HYDROUSA

H2020-CIRC-2-2017

Water in the context of circular economy

Full project title:

Demonstration of water loops with innovative regenerative business models for the Mediterranean region

Deliverable: D25

Relative Number in WP4 D4.5

Report on yields, health of crops and derived products

Due date of deliverable: 30.06.2023

Submission date of revised deliverable: 12.03.2024

This project has received funding from the European Union's Horizon 2020 Research and Innovation Programme under Grant Agreement No 776643

This project has received funding from the European Union's Horizon 2020 Research and Innovation Programme under Grant Agreement No 776643

DOCUMENT INFORMATION

Deliverable	**Number**	D4.5	**Title:**	Report on yields, health of crops and derived products
Work Package	**Number**	WP4	**Title:**	Agricultural Innovations

Due date of deliverable	**Contractual**	M60	**Actual**	M60
Version number	1.5			
Format	MS Office Word document			
Creation date	23.12.2022			
Version date	12.03.2024			
Type	☒ R	☐ DEM	☐ DEC	☐ OTHER ☐ ETHICS
Dissemination Level	☒ PU Public		☐ CO Confidential	
Rights	Copyright "HYDROUSA Consortium". During the drafting process, access is generally limited to the HYDROUSA Partners.			

Responsible authors	**Name:**	Heinz Gattringer, Johannes Kisser, Nektaria Efthymiou-Charalampopoulou, Vaggelis Statiris, Antonios Eleftheriou, Nicolas Bedau	**E-mail:**	office@alchemia-nova.net jk@alchemia-nova.net nec@alchemia-nova.net statir90@gmail.com eleftheriou@hydraspis.gr n.bedau@tinosecolodge.gr
	Partner:	ALCN	**Phone:**	+43(1) 810 1000

Brief Description	This report presents the performance of the agricultural sites in terms of crop production, crop and product diversity, total yield per m^2 and other key performance indicators. It also includes a comparison of the different crops grown with available literature data and international standards.
Keywords	crop yields; crop production; derived products

Version log Revision history			
Rev. No.	**Issue Date**	**Modified by**	**Comments**
1.1	23.12.2022	Heinz Gattringer, Johannes Kisser, Nektaria Efthymiou-Charalampopoulou	TOC (HYDRO5 as sample on 13.02.2023)
1.2	31.03.2023	Vaggelis Statiris, Nicolas Bedau, Antonios Eleftheriou	Inputs on HYDRO2, HYDRO3, HYDRO4, HYDRO6
1.3	14.04.2023	Heinz Gattringer, Johannes Kisser, Nektaria Efthymiou-Charalampopoulou	Review, introduction, conclusions, comparative analysis, formatting, etc.
1.4	30.6.2023	NTUA	Review and editing
1.5	12.03.2024	Polymnia Dagtzidou	Modification according to Final Review comments

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

EXECUTIVE SUMMARY

This deliverable report describes the actions undertaken in relation to sustainable agricultural practices based on innovative water sources used for irrigation in the Greek islands of Lesvos, Mykonos and Tinos which are characterized by water-scarce dry summer periods. Organic farming practices have been implemented in all agricultural sites for significant added value of the final crop production. Composted plant residues, green manures and composted sludge from the UASB of HYDRO1 have been used to increase soil organic carbon and establish healthy soil conditions.

Boosting of local agricultural production was accomplished through different schemes including agroforestry in HYDRO2 (Lesvos) with treated water effluents from a municipal wastewater treatment plant for irrigation and fertigation purposes, cultivation of Oregano in HYDRO3 (Mykonos) with irrigation through smart collection and storage of rainwater, cultivation of Lavender in HYDRO4 (Mykonos) with irrigation through domestic rainwater harvesting and aquifer storage, development of a tropical Productive Greenhouse in HYDRO5 (Tinos) irrigated with desalinated seawater from an innovative solar evaporation and re-condensation technology, cultivation of a high variety of local crops in an eco-tourist facility in HYDRO6 (Tinos) irrigated from different decentralized non-conventional water sources.

Certain challenges were encountered that affected the demo site activities, such as the global Covid pandemic and some extreme weather events, resulting in delays in cultivations in some demo sites and/or the need to implement adjusting measures and contingency actions such as replanting. Overall, the concepts for innovative sustainable water sources for agricultural activities proved to be technically viable and agricultural production was successful. Crop production through the valorised innovative water sources can profit fiscally the local society in the long term and offer the possibility of climate resilient agricultural practices in the water-stressed areas.

HYDROUSA has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 776643.

ABBREVIATIONS

DIG	**Days in Garden**
DTM	**Days to Maturity**
GH	**Greenhouse**
MS	**Mangrove Still**
PGH	**Productive Greenhouse**
PWU	**Product Water Use**
SOM	**Soil Organic Matter**
UASB	**Up-flow anaerobic sludge blanket**
USDA	**United States Department of Agriculture**
WUE	**Water Use Efficiency**

1. INTRODUCTION

A key objective of HYDROUSA is to demonstrate sustainable agricultural practices based on innovative and sustainable irrigation water sources in some Greek islands that are characterized by very dry summer periods. Besides sustainable irrigation water sources, adherence to organic farming practices was implemented. There are numerous organic farming principles, but for this project the organic farming guidelines of the EU were used[1].

Beyond these organic farming guidelines, good practices known as conservation farming were implemented, especially at the agroforestry site of HYDRO2. Here a combination of (fruit-) trees and perennials together with common edible vegetables and herbs were implemented. The desired result was the increase of organic soil carbon. This was supported for example by using green manure or compost additions wherever possible. Compost is a well-established and known technology. This project benefited from previous research on this area and went a step beyond by trying to produce and use compost that includes the sludge of a municipal wastewater treatment plant as a starting substrate. The idea being the reclamation of nutrients for plants that are generally wastefully discarded.

The biggest contributions of HYDROUSA are the technologies demonstrated for sustainable water sources for agricultural production. Amongst these is the use of the treated effluent of a municipal wastewater plant for irrigation of productive agricultural fields. Here not only the recovered water was used, but the residual inorganic nutrients (N, P, K) of this water stream was used to fertigate the plants. Other sustainable water sources include solar desalination from seawater, condensation water from humid air, rainwater collection and storage and other reclaimed water sources. This happened to contribute to the recommendations of the 2017 UN World Water Development Report, Wastewater: The Untapped Resource[2].

Achieving sustainability and circular use of resources both in terms of water and plant nutrients are therefore key contributions of the HYDROUSA project. This is especially in areas that are considered marginal for high yield farming. Creating jobs and employment opportunities at the demonstration site locations was another desirable goal pursued by the project.

To monitor the success of the different innovative practices, a series of Key Performance Indicators (KPI) were established at the onset of the project. This was done to allow comparisons of results with other practices or international standards, but it must be mentioned that the KPIs do not always integrate social or environmental benefits.

HYDRO2, located on the island of Lesvos, is an agroforestry type of cultivation that innovatively uses the reclaimed water that is produced through the treatment of municipal wastewater in HYDRO1 site for irrigation

[1] European Commission Directorate-General for Agriculture and Rural Development, 2023. Agriculture and rural development, Organics at a glance. https://agriculture.ec.europa.eu/farming/organic-farming/organics-glance_en
[2] UNEP 2017. 2017 UN World Water Development Report, Wastewater: The Untapped Resource. ,https://www.unep.org/resources/publication/2017-un-world-water-development-report-wastewater-untapped-resource

purposes. Interestingly, the remaining nutrients in the treated water obviate the need to use fertilizers and can be considered as fertigation water. Compliance with health and environmental safety guidelines has been closely monitored.

HYDRO3 is located on Mykonos, the well-known touristic location island. It uses an innovative subsurface rainwater collection and storage system to produce irrigation water. It uses the local geographic characteristics for the rainwater collection infrastructure and has minimal impact on landscape and ground. The irrigated crop was Oregano.

HYDRO4 is also located on Mykonos and uses a rainwater collection and storage strategy. Besides a water tank, storage in a natural aquifer is also implemented. The irrigated crop is Lavender.

HYDRO5 is located on Tinos Island, not far from Mykonos and close to the coast. The sustainable water source is seawater desalinated through an innovative solar evaporation and re-condensation technology. The produced water is of high quality and is used to irrigate a greenhouse with tropical and subtropical crops, including bananas, papayas, pineapple, maracuja, Aloe vera and others.

HYDRO6 is also located on Tinos Island but farther inland on a very hilly area. It is part of a touristic lodge receiving international visitors. Sustainable practices are consequently implemented in all activities of the lodge and so is sustainable farming since the water used for irrigation originates from collected rainwater, reclaimed water from guest showers and collected surface water. Collected rainwater irrigates edible vegetables, while the other water streams irrigate herbs and medicinal plants. A high variety of vegetables are grown year-round in intensive mixed- and poly-cropping systems with high crop rotation rates.

This project has received funding from the European Union's Horizon 2020 Research and Innovation Programme under Grant Agreement No 776643

2. HYDRO2

2.1 Demo site overview

HYDRO2 is an agroforestry system with a wide diversity of trees, shrubs, aromatic plants and annual crops and is located on Lesvos Island. The demonstration site is irrigated with nutrient-rich reclaimed water that is produced in HYDRO1 demo site, which treats the municipal wastewater from Antissa village. The irrigation water that is produced in HYDRO1 complies with the EU legislation about unrestricted agricultural use (Class A water quality) and is characterized by significant nutrient content in terms of nitrogen and phosphorus. This fertigation water is of high importance for the HYDRO2 site since no commercial fertilizers are needed for the plantation.

The site has an area of 1 ha and is divided into 2 fields. The main field of the site has an area of about 0.8 ha and includes more than 60 different plant species, while the second field includes a seasonal plantation of maize/barley accompanied with some aromatic plants and trees. Half the area of the second field is irrigated with conventional tap water for research and comparison purposes in order to evaluate the effect of the reclaimed water on the plant's growth, health, yield etc.

Agroforestry helps in integrating agriculture and forestry by creating systems, where trees and shrubs are planted side to side with agricultural crops and/or livestock in a dynamic system. This system provides a variety of environmental, economic and social benefits compared to conventional methodologies and approaches[3].

The irrigation of the agroforestry system is mainly applied through a drip irrigation system that has been finalized before the start-up of the system, while at the same time traditional stone channels coupled with furrow irrigation has been constructed and tested during the 2 years of operation. The irrigation of the main field is regulated by an irrigation panel while the second field is irrigated by an autonomous irrigation system, provided by AGENSO, that includes an automatic start/stop of the irrigation process in accordance with the soil moisture sensor's measurements.

The main field of HYDRO2 is located in the north-east of the HYDRO1 site, while the second field is located on the other side of the road of the wastewater plant as shown in **Figure 2.1**. More details about the position of the site were already presented in D 4.2 (Design of the preparation of sites).

[3] FAO, 2015

Figure 2.1: Overview of existing WWTP, location of HYDRO1 and the two fields of HYDRO2

Both fields of HYDRO2 were not cultivated during the past years and before the implementation of the agroforestry system a lot of preparation works had to be done to prepare the fields for the upcoming plantations. **Figures 2.2 and 2.3** present the past status versus the status of both fields after the first 6 months of operation and show the significant change in the cultivated areas.

Figure 2.2 HYDRO 2 main field before the start-up (left photo) and during late September 2021 (right photo)

 

Figure 2.3: HYDRO 2 second field before the start-up (left photo) and during late September 2021 (right photo)

The significant changes of the two fields of HYDRO2 since the start up are also depicted in **Figure 2.4 and Figure 2.5** which present the aerial view of both fields during the second year of the agroforestry system operation (September 2022).

Figure 2.4: HYDRO2 main field during September 2022

Figure 2.5: HYDRO2 second field during September 2022

2.2 Plant selection

The initial list of the plants that were selected for the agroforestry system was prepared based on the following activities that were presented in detail in D4.2(Design of the preparation of sites):

- Literature review of ethnobotanical studies and other related publications linked to Lesvos and HYDROUSA's demonstration site at Antissa (36 detailed studies were reviewed)
- Inputs of the local community through the participatory workshop which was organized in December 2018
- interviews with local experts and stakeholders
- Climate data and soil condition analysis

The initial idea was to use 3 main groups of plants such as fruit trees, bushes/herbs and annual crops with a variety of local vegetable crops. High value plants were combined with beneficial organisms attracting other species to create resilience with diversity. More than 60 different plant species were planted in the two fields of HYDRO2. The selected plant species are presented in the following Table (**Table 2.1**).

Table 2.1: HYDRO2 plant species

Category of plants	Plant species
Trees	Olive, Fig, Pomegranate, Almond, Apple, Pear, Quince, Hazelnut, Lemon, Laurel, Cherry, Mulberry, Willow, Plum, Loquat, Tabor oak, Plane
Shrubs	Hippophae, Blackberry, Raspberry, Physalis, Goji berry, Myrtus, Eleagnus, Aronia, Strawberry, Cistus creticus, Allium
Aromatic plants	Lavender, Oregano, Rosemary, Sage, Savory, Melissa, Mint, Annice, Pelargonium, Basil, Thyme, Calendula, Echinacea
Annual plantations	Maize, Barley
Seasonal vegetables	Watermelon, Melon, Tomato, Cucumber, Zucchini, Eggplant, Onion, Lettuce, Pepper, Beans, Cauliflower, Broccoli, Pumkin, Beetroot, Cabbage, Radish, Cale, Leek, Peas, Parsley, Celery, Spinach, Carrot, Potato

This project has received funding from the European Union's Horizon 2020 Research and Innovation Programme under Grant Agreement No 776643

Throughout the 2 years of the HYDRO2 operation, some changes/additions on the initial plant design took place in cooperation with the local agronomist. For example, some tropical plants that were initially selected (Moringa, Avocado etc.) were not able to survive the environmental conditions of Antissa region. Such species were replaced with plants thriving on the area like a variety of seasonal vegetables (tomato, Eggplant, Zucchini, watermelon, etc.) that so far produced high yields of valuable products for the local community. The local conditions in terms of climate data and soil analysis were already presented in detail in D4.2 (Design of the preparation of sites).

