily stomatal conductance box plot. Humidity was determined using a portable Leaf porometer (Model SC-1, Decagon Devices, USA) (31 January to 5 February 2021).

Relative water content

Relative water content (RWC) is the most common measure to quantify leaf water status. We estimated it using a portable Leaf porometer (Model SC-1, Decagon Devices, USA). Generally, RW in the leaf decreased with increased water stress levels, and it did not decrease in all treatments with EG. The water-saving using EG does not affect the plant water status during the first trial phase.

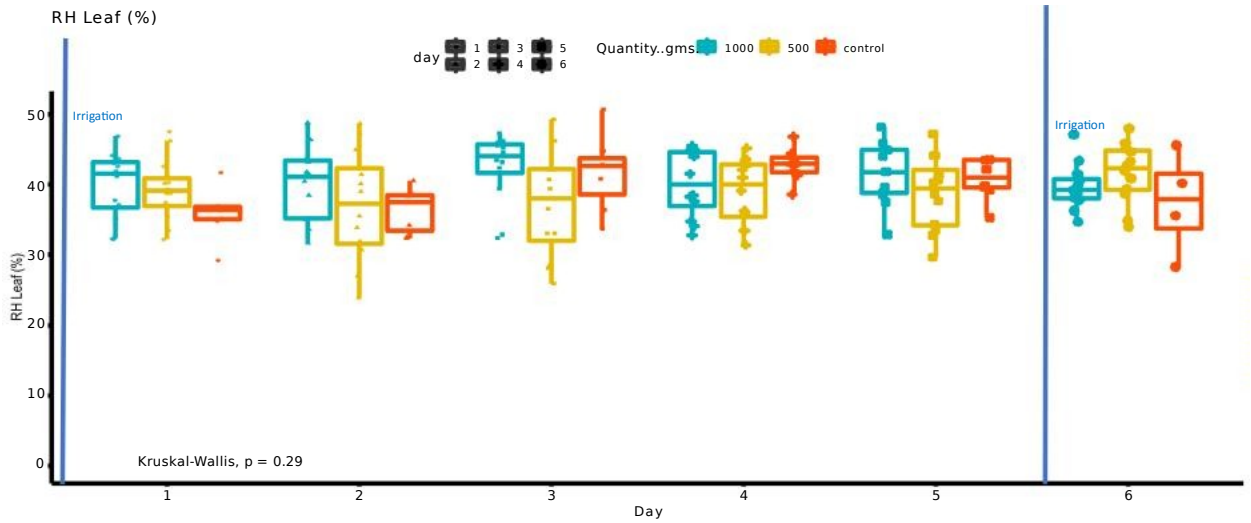


Figure 13: Daily Leaf relative humidity box plot. Humidity was determined using a portative Leaf porometer (Model SC-1, Decagon Devices, USA) (31 January to 5 February 2021).

Leaf temperature

Testing leaf temperature shows that no significant changes happened after applying the different Evergreen treatments. A general decrease or increase in leaf temperature reflects a physical

change in stomatal opening regardless of water availability changes. Stomata close under water deficits, and leaf temperatures rise. The lack of water causes the leaves and plants to warm up, and in our trial, the date palm trees did not suffer from any water stress even without irrigation for seven days.