2.3 Agricultural production

Challenges

The operation of a 1 ha agroforestry system with a wide diversity of plant species is quite challenging. During the start-up period we faced many difficulties in terms of plants availability due to Covid 19 restrictions. Nevertheless, with the support of the local agronomist we managed to find most of the desired plants by ordering from many different nurseries in Athens. Due to Covid, the scheduling of the plantation was postponed in some cases, but the start-up of the system was concluded on time.

A major challenge for the agroforestry system was to address the climatic conditions of the Antissa area, especially during the winter period. Some plant species were stressed due to long periods of heavy rains and low temperatures. **Figure 2.6 & Figure 2.7** present a representative graph of temperatures and rainfalls respectively during the two years of operation.

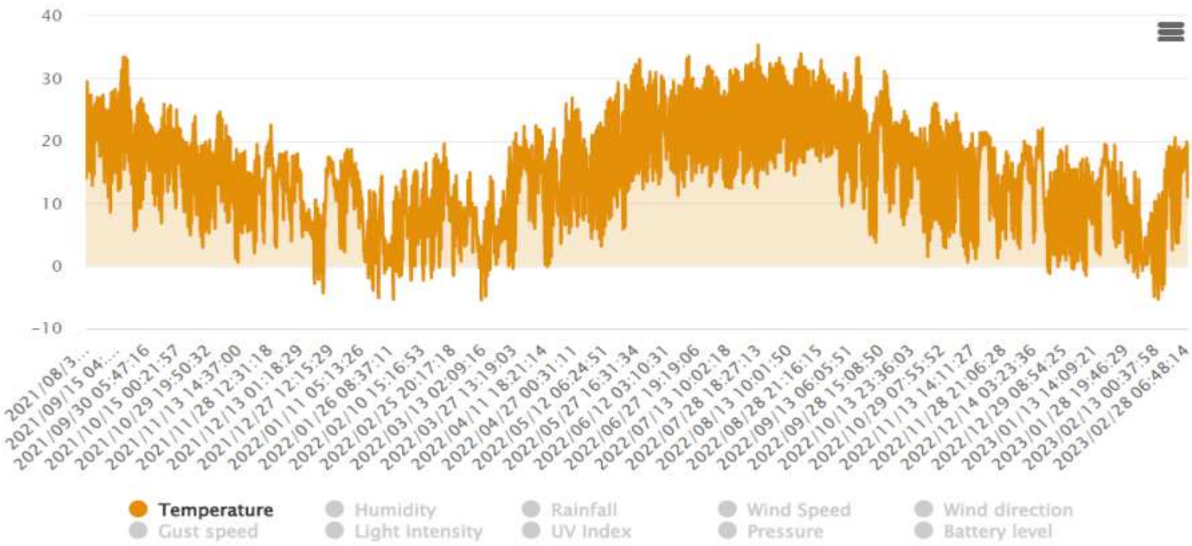

Figure 2.6: Temperature fluctuation on HYDRO2 as recorded by AGENSO's weather station

The main issue with the temperatures of the site area was not only the low temperatures that were recorded during the winter nights that reached values as low as -5 degrees Celsius. At the same time, it was observed that there was a wide fluctuation of the temperature values between days and nights. This phenomenon is quite stressful for many plants since they are not able to adapt to such significant and sudden temperature changes (>10 ^{0}C) during the same day. In our case, this fact seems to have a negative effect to plant species like Lavender and an individualized strategy had to be applied to protect these plants with the addition of

This project has received funding from
the European Union's Horizon 2020
Research and Innovation Programme
under Grant Agreement No 776643

biological preparations for antifreeze support.

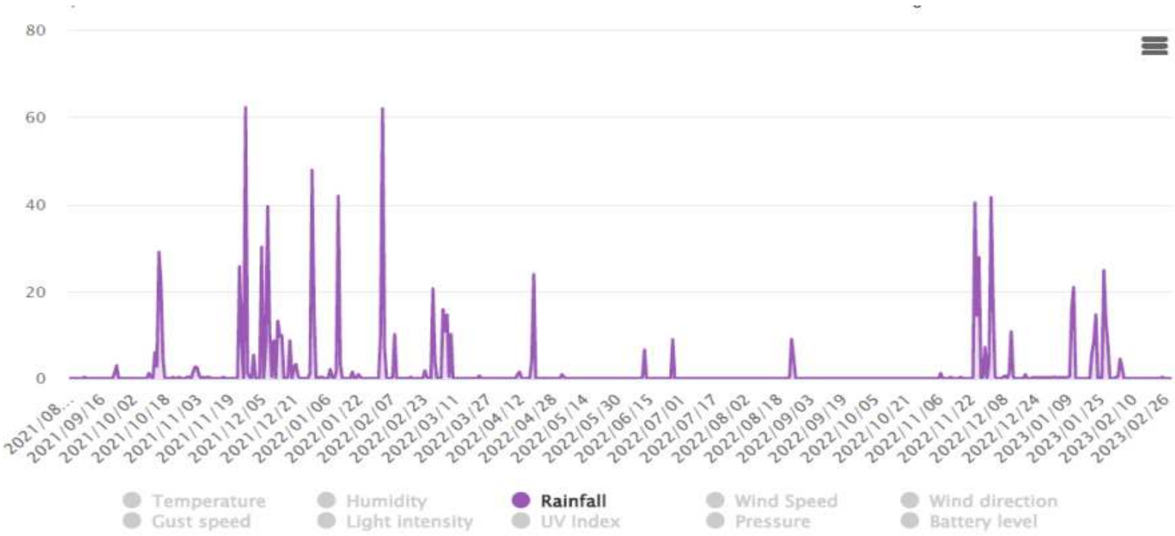

Figure 2.7: Rainfall fluctuation on HYDRO2 as recorded by AGENSO's weather station.

Regarding the rainfall effect on plants, it was observed that in many cases, after heavy rainfalls there were some specific small areas of both fields of HYDRO2 that were almost flooded (**Figure 2.8**). The water retention on the upper layers of soil and the slow drainage in these small parts of the field were responsible for severe mycological issues on the plant's roots in these areas. To avoid these issues, the application of manual carving works was the only solution to protect these plants after each heavy rainfall.

Figure 2.8: Second field flooded areas after heavy rainfalls

The operation and monitoring of a 1 ha agroforestry system was also quite a challenging task in terms of manpower needed. The operation of such a system required the optimum cooperation of the personnel of the site in order to achieve the optimal performance of the system. The local agronomist and the site manager had to schedule and supervise all the required works in the field and provide the corresponding assistance to the local workers. The variety of the plant species and their dispersed planting, especially in the main field, was quite challenging for workers with minimum experience in such cultivations, but the support of the experienced agronomist was decisive to overcome the initial difficulties.

Pest and disease control

The monitoring of HYDRO2, throughout the 2 years of operation, included the daily inspection of plants from the site manager with the supervision of a local agronomist, who was responsible for the identification of existing and forthcoming problems in terms of plant diseases and pest occurrence. For the management of all the identified plant infestations, only biological preparations were used while chemical substances were not used in any case.

Throughout this period of operation, various infestations were encountered in almost all the plant species from fungi, bacteria, viruses, insects, and soil nutrient deficiencies, as well as consequences from extreme temperatures like frost and intense heat. The major issue that we faced during the HYDRO2 operation was the maize plants infestation by the green worm that had to be systematically addressed to preserve the maize plantation. Some biological preparations and nematodes were applied during the second year of the maize plantation in order to avoid plant damage.

Another issue observed during these years was some mycological infestations, especially on Lavender plants, that were overcome with the addition of biological preparations that included mycorrhizae and nematodes to support the plant roots. The pest control was also implemented with the application of biological preparations like vegetable oils and extracts and some biological fertilizers that were quite successful since the plant losses during the 2 years of operation were minimum.

The previously mentioned infestations and diseases were recurrent and depending on the biological cycle of each one, interventions were made as early as possible before many cycles had the time to be completed and/or repeated. The success of the interventions was based on the time precision, the appropriate spraying apparatus (pressure sprayer), the repetition and the cultivation practices for the plant protection.

A more detailed presentation of the recorded plant diseases, pest occurrence and all the substances that were used in HYDRO2 is presented in D.4.6 (Report on food safety issues and pest control).

Weed control

A major challenge on HYDRO2 operation was the constant effort for weed control. The 1 ha agroforestry system was a fertile environment for the growth of many different weeds that could have a negative effect on the cultivated plants since they could compete for water and space or be plant disease vectors. The monitoring of the weeds was carried out daily and manual weed interventions were performed 3-4 days per week depending on the period and the weather conditions. All the weeds removed from HYDRO2, were collected, and donated to local farmers to use them as animal feed and could be characterized as a valuable by-product of such an agroforestry system (**Figure 2.9**).

Figure 2.9: Removed weeds given to local farmers to use them as livestock.

Measures and actions for soil improvement

The initial analysis on the soil characteristics of HYDRO2 (before the start-up) indicated that both fields were nutrient deficient and a bit poor in organic matter and microbial activity and a significant fertilization would be important for a successful cultivation. Considering that the irrigation water was a nutrient rich fertigation water, we decided to apply the minimum required fertilization during the first planting period with the addition of a small quantity of biological fertilizer in the planting pits. Since then, only some minor foliar fertilization was applied when needed without any soil improvement interventions. A detailed section with all the soil analysis data through the 2 years of HYDRO2 operation is reported in D.4.6(Report on food safety issues and pest control).

2.4 Comparative yields

The major scope of HYDRO2 was to demonstrate that an agroforestry system with a wide diversity of plants could thrive by using the reclaimed water produced in HYDRO1 as fertigation water in the region of Antissa, Lesvos. The implementation of the system required the planting of more than 10,000 plants in an area that has been used as grazing land in the past and many preparation works were required before the start-up of the system.

After the initial works on the two fields of HYDRO2 (fencing, plowing, installation of the irrigation systems, etc.), the first planting procedure was concluded between April 2021 and June 2021. Most of the plants that were planted in the field were quite young (ordered in small pots from the nurseries) (**Figure 2.10**) and therefore it was clear that for some species the time until the first harvesting would be more than one year (berries, aromatic plants, etc.) while for others (olive trees, almond trees, apple trees etc.) the time needed until the first fruit production would be even longer.

Figure 2.10: Lavender pots ready for planting in HYDRO2 fields

Even though most of the plants were quite young during the start-up of the system, the development process for most of them was quite fast. In parallel, the annual crops plantations of maize during the summer period and barley during the winter period, along with the seasonal vegetables that were also planted during the 2 years of operation, contributed to a significant crop yield so far. **Table 2.2** presents the overall yield produced in HYDRO2 between June 2021 and June 2023 and the crop yield per m^2 of cultivated area in terms of products harvested during the first 2 years of operation.

Table 2.2: HYDRO2 overall yield during the 2 years of operation

Plant	Total harvest (June 21-June 23) (Kg)	Total harvest 2021 (kg)	Total harvest 2022 (kg)	Total harvest 2023 (kg)	Crop yield per m^2 (kg/m^2)
Maize (biomass)	6,400	3,100	3,300	-	6.1
Barley (biomass)	1,940	-	1,100	840	0.9
Watermelon	852.6	488.6	364	-	6.5
Tomato	632	226	406	-	3.1
Zucchini	581.9	206.9	375	-	5.1
Eggplant	425	182.2	242.8	-	4.1
Mellon	488.2	110.2	378	-	2.5
Oregano	385.6	2.6	130	253	0.55
Pepper	220.5	49	171.5	-	1.2
Pumpkin	292	82	210	-	9.2
Cabbage	289.8	-	289.8	-	2.6
Lavender	755	5	200	550	0.3
Cucumber	95	42	53	-	5.1
Lettuce	102	12.2	89.8	-	0.76

Sage	250	3.5	95.5	151	0.7
Cauliflower	75.5	-	75.5	-	1.3
Aronia	54.8	5.6	49.2	-	0.37
Broccoli	54.5	-	54.5	-	0.75
Melissa	47	-	47	-	0.31
Onion	48.5	3.5	45	-	2.1
Goji berry	29.3	3.1	26.2	-	0.29
Leek	28.2	-	28.2	-	2.8
Cale	16.5	-	16.5	-	1.6
Beetroot	14	-	14	-	1.4
Mint	28.5	4.3	24.2	-	0.13
Rosemary	375	-	125	250	0.15
Blackberry	13.2	2.4	10.8	-	0.07
Savory	11.1	-	11.1	-	0.25
Pomegranate	10.2	-	10.2	-	0.51
Strawberry	28	-	28	-	0.9
Physalis	9.6	5.4	4.2	-	0.9
Radish	9.3	-	9.3	-	1.3
Raspberry	6.6	2.2	4.4	-	0.15
Fig	6.4	-	6.4	-	0.35
Apple	4.3	-	4.3	-	0.22
Hippophaes	3.8	-	3.8	-	0.19
Annice	3.8	-	3.8	-	0.01
Pelargonium	3.6	-	3.6	-	0.15
Basil	3.5	2.2	1.3	-	0.11
Pear	3.4	-	3.4	-	0.68
Parsley	3.2	-	3.2	-	0.32
Olive	2.2	-	2.2	-	0.11
Spinach	1.8	-	1.8	-	0.18
Celery	1.2	-	1.2	-	0.12
Thyme	1.2	-	1.2	-	0.09
Allium	0.8	-	0.8	-	0.08
Total yield	14,608.6 Kg	4,538.9	8,025.7	2,044	

HYDRO2 demo site was very successful in terms of crops production since more than 14.6 tons of crops were harvested and donated to local farmers and families in Antissa during the 2 years of operation. The harvested crops originated from almost all the plant species of the fields as presented in **Table 2.2** and an aggregate analysis by plant category is presented below. However, it should be mentioned that the total production for 2023 shown in **Table 2.2**, which is lower than in previous years, is due to the fact that the harvest period for most products is after the end of the project (after June 2023). Nevertheless, as can be seen in **Table 2.3**, the corresponding KPI for HYDRO2 (10 tons/ha) was overachieved as 14.6 tons/ha were harvested during the 2-year operation period.

Table 2.3: KPI set and achieved for HYDRO2

HYDRO2 KPI	June-23
Production of > 10 tons of fruits, herbs, vegetables (with biomass)/ha	14.6 tons

Annual crops production

Two annual crop plantations of about 0.1 ha were cultivated in the second field of HYDRO2. Since the start-up of the site, two maize cultivations and two barley cultivation have already been harvested. The maize biomass production was equal to 3.1 and 3.3 tons during 2021 and 2022, respectively, and was donated to local farmers to use it as animal feed (**Figure 2.11** and **Figure 2.12**). The first barley plantation faced some difficulties due to heavy rainfalls during winter 2021-2022 resulting in poor drainage of the field and slow growth of the plants, nevertheless the total mass production of barley biomass was equal to 1,100 kg. A similar mass of barley was harvested during the 2023 period (840 kg).

Figure 2.11: Maize harvesting during November 2022 and donation to local farmers

Figure 2.12: Barley harvesting and use of harvested maize biomass as animal feed in a nearby farm.

This project has received funding from
the European Union's Horizon 2020
Research and Innovation Programme
under Grant Agreement No 776643

Seasonal vegetables production

A variety of seasonal vegetables were tested in HYDRO2 during the 2 years of operation. Summer vegetables like watermelons, melons, tomatoes, eggplants etc. and winter vegetables like cabbage, cauliflower, broccoli etc. were planted in an area of less than 0.1 ha and were quite successful plantations in terms of harvested products (**Figure 2.12**). The field properties seemed to fit with such plant species and even under a limited space used for these plantations, the crops yield was significant.

Figure 2.12: Harvested vegetables

Shrubs/superfoods production

The agroforestry system includes many superfood plants like aronia, goji berries, blackberries and raspberries. These plants can produce high yields after about 3 years after plantation, nevertheless we were already able to harvest some fruits during the second summer of operation (summer 2022). The most notable production came from the aronia plants since more than 50 kg of aronia berries were harvested from about 100 plants that are cultivated in HYDRO2 fields.

Figure 2.13: Aronia harvested during late September 2022

Aromatic plants/herbs production

HYDRO2 also includes a variety of aromatic plants like Lavender, Oregano, rosemary, sage, mint, thyme and melissa. The planting of these species took place during summer 2021 by using small plants and during the first year we decided to support the plants' growth without risking an immature harvesting that could negatively affect the plants' long-term performance. Some minor pruning was implemented during September 2021 mainly in Lavender and Oregano and a trial harvesting was applied during late September 2022. During this harvesting procedure about 500 kg of green leaves/flowers of Lavender, Oregano, sage and melissa were collected (**Figure 2.15**). A systematic harvesting in all aromatic plants was also be applied during May-June 2023 with a harvested mass of more than 1 ton in terms of green weight.

Figure 2.14: Lavender and Oregano harvesting during late September 2022

<u>Trees production</u>

A variety of trees were planted in the agroforestry system during the start-up of the system in spring/summer of 2021 like olive trees, pomegranate trees, quince trees, almond trees etc. The majority of these plants require many years before a significant fruit production will occur. In our case all the trees selected for HYDRO2 demonstrated a quick development and even in less than two years of operation we were able to harvest some first fruits like pomegranates, figs, apples and olives (**Figure 2.16**).

Figure 2.15: Pomegranates and olives harvested during October 2022

Crop yield comparison with other studies

This section presents some data regarding the comparison of the crop yield production of some representative plants of HYDRO2 with other sources like FAOSTAT and EIP-AGRI. **Table 2.4** show the HYDRO2 production per cultivation and ha.

Table 2.4: Cultivation and total production

Cultivation	Production (kg/ha)
Maize (corn)	11,500
Barley	7,500
Watermelon	65,200
Melon	26,850
Tomatoes	31,100
Zucchinis	25,100
Eggplants	40,600

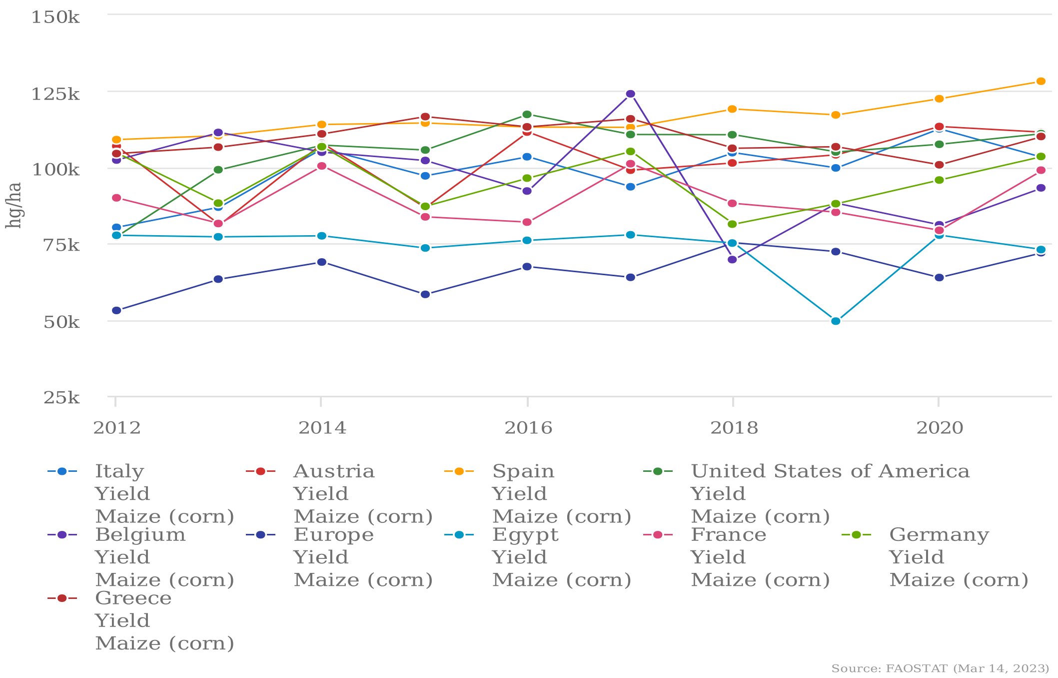

Figure 2.16: Production of maize (corn) in various countries between 2012-2021 according to FAOSTAT

As shown in **Figure 2.16** the mean production of corn (Zea mays) in the countries included in the above figure varies between 5,000 kg/ha to 12,500 kg/ha with high yields noted in Greece (FAOSTAT 2023). In HYDRO2 site, the yearly production of corn crops in the cultivated area of the field corresponds to a production of 11,500 kg/ha which can be considered as a quite good production for a small-scale cultivation where no fertilizers are used.

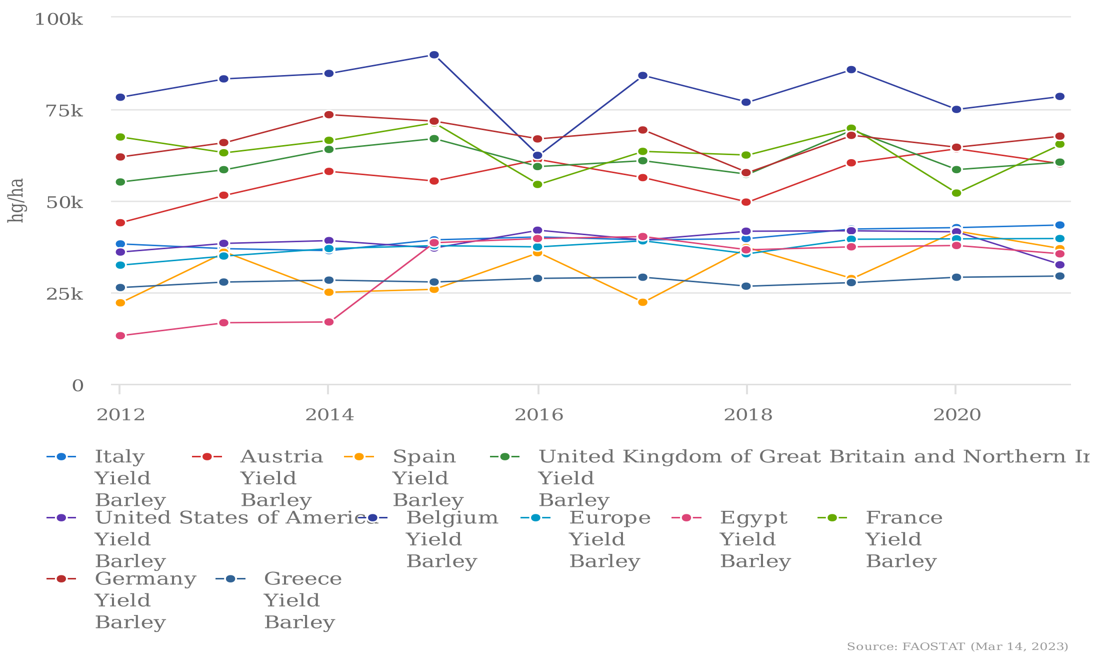

Figure 2.17: Production of barley in various countries between 2012-2021 according to FAOSTAT

Regarding the production of barley (Hordeum vulgare) as shown in **Figure 2.17** the minimum amount produced is 1,300 kg/ha and the maximum 9,000 kg/ha between 2012 and 2021 with Greece having an almost stable production of around 2,700 kg/ha (FAOSTAT 2023). In HYDRO2 the production was calculated to be around 7,500 kg/ha but in terms of barley biomass, since it was decided that the cultivation would be used as animal feed. Even though a direct comparison cannot be done, the overall yield of barley biomass seems quite satisfactory for a small-scale cultivation.

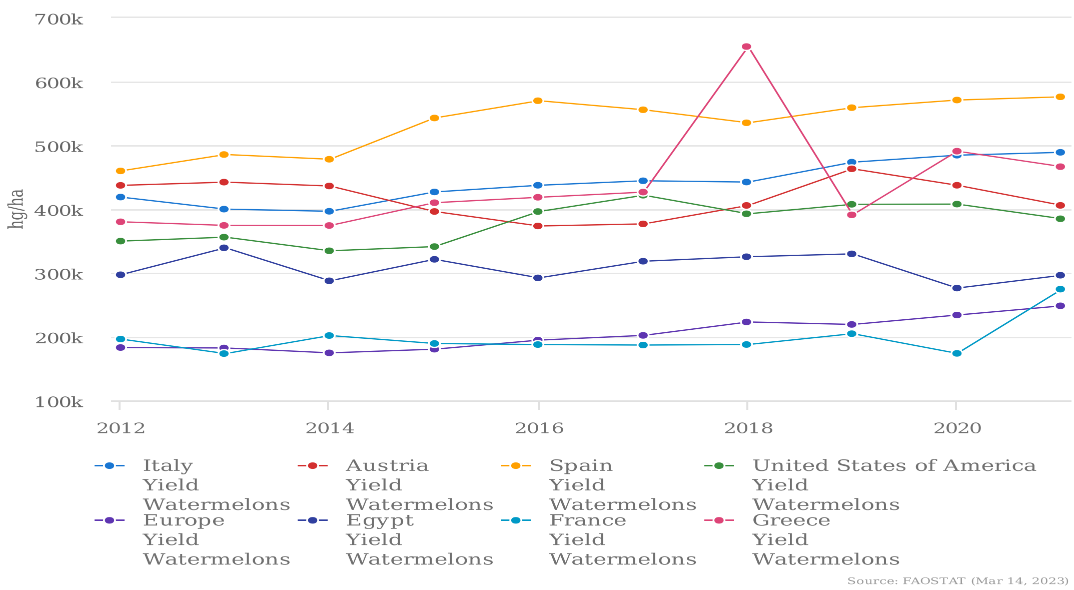

Figure 2.18: Production of watermelon in various countries between 2012-2021 according to FAOSTAT

The production of watermelon (Citrullus lanatus) in the countries included in the previous figure vary between 17,300 kg/ha and 65,500 kg/ha with this maximum production being in Greece in 2018 (FAOSTAT 2023). On the other hand, the estimated production of watermelon in HYDRO2 was 65,200 kg/ha.