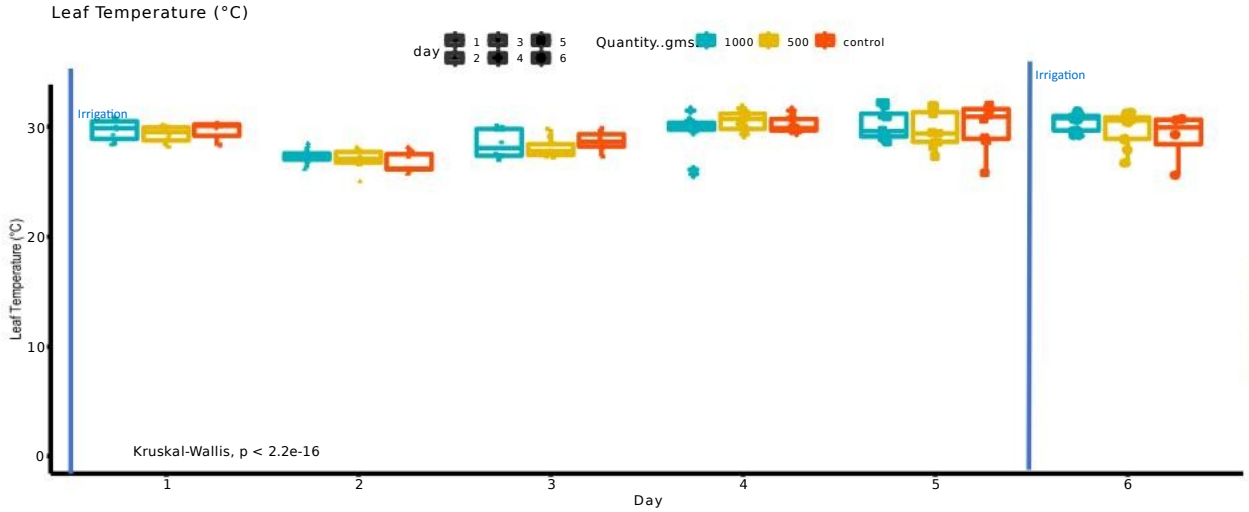


Figure 14: Daily Leaf Temperature box plot. The temperature was determined using a portable Leaf porometer (Model SC-1, Decagon Devices, USA) (31 January to 5 February 2021).

Photos (Figure 15) were taken by Thermal Imaging Camera, which visually shows that there is no difference between control irrigated with 120 L per day and EG irrigated with 120 L every 5 days.

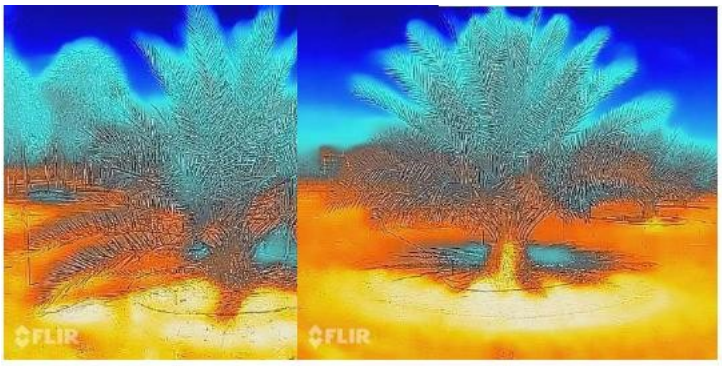


Figure 15: EG tree (right) Vs. control (left) photos by Thermal Imaging Camera

Root development and volume

In mid-December 2020, 0.3 m x 0.3 m deep and 0.7 m deep of soil tangent to Evergreen were dug, and all roots were removed. The soil was returned, and two months later, the same operation was performed. The size of the newly developed roots is shown in the Figure.

This confirmed two critical conclusions.

- ✓ **Non-toxicity of the product, otherwise new roots would have not developed.**
- ✓ **The best way to apply EG is by injection to reduce damage to the roots.**

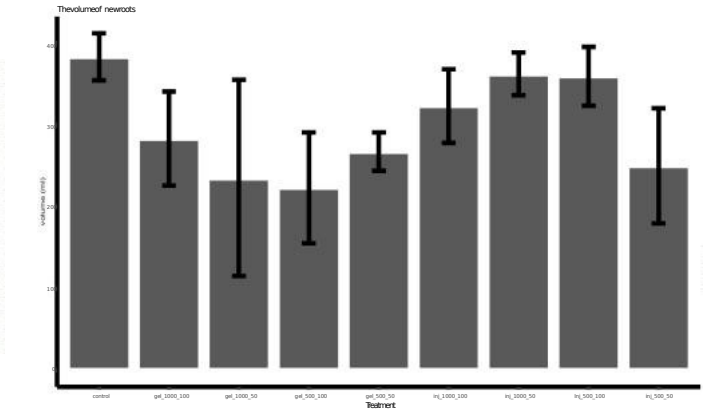


Figure 16: Photos of the root extraction from the soil tangent to Evergreen (0.3 m x 0.3 m x 0.7 m) and roots volume for each treatment.

In-field assessment of visial Drought Damage Index (DDI)

DDI was scored averaging the damage index from zero to ten (0-no visual symptoms of the damage, 5-
symptoms are very visual) using criteria such as the extent of leaf chlorosis, the number ofnew leaves and dead
leaves.

The in-field assessment showed the absence of any damage index on the date palm tree, and the DDI was around 1 for all the trees (Figure 17).

Figure 17: The photo was taken from the field at the end of trial phase one.

Impact of Evergreen on the date palm yield and fruits quality

During August, harvest and yield and fruits quality estimation has been done to assess the technology's impact on the yield and quality of dates and confirm its efficiency when temperature and evapotranspiration are high. Also, it is after enough period from the date of application (around 300 days) to assess any adverse effect on the soil or crop.