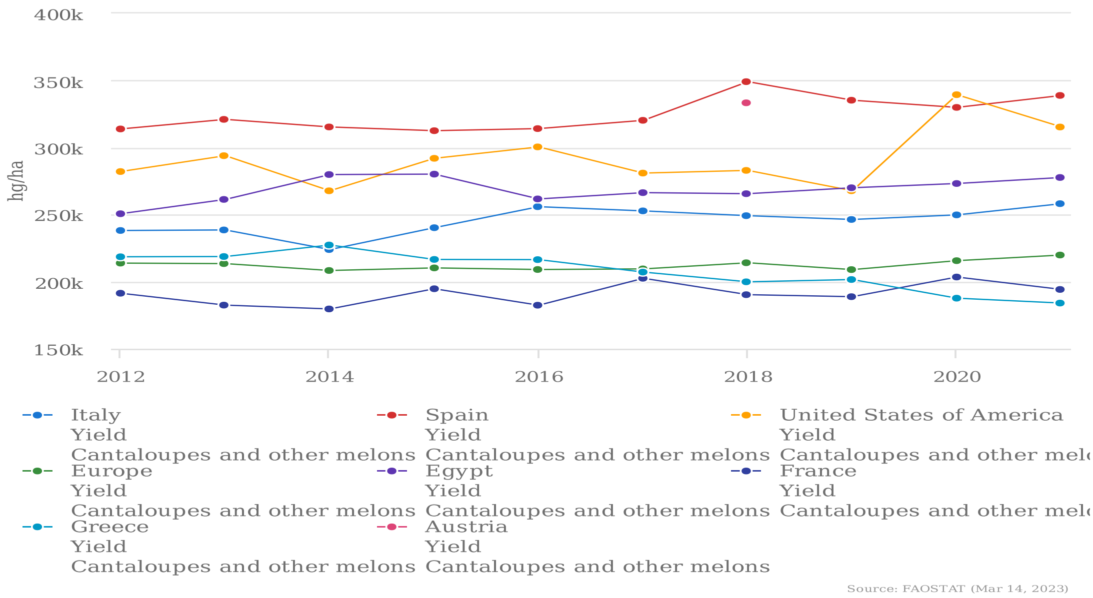

Figure 2.19: Production of cantaloupes and other melons in various countries between 2012-2021 according to FAOSTAT

In **Figure 2.19** the production of cantaloupes and other melons (Cucumis melo) are shown in Greece, Spain, France, Italy, Austria, Egypt, Europe (total) and the United States of America (FAOSTAT 2023). According to the data provided by FAOSTAT, the minimum quantity produced was 18,200 kg/ha in 2016 in Egypt and the maximum was 34,900 kg/ha in 2018. In HYDRO2 site, on Lesvos Island, the estimated production of melons was equal to 26,850 kg/ha.

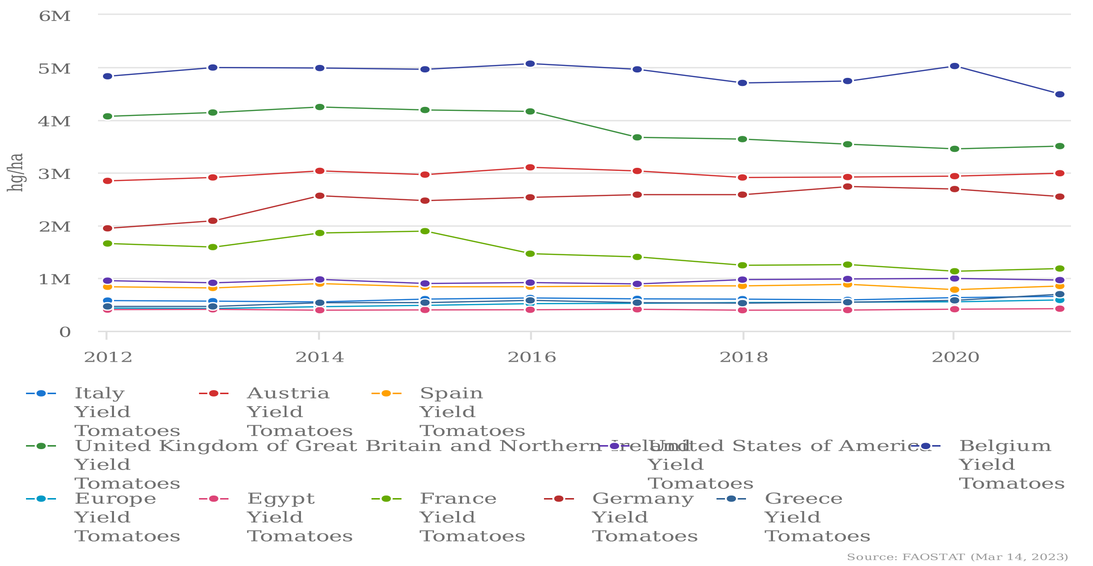

Figure 2.20: Production of tomatoes in various countries between 2012-2021 according to FAOSTAT

Concerning the production of tomatoes (Solanum lycopersicum), it ranges between 38,000 kg/ha and 500,000 kg/ha with the lowest production being constantly in Egypt and the highest in Belgium (FAOSTAT, 2023). The production of tomatoes in HYDRO2 is estimated up to 31,100 kg/ha and is slightly lower than the overall yield that can be achieved in an intensive cultivation.

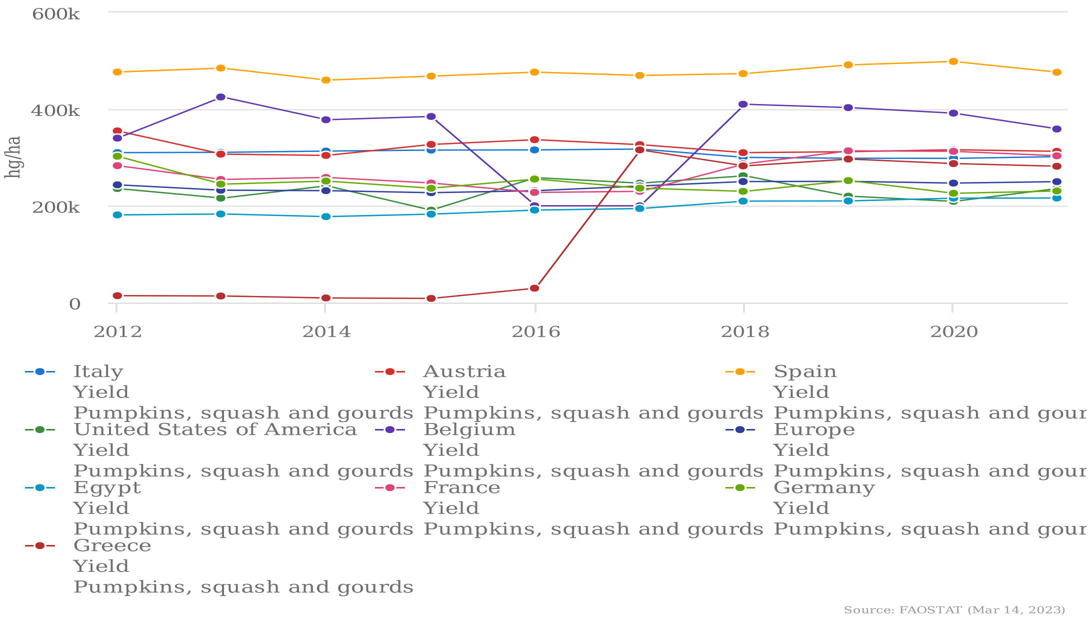

Figure 2.21: Production of zucchini in various countries between 2012-2021 according to FAOSTAT

The data concerning the production of zucchini (Cucurbita pepo) in the countries included in the previous figure shown that Greece had a relatively low production compared to other countries from 2012 to 2016 of 14,600 kg/ha, situation that changed from 2017 where the production almost doubled. Meanwhile in the other countries included in the previous figure (**Figure 2.21**) the production was almost stable during these years except for Belgium where during 2016 and 2017 the production dropped (FAOSTAT, 2023). In HYDRO2 demo site, the zucchini yield is among the average worldwide values since it is measured equal to 25,100 kg/ha.

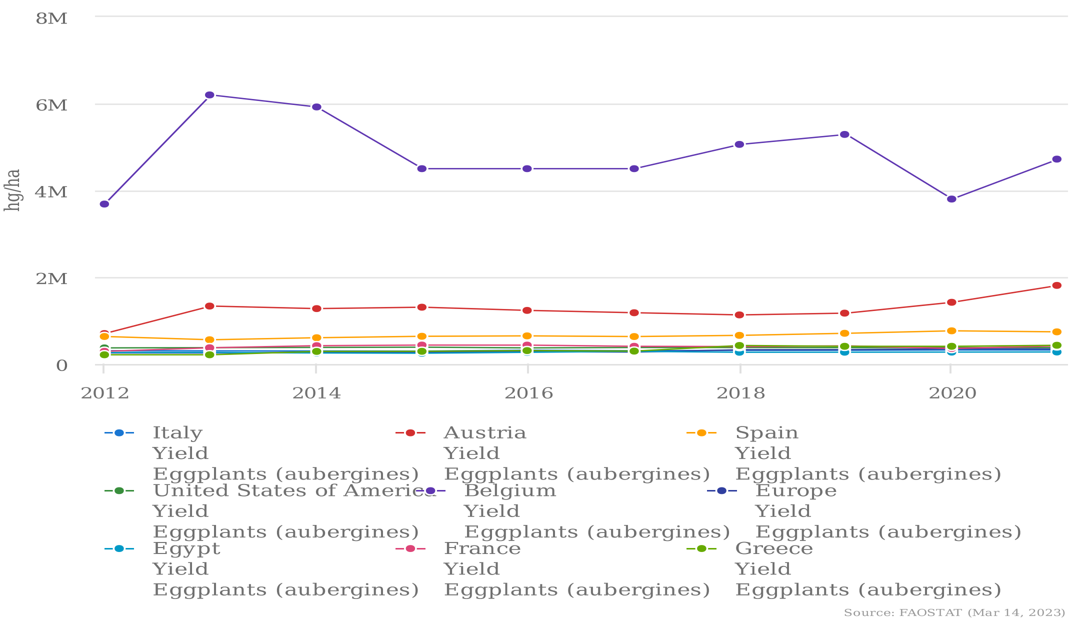

Figure 2.22: Production of eggplants in various countries between 2012-2021 according to FAOSTAT

The production of eggplants (aubergines) (Solanum melongena) in Greece, Spain, France, Italy, Austria, Egypt, Europe (total) and the United States of America ranged within 2012 and 2021 between 2,000 kg/ha to almost 200,000 kg/ha, when in Belgium the production has been from almost 400,000 to 600,000 kg/ha (FAOSTAT 2023), (**Figure 2.22)**. The production of eggplants in HYDRO2 site is estimated to 40,600 kg/ha.

<u>Water quantity for irrigation</u>

The required water quantity for irrigation per year was equal to about 6,500 m^3 (13,200 m^3 of reclaimed fertigation water has already been used since the start-up of the agroforestry system). From our experience so far, this quantity is mainly used between April and November since no irrigation is required during the winter period due to high soil moisture content resulting from the rainfalls of the period. The maximum water needs of the agroforestry system are up to 45 m^3/d during July and August, while during April and November the water need for irrigation could be even less than 10 m^3/d, depending on the weather conditions. The summary of the required water amount for irrigation corresponds to about 650 L/m^2/year (**Figure 2.23**).

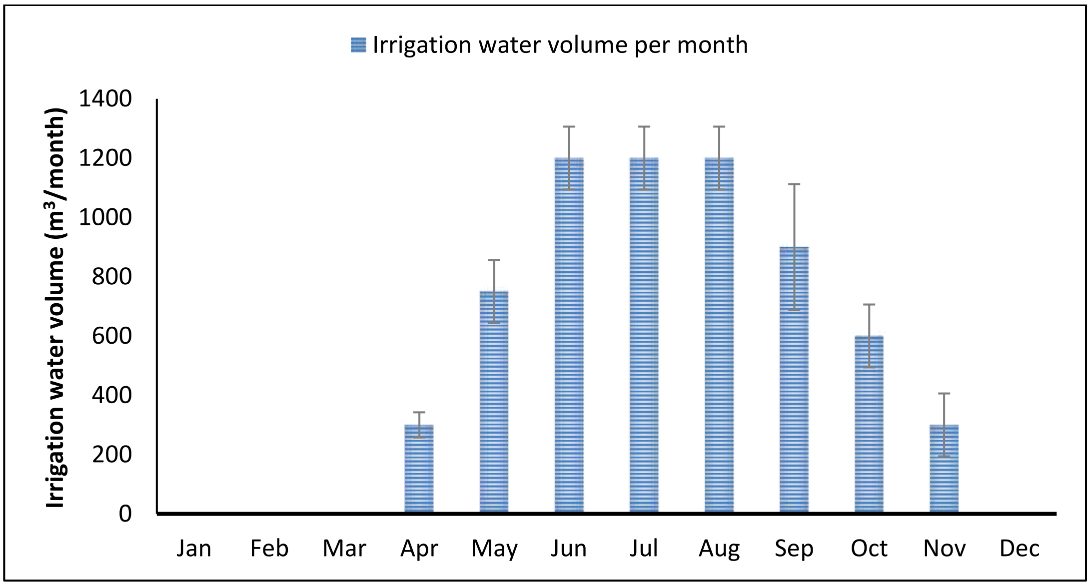

Figure 2.23: Reclaimed water volume used for irrigation per month

Reclaimed water effect on the plants growth and produced yield.

During the operation of the agroforestry system a variety of aspects were examined. The use of reclaimed water in terms of plants growth, health, fertigation needs, and productivity was examined on the annual plantations of maize and barley in the second field of HYDRO2. In this field an annual 0.1 ha plantation of maize (during June-November) and barley (during November-May) was established. Half of the annual plantation was irrigated with reclaimed water while the other half was irrigated with conventional tap water for comparison purposes. Some results in terms of plants growth (final length) and plants yield in terms of biomass production are presented in **Figure 2.24** and **Figure 2.25**.