Yield

Figure 18 shows the Date palm yield under different treatments: the two application rates: 1 0 0 0 g/tree and 500 g/tree; the two methodologies: Injection and Gel application; the two different distances from the tree's trunk: 100 cm and 50 cm; with 3 replicates.

The results show the positive effect of the use of the EVRGREEN on the yield for all the treatments except the application of 500g using the injection method at 0.65 m distances from the tree's trunk.

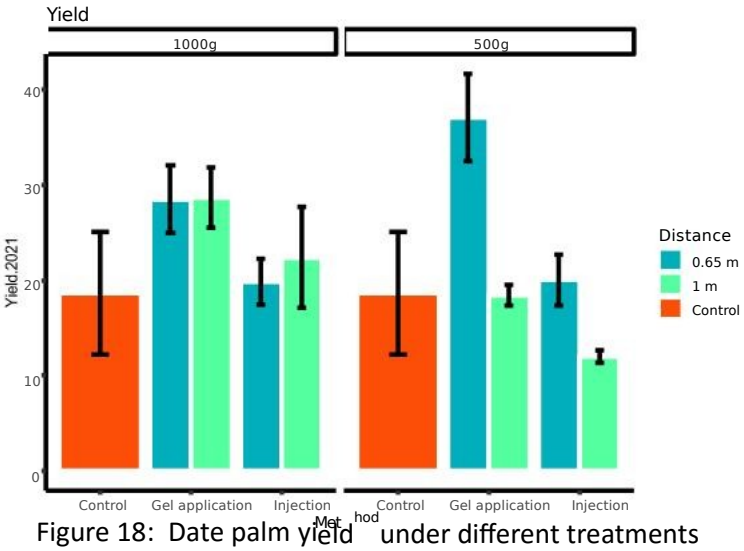


Figure 18: Date palm yield under different treatments

In general, the gel application helps the tress to achieve a better yield relative to control with a water-saving up to 80 %. In addition, except for the gel application of 500 g at 0.65 m, the use of 1000g of the hydrogel is more beneficial for the date palm trees for better yield.

Part of the saved water comes from reducing the added amount dedicated initially for a factor-of-safety (25%) and the salt leaching fraction (25%), According to ICBA's previous work (Al-Muaini et al., 2019; https://doi.org/10.1016/j.agwat.2019.05.022).

Fruit yield increased by an average of 20%, especially for applying 1000 g of Evergreen per tree. This can be explened in part by enhancing the nutrition uptake and its availability for the trees for a more extended period. Indeed the hydrogel reduce the loss of water and minerals

Figure 19: The photo was taken from the field at the harvest on 29 August 2021.

Table 6: Yield in kg per tree for the 2020 and 2021 after Evergreen application, the relative yield to control for the 2021 production, yield increase 2021 relative to 2020 (%), the estimated Evergreen. effects

Method	Quantity	Distance	2020 Yield (kg/tree))	2021 Yield (kg/tree) EVERGREEN	yield increase 2021 relative to 2020 (%)	2021 Yield relative to control (%)	Evergreen effect in % yield *
Injection	500	0.65 m	6.05	20.03	69.78	7.71	49.78
Injection	1000	0.65 m	15.88	19.86	20.05	6.79	0.05
Injection	500	1 m	10.01	11.99	16.46	-35.56	-3.54
Injection	1000	1 m	14.54	22.41	35.13	20.50	15.13
Gel application	500	0.65 m	21.36	37.13	42.47	99.61	22.47
Jel application	1000	0.65 m	17.02	28.52	40.32	53.33	20.32
Jel application	500	1 m	10.15	18.43	44.93	-0.93	24.93
Jel application	1000	1 m	13.51	28.74	53.00	54.52	33.00
Control			16.49	18.63	20	0.13	-

Table 6 shows the yield in kg per tree for 2020 and 2021 after Evergreen application, the relative yield to control for the 2021 yield production, also the yield increase in 2021 relative to 2020 in %. The estimated EVERGREEN effects in the yield variation were estimated by the overall variation with the elimination of 20% as the age effect for the young trees (natural yield increases from season to season before retching the optimum). Thus, the 20% is the control trees yield increases.

The results show the significant positive effect of the hydrogel.

Fruits quality

Fruits weight and dimensions

Figure 20 shows that the fruits produced using the injection method with 1000g of hydrogel have the same 50 fruits weight as the control, which is a criterion considered for evaluating the quality of the dates in the UAE market (Al Foa).