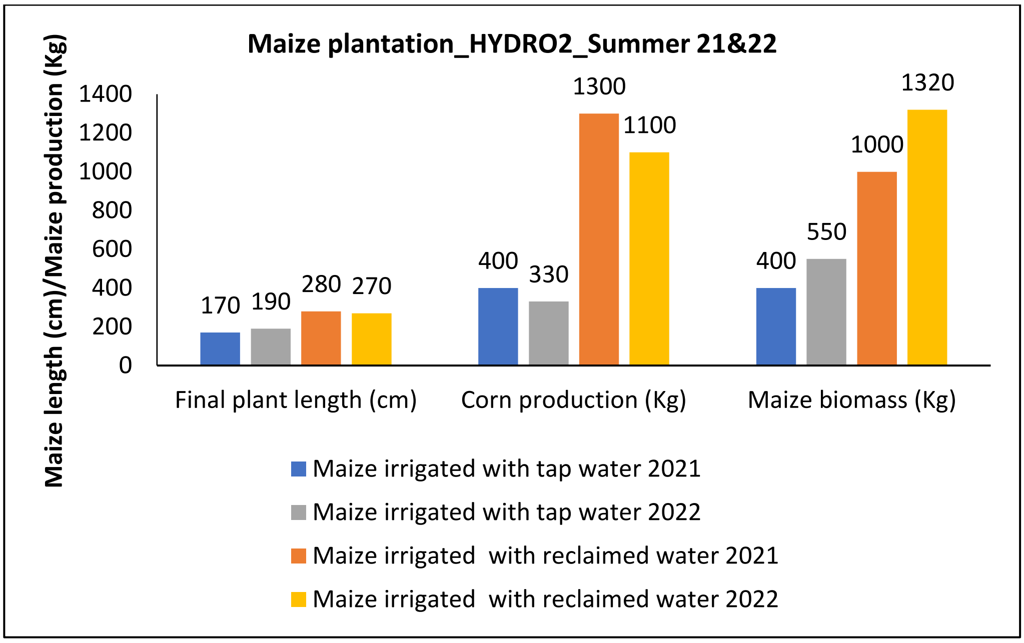

Figure 2.24: Maize plantation irrigated with reclaimed water vs maize irrigated with tap water

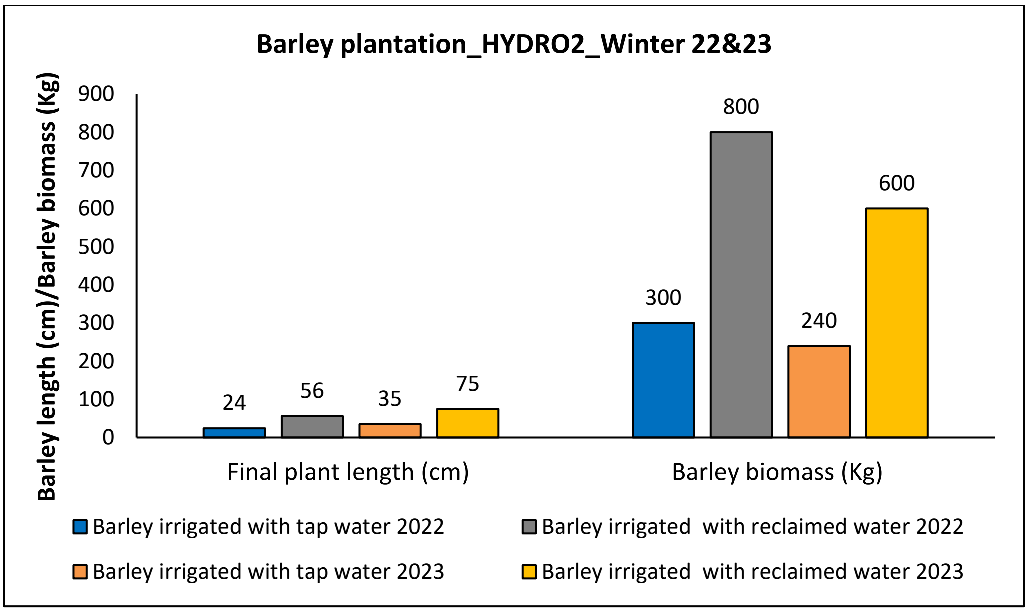

Figure 2.25: Barley plantation irrigated with reclaimed water vs barley irrigated with tap water.

From the above figures it is quite clear that the use of reclaimed water could contribute to both better health and growth of the irrigated plants as well as in terms of produced biomass compared with the use of conventional tap water. A conventional maize plantation requires great amounts of fertilizers that had to be provided in order to achieve high yields. These amounts of fertilizers could totally be saved if fertigation water such as reclaimed water from wastewater treatment is used.

This project has received funding from
the European Union's Horizon 2020
Research and Innovation Programme
under Grant Agreement No 776643

2.5 Valorisation and derived products

HYDRO2 utilizes the reclaimed water that is produced from the wastewater treatment in HYDRO1 demo site. A 1 ha agroforestry system with more than 60 plant species is irrigated with this reclaimed water and a variety of products in terms of biomass for animal feed and fresh crops have already been harvested. The maize and barley biomass, as already presented, were donated to local farmers to use as animal feed while a variety of fresh fruits were donated to locals and deprived families of Antissa village.

Since the scope of HYDRO2 was not to make an economic profit through sales during these two years, the majority of the produced crops were donated to locals. At the same time, mainly during the second year of operation we were able to test the production of some secondary products. The main products that could be produced from the harvested crops and herbs of HYDRO2 are: essential oils, hydrosol waters, liqueurs, marmalades, dry herbs etc.

The variety of fruits and herbs, the environmental qualities, the applied organic procedures, and the novelty in terms of water used would be able to achieve better prices in the market compared with similar conventional products. In any case, from now on, all the secondary products are produced as trials in order to evaluate the possibilities of producing these valuable products in the future and were given mainly to visitors of the site (**Figures 2.27-2.30**).

The major derived products that were produced so far are the following:

- 50 L of aronia liqueur (2022)
- 3 L of different liqueurs from fruits like pomegranate, blackberries, raspberries, strawberries (2022)
- 5 Kg of aronia marmalade (2022)

The production of essential oils for 2022 and 2023 from Oregano, Sage, Lavender, Rosemary and Melissa are presented in **Table 2.5**.

Table 2.5: Essential oils production

<table>
<tr><th>Year</th><th>Product</th><th colspan="2">Oregano</th><th colspan="2">Sage</th><th colspan="2">Lavender</th><th colspan="2">Rosemary</th><th colspan="2">Melissa</th></tr>
<tr><td rowspan="2">2022</td><td>Essential oil</td><td rowspan="2">130.6 kg</td><td>295 mL</td><td rowspan="2">95.5 kg</td><td>140 mL</td><td rowspan="2">200 kg</td><td>202 mL</td><td rowspan="2">-</td><td>-</td><td rowspan="2">47 kg</td><td>-</td></tr>
<tr><td>Hydrosol</td><td>8 L</td><td>10 L</td><td>22.5 L</td><td>-</td><td>5 L</td></tr>
<tr><td rowspan="2">2023</td><td>Essential oil</td><td rowspan="2">195 kg</td><td>438 mL</td><td rowspan="2">150 kg</td><td>60 mL</td><td rowspan="2">550 kg</td><td>3.3 L</td><td rowspan="2">250 kg</td><td>1.1 L</td><td rowspan="2">-</td><td>-</td></tr>
<tr><td>Hydrosol</td><td>14.5 L</td><td>4 L</td><td>42 L</td><td>12 L</td><td>-</td></tr>
</table>

**In 2023, 58 kg of oregano were distilled in Mykonos from DEL and produced 286 mL essential oil and 5.5 L hydrosol.*

This project has received funding from
the European Union's Horizon 2020
Research and Innovation Programme
under Grant Agreement No 776643

Figure 2.26: HYDRO2 aromatic plants and liqueurs

Figure 2.27: Different dried herbs harvested in HYDRO2 during September 2021

Figure 2.28: Aronia liqueurs produced during October 2022

Figure 2.29: Lavender, Oregano and sage essential oils along with aronia marmalades

3. HYDRO3

3.1 Demo site overview

HYDRO3 is located in Ano Mera, Mykonos Island. It is an innovative, nature-inspired rainwater harvesting system consisting of a shallow, sub-surface rainwater collector of 280 m^2 surface areas collecting rainwater by draining that is transported by gravity pipes into two cylindrical light structure storage tanks, having a total water storage capacity of 60 m^3 (**Figure 3.1-3.2**). The harvested water is used to irrigate 0.4 ha of Oregano cultivation using a drip irrigation system. In each crop row, a drip line is used for irrigation. Drip irrigation lines were installed in parallel with the field contours for avoiding soil erosion. The drip emitters distance is 0.5 m to provide appropriate water application to the crop. Various sensor types have been installed in the site for monitoring crop water needs and optimizing water irrigation from the water tanks (e.g., soil moisture sensors, water level sensors, solenoid valves etc.). All the collected data are sent to the HYDROUSA platform for optimizing the irrigation scheduling of the field.

At the southwest side is an old warehouse which was restored and used for storage facilities for agricultural tools, installation of the oil distillation unit as well as the two dehumidifiers and small machinery, HYDRO3 automation and electronic automation systems - control panel, pumping system, data logging).

Irrigation works with the following logic. The moisture sensor of every plot of HYDRO3 sends a notice to the HYDROUSA platform for the irrigation needs and the percentage of soil moisture. If the measurement is under 10%, the signal sent will be to switch on the electro valve of this specific plot. The hydraulic pressure decreases, and the pump starts. The flowrate of the irrigation pump is 4 m^3/h. The electro valve remains open for 4 minutes and then closes, allowing the time for the water to be absorbed and so the moisture sensor, which is 10 cm deep shall record the right measurement.

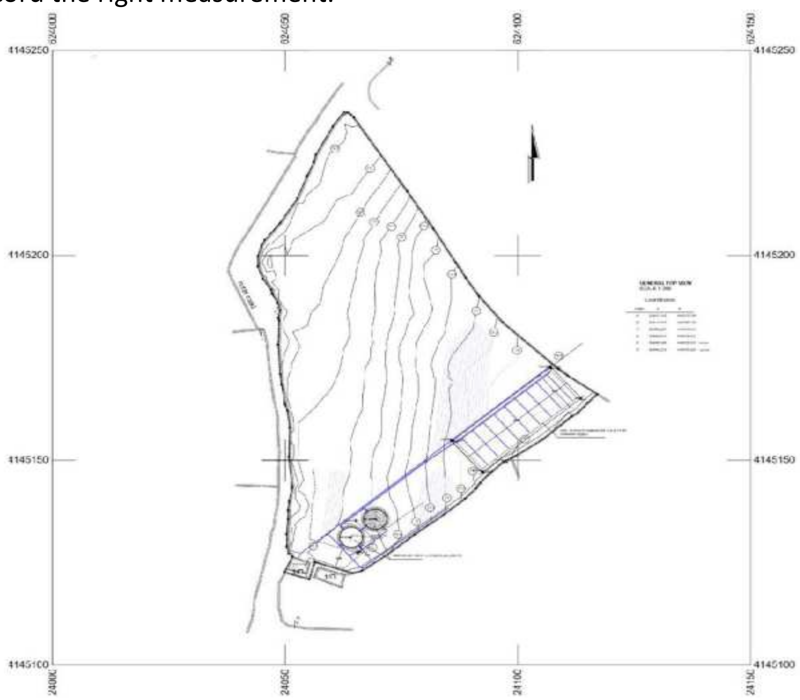

Figure 3.1: HYDRO3 master plan showing the positioning and elevation of the field and location of water collection tanks and irrigation pipes.

Figure 3.2: Rainwater Collector in HYDRO3 and irrigation pipes

3.2 Plant selection

Meteorological data were collected for HYDRO3 regarding the sunrise and sunset times and duration of the day as well as the sun path upon the field to determine the most appropriate plantation direction to avoid shading and heat. This data was collected for the 4 quarters of the year 2019. Based on the meteorological data analysis, it was observed that a sub-dry to wet period ranges from November to March, which is followed by a dry period from April to October.

Soil samples were analysed for their physical and chemical properties. Data showed that the soil pH is close to neutral, ranging from 6.7 to 7.1. This pH level shows that the conditions for mobilization of nutrients is not optimum but feasible. The soil composition analysis showed that the structure of soil is almost 75-80% sandy soil with 15 - 20% silt and the rest is 4 - 5% clay. These characteristics indicate that the soil would not have a good water holding property for the irrigation water and thus it would dry fast, especially during summertime. Therefore, a drip irrigation system was installed to achieve optimum water management.

The nature of Mykonos Island is highly touristic and given the data of the soil analysis the plant type to be selected for cultivation in this field must fit both features. Perennial plants with high added value were foreseen for this field. After research, Oregano was selected as the crop that fits the weather and soil conditions of Ano Mera, in Mykonos. Oregano has been used for centuries for its various health improving properties. It contains multiple antibacterial and antimicrobial properties. It has been used to relieve coughs, reduce body odour, soothe digestive muscles, and achieve lower blood pressure. Oregano is a strong antioxidant, with high levels of beneficial acids and flavonoids.

Figure 3.3: Oregano re-plantation 2021.

Figure 3.4: Weed cleaning.

Planting seedlings or offshoots can be done in two periods: in October-November and March. Seedlings or offshoots are planted at distances from 60 to 80 cm between the lines and 30 to 40 cm between the plants on the line. In HYDRO3 field, the plants were placed at distances of 75 cm between the lines and 50 cm on the line. The Oregano crop can remain in the field producing good yields for up to 8 years.