Thus, the yield increases under some treatments induce a weight reduction of fruits; this negative correlation between yield and fruits size is very common in the date palm. However, the results confirm that the use of 1000 g of Evergreen allow keeping a good fruit volume

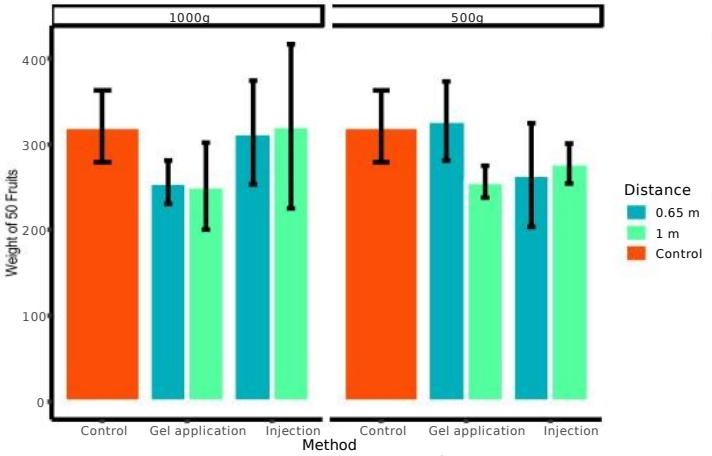


Figure 20: Fruits weight under different treatments

Figures 21 and 22 illustrate the length and width of the fruit in cm. we observe the same trend of the weight of the fruits. Thus, the use of Evergreen allows keeping some fruits dimension event applying lest water for irrigation.

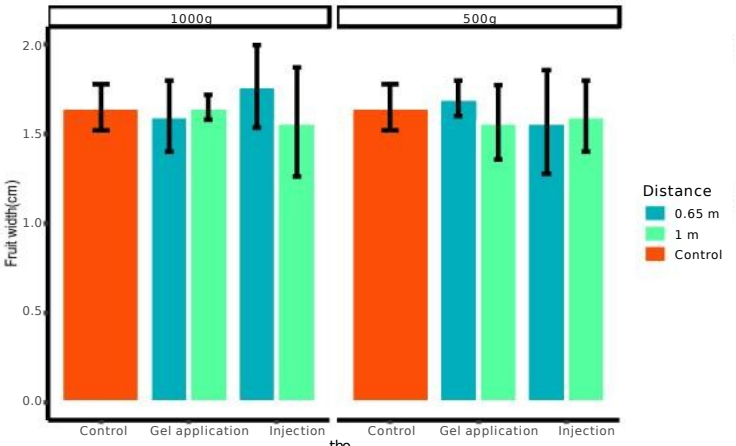


Figure 21: width of the fruit in cm under different treatments

The quantity of 1000g was always the best treatment for fruits. The injection method was the best for the quality of the fruits in terms of volume

Fruit yield increased by applying 1 0 0 0 g of Evergren per tree. Meanwhile, the application of only 500g per tree was not enough for having a good fruit size. Indeed, it decreased by 13 to 20%.

Note: The digital Vernier caliper measured the fruit length and width, and 50 fruits weight was measured using an electronic balance.

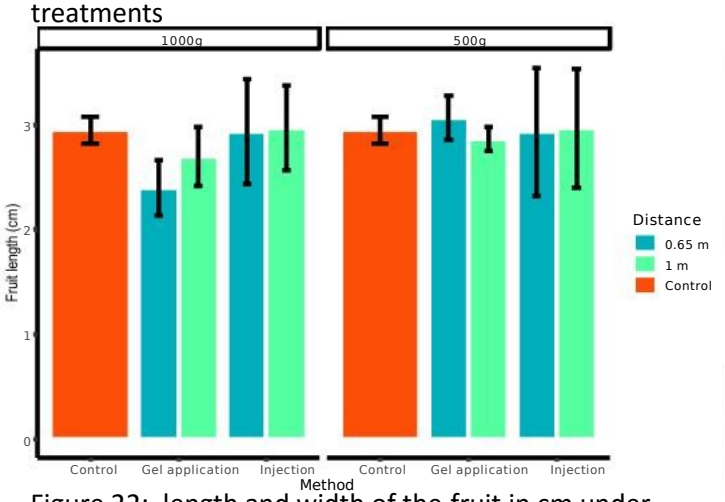


Figure 22: length and width of the fruit in cm under different treatments

Fruit sugar content

Sugar concentration was measured for 27 date fruit trees used in the trial.
The result showed that even after decreasing the irrigation water quantity for the trees by almost 82% compared to the control group. Thus, the quality of the fruit from the trees treated by Evergreen hydrogel was not negatively affected. But event we observe an enhancement by 2 or 3 degrees on the percentage of the total sugar content for most treatments.