The HYDRO3 system is an innovative sub-surface rainwater collection system where the water flows by gravity from the collection area to the storage tanks. These tanks are connected to the main irrigation pipes. The drip irrigation system uses the stored rainwater from the tanks for the irrigation of the crops.

3.3 Agricultural production

The agricultural site of HYDRO3 was finalized in December 2019. Field preparation was carried out according to the designs, the drip irrigation pipeline network was designed and installed, the type of Oregano was selected (Origanum vulgare - Oregano crop) and 10,000 seedlings were ordered and planted in December 2019.

In HYDRO3, the recovered rainwater is used for the irrigation of the Oregano field already since the summer period of 2020. Specifically, from April 2020 to November 2020 the field was irrigated every 15-20 days. In February 2021, the field was cleaned of weeds (**Figure 3.4** & **Figure 3.5**) and foliar spraying was applied with algae extract and amino acids (suitable for organic farming according to Regulation (EU) 834/2007 and Regulation (EU) 889/2008). In March 2021, 1,000 more plants were planted (**Figure 3.3**), this time with the addition of soil conditioners/nutrients and physical soil improvement fertilizer was applied during the plantation process.

At the beginning of June 2021, part of the plantation (20-30% of the plant) exhibited drying of the above ground part due to the adverse climatic conditions (very strong wind and very high temperatures for the specific season). After analysis of the samples, it was decided to spray the plants with bordigal pulp to protect them, but at the same time, an order was made for 1,500 new Oregano plants in pots, so that in October, potential gaps can be filled. After the necessary time since the application of the bordigal pulp, on 15 **June 2021** and for about a week, the Oregano was harvested (**Figure 3.6**). **The Oregano production was 50 kg.** The 15 kg was given to local agritourist units and groceries. The 35 kg were left to dry and used to produce essential oil in 2022. The irrigation of the field continued a ten-day basis.

Figure 3.5: HYDRO3 Oregano plantation after weed clearing.

This project has received funding from the European Union's Horizon 2020 Research and Innovation Programme under Grant Agreement No 776643

Figure 3.6: HYDRO3 harvesting of Oregano plantation.

In March 2022, 30-35% of the crops that were at the piece of land with a low slope were lost due to the rise of the aquifer. In April 2022, cleaning the crops from reeds and fertilizing the plants with an organic mixture of fish and algae every 15 days took place. Irrigation was performed 2-3 times per week. In **June 2022** irrigation was stopped for a week so that the Oregano plants raise essential oils in the foliage and the harvesting followed. **A total of 135 kg of Oregano was collected**.

Until the end of November 2022 watering continued twice a week because there was no rain at all. Every 15 days the roots and leaves were sprayed with algae and amino acids. At the end of December, weeding began to allow the oregano roots to thrive. The compost from the distillation was spread on the field and in conjunction with the rains, the new planting of the losses was prepared. 2,500 oregano plants were ordered and replanted during winter 2023. In 2023 **a total of 330 kg of Oregano was collected**.

3.4 Comparative yields

The harvested yields were comparatively low when compared to common indications from other regions in Greece, where 8 tons/ha/year are expected from mature plantations. However, those numbers are for locations with denser planting and more water availability and mostly with conventional use of agro-chemicals. Also, the results obtained so far are from a young plantation. From **Table 3.1**, it is observed that yields increased rapidly each year and reached the set KPI in 2023, as 330 kg oregano was harvested.

Table 3.1: KPI set and achieved for HYDRO3

HYDRO3 KPI	June 2021	June 2022	June 23	Total
> 800 kg Oregano/year /ha > 320 kg/year for 0.4 ha	50 kg	135 kg	330 kg	487 kg

On the other hand, the production in this demonstration site can be compared to the production gained from other plantations with similar conditions (water stress). An experiment with oregano plantation under different levels of water stress was conducted in Oklahoma State University by Turgut-Dunford & Silva-

Vasquez (2005)[4]. It can be noted that in their experiment the production gained from the different oregano treatments, and in maturity state of the plants, ranged between 11.9 to 56.6 g per plant. Another similar research was realized in Akdeniz University Experimental Research Area of Agricultural Faculty by Hancioglu et al. (2019)[5] where the production in the various treatments ranged between 26.2 to 119.7 g per plant. In HYDRO3 the production gained in the three different years, 2021, 2022 and 2023, with the conditions mentioned previously, was 12.5, 26.7 and 82.5 g per plant respectively. Taking into consideration the above, it should be pointed out that Oregano production in HYDRO 3 ranges within normal extents, considering the water stress, which is frequent on the Greek islands, especially during the summer.

To sum up, at this demonstration site a lot of knowledge was gained regarding the innovative irrigation water source and the extremes of water surplus in winter and hot dry summer for the Oregano crop. Further optimizations may lead to a more stable harvest. The value of cultivating Oregano at this location resides not on its very high yield potential, but rather on its proximity to markets that are willing to pay a premium price for locally produced organic cultivated Oregano irrigated through environmentally friendly technologies, as well as for the added value products.

3.5 Valorisation and derived products

The main product derived from the agricultural production of Oregano is the essential oil. In an internationally popular destination like Mykonos, the goal is not primarily to export the produced products, since due to the increased tourism there is a very high local demand. As the product is produced in a sustainable and innovative way on the island, it is a great business opportunity to combine sustainable tourism with health tourism, which are developing rapidly in connection with the trends in the tourism market and are divided into three categories: health tourism, medical tourism and wellness tourism. Each sub-category is specific in its action and develops according to the needs of the tourist market. The offer of health tourism, as a product motivated by personal health, will necessarily need to take care of environmental health and, in this context, provides for a strong shift towards a comprehensive green practice, from the use of natural ingredients in treatments and nutrition, through the use of natural materials, light or ventilation in the decoration of the premises to the environmentally responsible management of energy, water, and waste at the level of facilities and whole destinations.

Apart from beautiful beaches and entertainment, Mykonos is a destination that can combine wellness, sports and active holidays, conferences and team building with a wonderful culinary experience and beautiful nature. There are many luxury villa resorts with marine therapy pools, wellness centres, spa culinary cuisine in which holistic programs are conducted, individual approaches and with modern equipment that provide unity of mind and body. The distribution of the final products in the local market is a successful scheme with fast positive results in terms of advertising, recognition, cost reduction, promotion in the local community.

For this purpose, packages were made as sample promotions and given to tourism units to use for various purposes. Specifically, Oregano oil in the form of sprinkles was provided in restaurant kitchens or for olive oil aromatization, and for use by beauticians in hotel spas. From the harvest in 2022, approximately 1 L of

4 Dunford, N. T., & Silva Vazquez, R. (2005). Effect of water stress on plant growth and thymol and carvacrol concentrations in Mexican oregano grown under controlled conditions. *Journal of Applied Horticulture* (7), 1.

5 Hancioglu, N. E., Kurunc, A., Tontul, I., & Topuz, A. (2019). Irrigation water salinity effects on oregano (Origanum onites L.) water use, yield and quality parameters. *Scientia Horticulturae*, *247*, 327–334.

Oregano essential oil and 9 L of hydrosol were produced from 135 kg of dried Oregano. From the harvest in 2023, 2.5 L of Oregano essential oil and 26 L of hydrosol were produced from 330 kg of Oregano. More details are available in D4.4 (Development of High Added Value Products).

Figure 3.7: Products from essential oil

This project has received funding from
the European Union's Horizon 2020
Research and Innovation Programme
under Grant Agreement No 776643

4. HYDRO4

4.1 Demo site overview

HYDRO4 is located in the small village of Ano Mera, on Mykonos Island and the agricultural area cultivated is about 0.2 ha. The HYDRO4 system is based on collection of rainwater and surface runoff which is stored in tanks and into the aquifer (**Figure 4.1**). The amount of water for the irrigation needs of the Levander field is collected from the following two sources.

1. Through a bioswale system (an open-channel linear drainage system)

When it rains (mainly the wet period), water is collected from the bioswale system and reserved in an open tank (acting as a buffer tank) and then stored in the subsurface “basin” through artificial recharge in the optimum location where the AR well is constructed. When water is needed for irrigation (usually the dry period) this is recovered from the AR well first and the open tank second. When water is recovered in the AR well (some days later) this is sent back to the open tank so that it is always full.

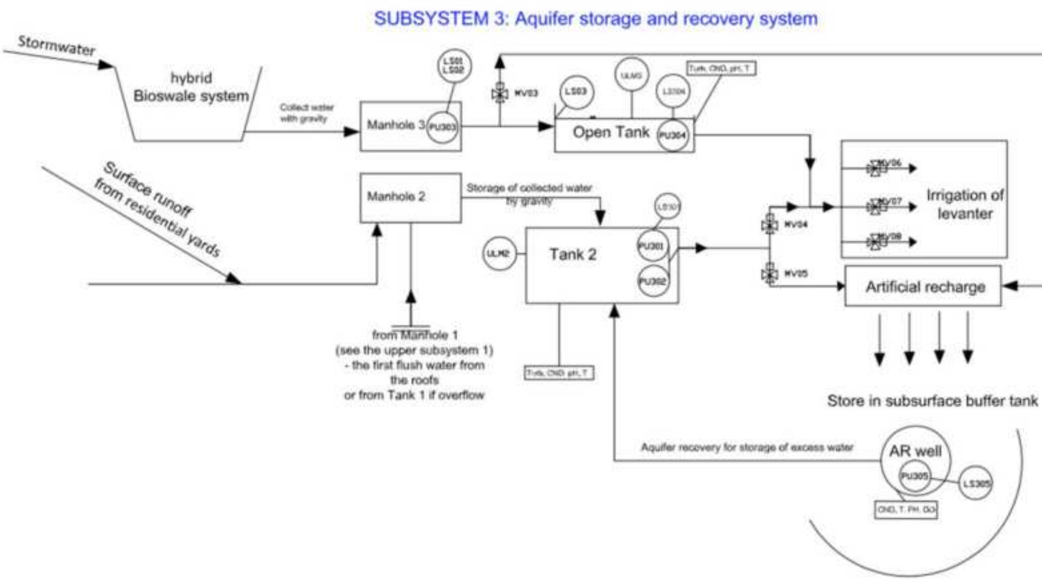

Figure 4.1: Aquifer storage and recovery system

2. Through surface runoff

When it rains (wet period), the surface runoff of the impermeable surfaces of the site is collected, stored in Tank 2 and the excess water is transferred to recharge the aquifer (subsurface “basin”) in the location of the (AR) well. When water is needed for irrigation (dry period) this is recovered first from the AR well and then from Tank 2. When water is recovered in the AR well (some days later), this is sent back to Tank 2 so that it is always full.

The buffer tank, the AR and the bioswale system are shown in **Figure 4.2**, **Figure 4.3** and **Figure 4.4**.

Figure 4.2: Open tank acting as buffer tank

Figure 4.3: AR well that stores excess water to recover it in the summer period

Figure 4.4: Bioswale / drainage system: geotextile and geomembrane

4.2 Plant selection

Meteorological data were collected from HYDRO4 regarding the sunrise and sunset times and duration of the day as well as the sun path upon the field to determine the most appropriate plantation direction to avoid shading and heat. The data indicated a sub-dry to wet period from November to March, followed by a dry period from April to October.

Soil physical and chemical properties were identified through soil analysis. Data showed that the soil pH is neutral 6.7 to 7.1. This pH level shows that the conditions for mobilization of nutrients is not optimum but still feasible. The soil composition analysis showed that the structure of soil is almost 75-80% sandy soil with 15 - 20% silt and the rest is 4 – 5% clay. These characteristics indicate that the soil would not have a good water holding property to hold the irrigation water and thus, it would dry fast especially during summer. Therefore, a drip irrigation system was installed to preserve the water.

The nature of this island is very touristic; given the data of the soil analysis the plant type selected for cultivating this field must fit both features. Perennial plants with high added value are foreseen for this field. Perennial plants with high added value were foreseen for this field. Lavender was selected based on the local weather and soil requirements. Lavender is a perennial plant that can live up to 20 years, if the conditions are optimum. It produces purple flowers, which contain high levels of essential oil. Mediterranean countries (Italy, France, and Spain) have long tradition in growing Lavender. Nowadays, countries such as USA, Canada, Japan Australia and New Zealand are also considerable commercial Lavender producers. The essential oil of Lavender is recognized globally as a respected commodity. It has several medicinal and other uses. It also has remarkable antiseptic and antimicrobial action.

In HYDRO4 site, a novel solution for rainwater harvesting, storage and recovery was developed, to store the available water during the winter months and reuse it for irrigation during summer. HYDRO4 demonstrates how a residential rainwater collection system was upgraded to enable the optimal use of low-cost rainwater and the natural services provided by the subsurface, with a positive impact on the environment. Rainwater storage tanks as well as subsurface natural water reservoirs are used to enable the buffering effect and extend water availability towards the dry period. These tanks are connected to the main irrigation PVC 90 mm pipe where different valves are connected to the surface pipes. The latter is connected to hoses used for drip irrigation.

A drip irrigation system is installed in HYDRO4 for the irrigation of the field. The drip irrigation system utilizes the rainwater/surface runoff stored in the aquifer and the tanks. Additionally, almost 2000 meters of drip irrigation pipes are installed for the application of water to the crops (**Figure 4.5**). The drip emitters distance is 0.5 m to provide appropriate water application to the crop. In addition, a water pump is installed to transfer the water to the drip irrigation lines from the aquifer. Finally, various sensors are installed in the site for the monitoring of crop water needs and optimizing water irrigation (e.g., soil moisture sensors, water level sensors, solenoid valves etc.). All the collected data are sent to the HYDROUSA platform for optimizing the irrigation scheduling of the field.

Figure 4.5: Illustration of main irrigation pipe and rows of HYDRO4

4.3 Agricultural production

In the agricultural site of HYDRO4, initially the ordering of 6,000 plants of Lavandula angustifolia (Lavender) was conducted and the irrigation system was designed. DEL had planned to proceed with the plantation of Lavender and the final installation of the drip irrigation system in early spring 2020. However, COVID-19 travel restrictions postponed these activities to autumn 2020.

The Lavender plants were sent to Mykonos in October 2020 but due to COVID-19 the plantation was postponed, and the plants were put to storage. The designed irrigation system was finally installed in early March 2021 and the soil preparation steps were also undertaken. The plantation process was completed, but regretfully the plants did not recover. Lavender was reordered and replanted in March 2021. Weather conditions that were prevailing did not allow the plants to grow properly and eventually led to their withering. 6,000 new plants were ordered in May 2021 to be planted during autumn 2021.

Figure 4.6: HYDRO4 Lavender plantation

The soil was prepared for the new planting of Lavender in early December 2021, expecting the first rains of the wet season. The area was cleared of weeds and then the soil was dug up around the irrigation lines. After a week, the planting of two of the four sections with Lavender plants took place. The plants were 25 cm tall and were growing in a pot with diameter of 10 cm. These were 8-month-old plants with a larger root system. After planting, irrigation started in order to aggregate the soil with the root and to release any amount of air that was trapped in the root system of the plants. This was followed by root area and foliar spraying with a mixture of algae and amino acids.

This project has received funding from
the European Union's Horizon 2020
Research and Innovation Programme
under Grant Agreement No 776643

Figure 4.7: HYDRO4 Lavender in pots (left) and extreme weather conditions on the island- snowfall (right)

At the end of January 2022, for the prevention of severe losses due to weather phenomena, with very low temperatures and snowfall (**Figure 4.7**), the roots of the plants were covered with straw for their protection. Nevertheless, the Lavender leaves dried but the plants survived. At the end of February 2022, the remaining two sections were planted, and the same planting procedure was followed.

Figure 4.8: Aquifer level rise due to flood event at the Lavender field (left) and flooded Lavender field (right)

Figure 4.9: Lavender field in May 2022

Irrigation was applied for both the existing and new crops. Since December 2021 when the plantation took place, the irrigation system was used only twice, during the day of planting, as it was raining once per week and the soil moisture was always acceptable.

One month after January 2022 when the planting was concluded, it was observed that the leaves of the plants dried gradually at a rate of 60%. After an examination by the agronomist, it was found that due to the intense and short rainfall, the amount of water was so high that it caused the aquifer to rise, thus covering the root system of the plants and causing them to dry out. The use of fish-fert for root spraying and then a mixture of seaweed with amino acids every 20 days was recommended.

In April 2022, cleaning the crops from weeds and fertilizing the plants with an organic mixture of fish and algae every 15 days took place. Irrigation was performed 2-3 times per week. In the beginning of **September 2022** irrigation was stopped for a week for the Lavender plants to raise essential oils in the foliage, and the harvesting followed. **A total of 17.5 kg of Lavender was collected**.

Until the end of November 2022 watering continued twice a week because there was no rain at all. Every 15 days the roots and leaves were sprayed with algae and amino acids. At the end of December, weeding began to allow the roots to thrive. The compost from the distillation was spread on the field and in conjunction with the rains, the new planting of the losses was prepared. 2500 new Lavender plants were planted in winter 2023 and algae spray was applied to avoid shock of the new environment. In 2023 **a total of 105 kg of Lavender was harvested**.

4.4 Comparative yields

The problems caused by the delay in planting of the first batch of plants due to Covid lockdowns delayed the whole demo site. Unexpected high-water levels in winter 2021 and 2022 also had a negative effect on plant development and yield. The quality of the harvest was satisfactory, but the quantity, as shown in **Table 4.1**, was lower than that set in the corresponding KPI (<200 kg/year). The results thus far are still inconclusive about the true potential of Lavender cultivation under the specific conditions tested by this project in Mykonos.

Table 4.1: KPI set and achieved for HYDRO4

HYDRO4 KPI	Sep-22	Jun-23	Total
1000 kg Lavender /year/ha 200 kg/year for 0.2 ha	17.5 kg	105 kg	122.5 kg

In a study conducted at the Plant Science Department of Federal University of Santa Maria (UFSM) by Mambri et al. (2018)[6] the parameter studied was the shading. In the non-shaded replications, a production of flowers ranging from 14.29 to 33.88 g per plant and of leaves from 276.43 to 395.31 g per plant were collected. In this specific experiment though the plants had all the desirable conditions to grow normally in the non-shaded treatments. According to the study of Shoeip et al. (2022)[7], a production of leaves between 70.49 to 300 g was noted during three respective cuts one on February, one on August and one on November. Again, in this study, chemical fertilizer was applied on the plantation, while the plants were provided the necessary conditions to grow. On the other hand, in HYDRO4, the production ranged between 5.83 to 35 g per plant within the two respective years 2022 and 2023. Given the harsh conditions these lavender plants grew into, it can be considered a sufficient production.

4.5 Valorisation and derived products

The main product resulting from the agricultural production in HYDRO4 site is the essential oil from Lavender (**Figure 4.10**). The same valorisation pathways described above for the Oregano essential oil in HYDRO3 were applied also for HYDRO4. Lavender oil and hydrosols were provided to aromatize gift packaging as well as aromatize water in spas. From 17.5 kg of dried Lavender harvested in 2022, approximately 180 mL of Lavender essential oil and 2 L of hydrosols were produced. In 2023, about 1.1 L of Lavender essential oil and 11 L of hydrosols were produced from 105 kg of Lavender. More details are available in D4.4 (Development of High Added Value Products).

[6] Mambrí, A. P. S., Andriolo, J. L., Manfron, M. P., Pinheiro, S. M. G., Cardoso, F. L., & Neves, M. G. (2018). Yield and composition of lavender essential oil grown in substrate. Horticultura Brasileira, 36(2), 259–264.

[7] Shoeip, A. (2022). Improving growth, yield and essential oil of lavander Lavandula Officinalis L. by using compost and biofertilizer application in clay soil. Egyptian Journal of Agricultural Research.

Figure 4.10: Essential oil products

5. HYDRO5

5.1 Demo site overview

The demo site of HYDRO5 is located within the premises of the municipal desalination plant of Tinos City on Tinos Island in Greece. At this location the crucial key technology of Mangrove Still System (MS) from the project partner PLANET has been demonstrated. This technology basically uses solar power and direct solar radiation to evaporate water from seawater and almost immediately condenses distilled water on a cooler surface and guides the almost pure water into tanks for storage and further use.

The location is ideal for the demonstration of this technology as the municipality of Tinos is a partner in this project and additionally, the desalination plant has already a big seawater storage tank that is easily accessible for the project partners, avoiding the need to pump fresh seawater over longer distances and elevations.

Next to the sustainable generation of fresh water, the particularities of the location and the island of Tinos were used to maximize the economic return of the generated fresh water. For this purpose, the project partner ALCN designed a production greenhouse (PGH) to accommodate common tropical fruit crops all year round that are irrigated with the water generated by the Mangrove Still system from PLANET. The innovative idea of selecting tropical fruits was based on several factors. Tinos is increasingly experiencing weekend touristic activity from Greek mainlanders visiting relatives and the renowned pilgrimage church on Tinos, but also international tourism. Hotels, restaurants, and diverse shops are trying to offer food and products of interest to tourists and local tropical fruits may be an interesting offer, while replacing imports. Also, the island of Mykonos, one of the most preeminent tourism hot-spots in Europe, is very close to Tinos, about a 40-minute ferry ride with many daily connections. This is also potentially a very big market for local exotic fruit production. It generates employment, added value and therefore multiple benefits for the island. Also, the mild winter climate allows tropical plants to survive in Tinos with just a basic greenhouse without any active heating necessary. The heat trapped from solar radiation is enough to keep the greenhouse frost-free and heat the soil to overcome low night temperatures.

The schematic layout of the site can be seen in **Figure 5.1.** The MS-System takes up an area of 189 m^2 and the PGH slightly more space at about 200 m^2. The expected output of the MS system would be, on average, enough to supply the PGH with irrigation water. In case of need, the irrigation water was complemented by tap water from the municipal desalination plant. The irrigation was controlled by an intelligent system from the project partner AGENSO that is based on soil humidity sensors and electronic valves powered by solar power cells, that only delivers irrigation water when it is really needed.

5.2 Plant selection

Selection criteria

The two main selection considerations for the tropical plants in Tinos are:

- to maximize value (market value) per unit of harvest or even better, by unit of irrigation water from Mangrove Still.
- to grow new and exotic crops that may create new value chains on Tinos, generating employment and potentially diversifying and strengthening its economy.

Other important criteria were:

- plants must be able to produce a reasonable harvest within the timeframe of the project,
- plants must have a growth habitus that fits into a standard greenhouse (therefore most trees were excluded),
- plants should be possible to be procured as young plants in necessary quantities preferably directly from nurseries in Greece.

For the first planting season, the following crops were selected: Ananas (Ananas comosus), Banana (Musa x paradisiaca), Papaya (Carica papaya), Ginger (Zingiber oficinale), Curcuma (Curcuma longa), Maracuya (Passiflora edulis), Pepino (Solanum muricatum), Dragon fruit (Selenicereus sp.)
In a second round of planting, the following crops were chosen: Aloe vera, Cardamon (Elettaria cardamomum), Physalis (Physalis peruviana), Colocasia esculenta.

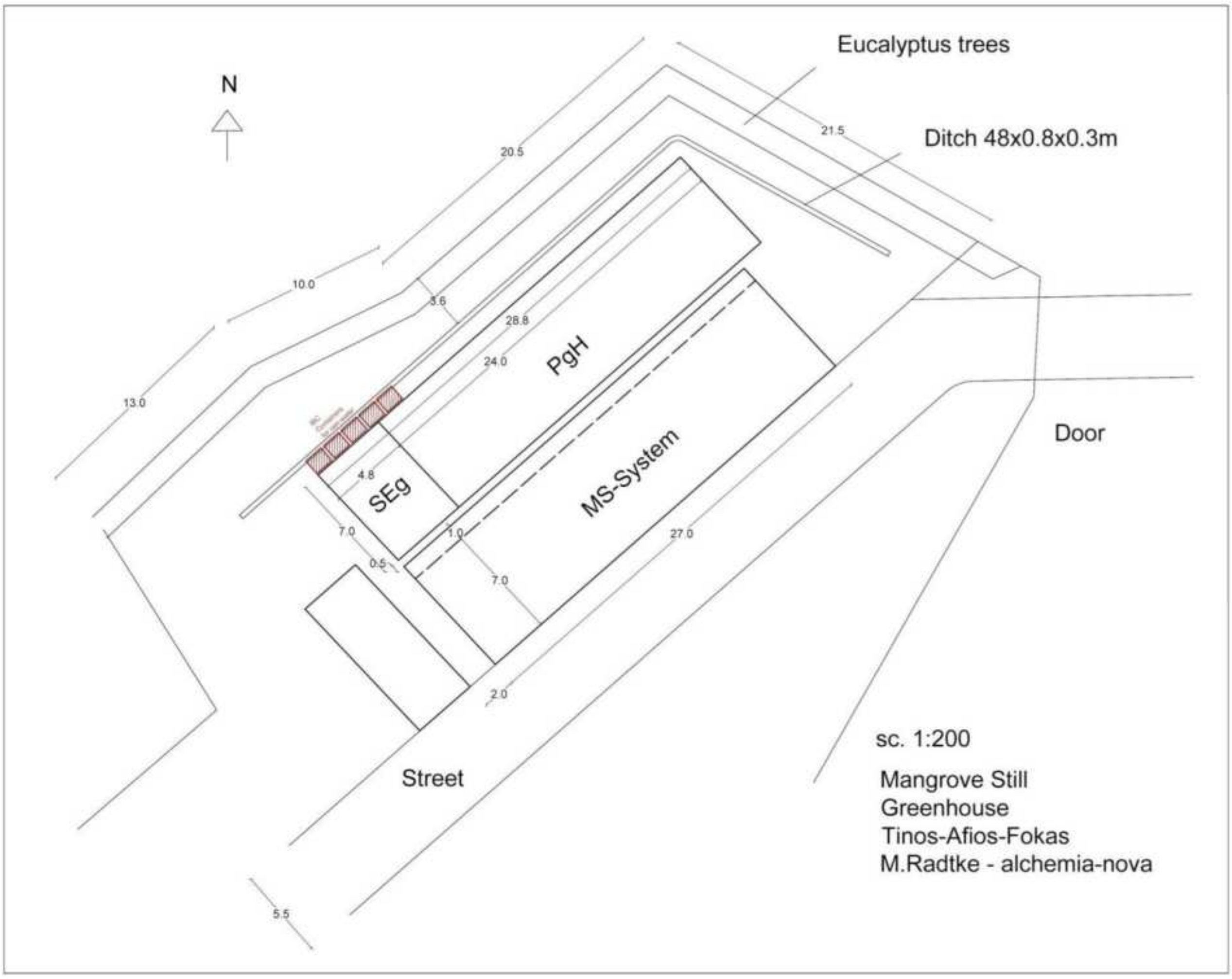

Figure 5.1: Schematic layout of the HYDRO 5 site

<u>Soil characteristics</u>

The soil at the site was not suitable for plant cultivation. Prior to this project, metal junk and water pipes of different types were piled on the site, with some weeds growing in between. The soil itself was very rocky and sandy with very little organic content. For this reason, at the area where the greenhouse would be located, the top 30 cm were dug up and moved off-site and a mixture of fresh agricultural soil and compost was used to refill the place. The soil pH tended to be high, at about 7.5 to 8.5.