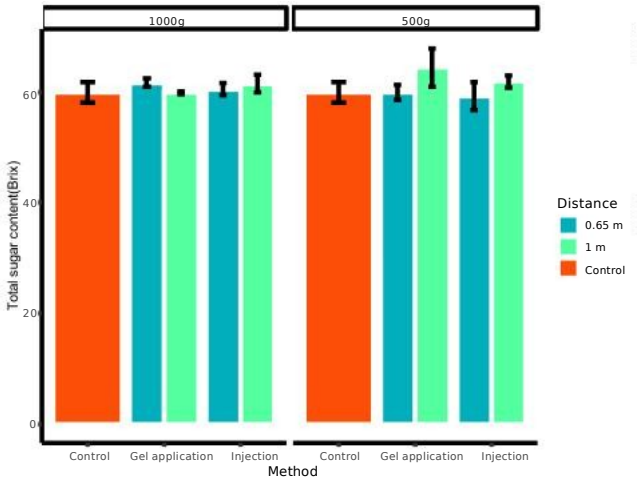


Figure 23: Fruit sugar content (°Brix) of the fruit in cm under different treatments

Note: Each date palm fruit's sugar content was determined using a refractometer device (Mettler Toledo Refracto 30PX Portable Handheld Refractometer) 100 mg of date palm was added in a centrifuge tube and mixed with 1 ml of distilled water. Then the sample was placed in the refractometer device to obtain the sugar content value in °Brix.

The Date fruit is excellent food with beneficial properties from a nutritional and therapeutic perspective, where it has a good source of sugar, energy, vitamins, minerals, and fibers. However, in CGG regions, freshwater is limited, and salinity is a global environmental problem that affects fruit trees' growth. Additionally, it causes a threat to agriculture in low rainfall and high-temperature regions. Therefore, a study using the Evergreen hydrogel as a soil amendment to save water was conducted at ICBA in collaboration with Evergreen, where different applications were used.

The results confirm the possibility of saving water by delivering water to tres roots areas effectively and efficiently. Thus it's possible to grow date palm in the marginal environment using significantly less water without the tress becoming under stress and produce good fruit quality.

Conclusions

- The results obtained so far from a single-season experiment showed that the irrigation water quantity for the trees decreased by **82%** compared to the control group during the whole season.
- During the last 7 months of the experiment, the saving was **85%** (one-seventh) without any damage or stress to the tree. This confirms that a stabilized **85%** water saving is achieved over long periods.
    - ✓ By the end of the Phase 1 trial (129 days), the total water savings was 12.5 m^3 per tree, equivalent to an average of 77% water saving, which was reached 82 % at the end of Phase 1.
    - ✓ The water meter reading results show that RC used an average of 82% less water than the control during the whole first project phase period (294 days). An average of 37.92 m^3 of water was used to irrigate one tree's control (reference tree) for 294 days. Meanwhile, only 6.79 m^3 of water was used to irrigate one EG tree, which means 82% saving.
    - ✓ Considering only the last 7 months of the experience, the saving was **85%** (one-seventh)
- Part of the saved water comes from reducing the added amount dedicated initially for a factor-of-safety (25%) and the salt leaching fraction (25%), According to ICBA's previous work (Al-Muaini et al., 2019; https://doi.org/10.1016/j.agwat.2019.05.022).
- Fruit yield increased by an average of 20%, especially for applying 1000 g of Evergreen per tree. This can partly be explained by enhancing the nutrition uptake and its availability for the trees for a more extended period. Indeed, the hydrogel reduce the loss of water and minerals
- Fruit yield increased by an average of 20%, especially for applying 1000 g of Evergreen per tree of similar age. The bigger tree might need more amount.
- . Meanwhile, the application of only 500g per tree was not enough for having a good fruit size. Indeed, it was decreased by 13 to 20%.
- Evergreen minimizes soil nutrient losses, including nitrogen, phosphorus, calcium and magnesium. Evergreen improved soil organic matter content and organic carbon content due to its high carbon content (More than 25%). The increase in soil nutrient availability could be attributed to two factors. 1- The enrichment of Evergreen with nutrient content and 2- due to the induced increase in soil nutrient availability due to available water and microbial activity and increased soil cation exchange capacity.
- Evergreen significantly increased soil salinity and soil available sodium when it's applied at the rate of 1000g nearby the track, i.e., in the middle of the roots zone. This is due to the decreased rates of irrigation water and the accumulation of sodium for the irrigation water in the treated zone, which require attention for the importance of soil leaching after or during the growth season.

- Evergreen increased soil respiration rate after the incubation simultaneously increased the soil microbial biomass carbon. This refers to the increase in soil microbial biomass due to its decomposition and the release of available nutrients. It could also be concluded that the product did not harm soil microbes or induce microbial toxicity.