Figure 5.2: Productive Greenhouse with tropical plants

Tropical crops have the advantage that they are adapted to the soils of humid tropical regions. Those soils usually have a very deep layer of very weathered mineral loam and clay with very little organic content, due to the prevalence of high temperatures and constant humidity leading to very quick decomposition of organic matter. Only a top layer of leaf litter and fresh organic matter supplies most of the nutrients to the soil and plants.

5.3 Agricultural production

A short summary of the most successful and less successful crops is given below.

Satisfactory results

Banana: The banana (**Figure 5.3**) showed to be quite sturdy and delivered first fruit stands after about 20 months, with the first harvests 28 to 30 months after planting. In some cases, during winter, it showed discoloured leaves with chlorotic patterns on the borders and occasionally dark discoloured young leaves, as a reaction to low temperatures. Ironically in summer under the PGH-roof it could also show excess heat damage on some top leaves with brown discoloration broad spots. However, the fruit bunches were resilient and ripe fruit bunches could be harvested, the ripening period of the fruits appears to be some 2 to 3 months longer than in tropical regions, very likely because of the effects of the cold winter temperatures reducing the physiological activity of the plants. The plant produces pubs or baby shoots naturally and these can be practically used to regenerate the shrub after harvest and could also be used to reproduce and expand the plantation. After harvesting the overall bananas fruit production by the end of the project, a fungal infection affected most of the plants. Currently, bananas cultivation is under dedicated treatment using organic copper, phosphorus, and zinc fertilizers along with bio-stimulants and beneficiary soil microorganisms in order to restore its condition. The plants, after carefully removing and discarding their infected parts show a positive response to that treatment.

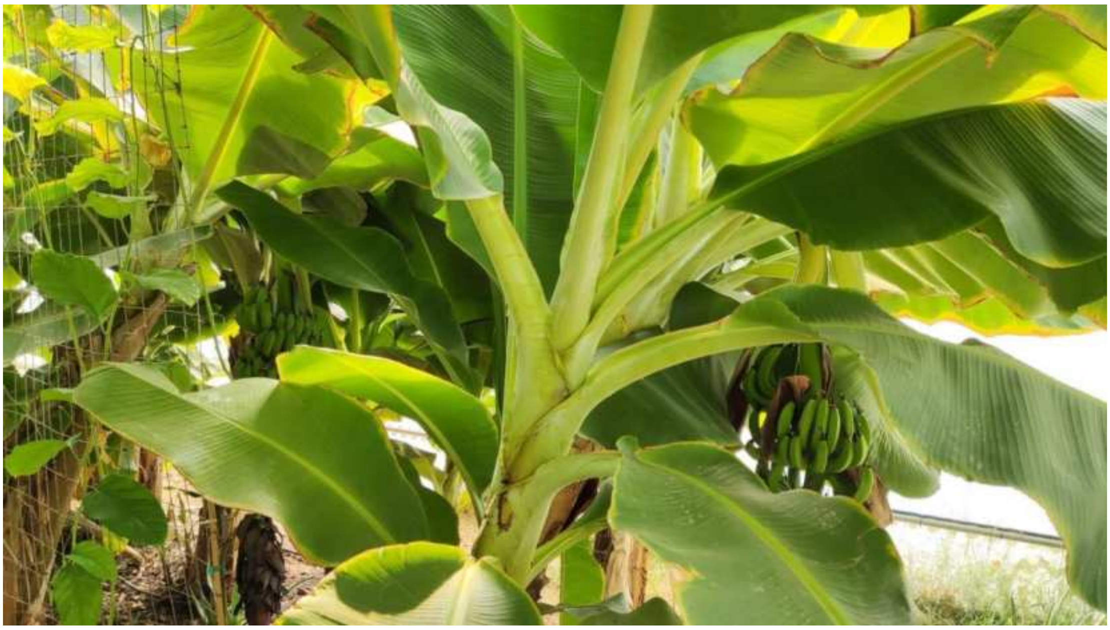

Figure 5.3: Banana plant

Papaya: This crop grew well, especially when it was provided with enough nutrients to sustain its fast growth. It had some susceptibility to spider mites, but other than that it showed no problem. It appears to suffer only little negative effects from the cool winter temperatures in Tinos with the simple protection of the PGH. Its stable and constant fruit production might allow a harvest that is almost year-round (**Figure 5.4**). Its end of life might be when the pseudo-tree reaches the top of the roof of the PGH and general loss of vitality that older plants naturally have. Fungal infections had to be controlled occasionally with copper-based fungicides.

Figure 5.4: Papaya plant

Aloe vera: This plant is quite sturdy and very resistant to pests and diseases. It was planted as a side-crop next to papayas, bananas, Passiflora and some of the other crops (**Figure 5.5**). It delivers harvestable leaves very reliably almost all year round, it suffers only a slight slowing of growth during winter and is resistant to interruptions in the irrigation supply.

Figure 5.5: Aloe vera plants

Passiflora: From all the crops, the maracuja was the first to produce flowers and started its production phase. It is important though to have a good fruit-producing variety delivered from the nursery. Half of the plants acquired by this project turned out to be a "decorative" variety with pretty flowers but no fruit set. The plant is susceptible to dryness and reliable irrigation is important. Passiflora flowers are preferentially pollinated by bumblebees or alternatively normal bees. During the winter months and in a closed PGH there is basically no flight of pollinators and hand-pollination using a brush may be necessary. This crop has quite an intensive need of pruning, almost like a very fast-growing wine-crop. High nutrient demand.

Physalis: This plant quickly produced flowers and fruits in notable numbers. The plant needs to be protected from spider mites particularly during the winter. Frequent replanting may be necessary to produce a harvest all year round and due to the fact that the plant loses vitality quickly. The PGH allows to produce harvests on Tinos at times that would not normally be possible on the island (winter and spring) and also increases the harvest.

Cardamon: The crop thrives quite well (**Figure 5.6**). Its production cycle seems to be too slow to deliver sizable harvests within the project timeframe, but it certainly seems viable at the time of this writing. The cool temperatures of only a few degrees above 0 °C that occasionally are experienced in the PGH in Tinos, may slow its development but does not seem to be an impediment. A pest infection caused from "Coccidae" insect affected the plants in a low level by the end of the project. The infected parts were removed and offered as goat feed. After applying dedicated treatment using natural pyrethrin and paraffin oil agents, cardamom's condition restored, and new healthy plants grow up.

Figure 5.6: Cardamon plants

Ginger: This crop is easy to reproduce, even from supermarket bought imports for food consumption. Unfortunately, in this project the plot where it was planted accidentally received inflows of salty brine-water, which severely affected its performance. Still, the few areas that were spared the accident, the ginger offered satisfactory production. It certainly would prefer better, richer soil, but fertilization can overcome this problem.

Unfavorable or inconclusive results:

Curcuma: Unfortunately, the plots where they were planted accidentally received overflow-streams from the brine tank from the Mangrove Still system right next to the PGH and therefore it was not possible to assess the viability of this crop. It seems that they might survive, but it is unclear if the harvest would be satisfactory. Tuber based plants do not seem to achieve the best results under drip irrigation and with tight irrigation water supply.

Ananas: This plant (**Figure 5.7**) seems to dislike drip irrigation. As its habitus suggests, its funnel-like leaves would guide rainwater towards the centre and stem of the plant. Its root system is rather weak. It was therefore also difficult to supply proper nutrient levels to the plant. Particularly, if working under organic cultivation without chemical fertilizers and without overhead sprinkler irrigation. Further effort beyond the scope of this project may lead to successful cropping on Tinos, but growing this organically and with restricted water supply seems quite challenging. The market demand though may be an incentive to try.

Pepino: Although the initial growth and quick flower production of the plant seemed encouraging, the first cool temperatures and high humidity in the PGH in the first couple of months of winter, produced an intensive spider mite infestation that could not be controlled effectively with organic intervention methods. The dense

Figure 5.7: Ananas plant

pest populations on pepino were starting to affect the other crops like papaya or Passiflora, so it was decided to eliminate this crop. Under conventional monocultural cropping under drip irrigation it seems entirely feasible that this crop could be produced on Tinos year-round, but that was not the aim of these trials.

Dragon fruit: This plant grew excessively slowly during these trials. It may have suffered from the competition and partial shading of adjacent crops like Passiflora, it may have been incompatible with the soil characteristics, or the cool winter temperatures just dampened its growth too much. It was also affected by accidental inflows of salty brine water. Probably the combination of all these factors prevented successful growth and there seem to be plenty of safer options.

Colocasia: This plant seems to be very susceptible to interruption in the irrigation supply or insufficient water supply. It is also a tuber crop, so not very compatible with drip irrigation and probably would require much higher organic content in the soil. Its huge leaves on stems with very spongy tissue seem to be easily affected by cold temperatures. Its low recognition among potential clients does not make it a prime candidate for further efforts.

Challenges faced

The aspiration to grow the tropical crops under organic farming standards to achieve the highest quality of the product, while also trying to minimize negative environmental and human health effects, meant that additional difficulties were at times encountered, besides those of testing inherently exotic crops on Tinos Island.

Firstly, it can be mentioned that there is no easy availability of plants on Tinos and the procurement demanded quite some effort and costs. In the end, young plants were sourced from nurseries on Crete and mainland Greece. The quality was not always optimal. For commercial production a reliable and effective relationship with the producing nurseries must be established and it would be preferable to have a specialized nursery on Tinos Island. This could be a business opportunity.

Drip irrigation is an ideal form of irrigation to minimize wastage and allow exact water supply to the plants. This water delivery form, however, is incompatible with some of the crops tested, like Ananas or Colocasia.

Since on this demo site a variety of crops partially mixed together were tested, the water supply may have been too scarce for some of the crop types.

The cool winter temperatures on Tinos could be overcome surprisingly well with just the simple plastic foil PGH and the very hot temperatures in summer apparently were no problem. A challenge was the very strong typical Tinos wind. The PGH provided good protection against the wind. Unfortunately, there are periods on Tinos where the wind is so strong (particularly during summer), that the ventilation flaps (or windows) of the PGH had to be kept almost shut, to prevent the risk of the wind tearing off the roof from the PGH. This meant that the temperature inside the PGH could rise to levels beyond what is optimal for the plants. To partially counteract this, the roof of the PGH was painted with opaque “lime-white” powder that partially reflected the sunshine away, to reduce solar radiation inside the PGH. This reduced temperatures by up to 5 °C. The winter rains would wash away the lime powder to get the desired full solar radiation in winter.

Local laborers could be trained easily. There was an initial apprehension towards the unknown plants, but they quickly got to learn their peculiarities. Since little disease or pests were observed, at least in the timeframe of the project, further expertise was not required in terms of problem detection. Besides that, only usual maintenance like clearing out weeds, keeping to fertilization schedules, giving permanent maintenance to the drip irrigation system and timely harvest were the main activities. The very hot temperatures inside the PGH in summer could be detrimental to the work enthusiasm of people.

Pest and disease control

Limited availability and supply of organic farming crop protection agents or fertilizers added a level of difficulty since many products had to be brought in from the mainland. It would have been desirable to have a better supply of beneficial insects released intentionally and periodically.

Spider-mites and aphids were controlled by spraying vegetable-oil or soap-based formulations that asphyxiate the pests. On severe infestation synthetic pyretroids allowed for limited use under organic farming were applied. No critical fungal or microbial diseases were observed, but copper-based formulations were sprayed when *Botrytis cinnerea* or *Anthracnosis* seemed to be affecting some plants or flowers after aphid infestation and / or low winter temperatures seemed to be facilitating infestation.

Weed control

All weed control inside the PGH was done exclusively by hand. When done frequently, the effort is very low since small weeds are easily removed.

Soil improvement

As described before, 30 cm of the stoney sand topsoil in the PGH was removed and replaced with a mixture of compost and agricultural soil sourced from the island itself. Since the pH was quite high, some elementary Sulphur was applied to the soil. Occasionally some citric acid was applied to the irrigation water tank and thus applied to the soil. This also helped remove mineral deposits from the irrigation pipes. A layer of tree-bark based mulch was applied to all the cultivated soil to protect it from direct sunlight. Chicken-manure based fertilizer was applied to the soil 2 or 3 times per year, complimented with some foliar sprays of liquid fertilizer and activated microorganism mixtures.

Table 5.1: Overview of crop specific challenges in HYDRO5

Crop type	Challenge	Characteristics	Mitigation action
Passiflora	Saltwater	Damaged roots	
Papaya	Cold winter	Leaf discoloration	Recovery after temperature increased Cutting of damaged leaves Copper-based fungicide sprays
Bananas	Cold winter	Leaf discoloration, tissue weakness and possibly resulting to botrytis infection	Recovery after temperature increased Copper-based fungicide sprays Cutting of damaged leaves
Ananas (new variety)	Fungi	Dark spots on the leaves	Copper-based fungicide sprays
All plants	Cold damage	Low temperature impact on plants	Experience from first winter indicates little risk of severe damage
All plants	Soil salinity	Sea-water overflow into PGH	

5.4 COMPARATIVE YIELDS

The harvest numbers are summarized in the **Table 5.2**.

Table 5.2: HYDRO5 harvest until end of June 2023

Tropical fruit	Number of Harv.Pc**	kg/Harv.Pc *(Mean value)*	Total harvest - June 2023 (kg)
Ananas	32	0.5	16
Passiflora	46	0.035	1.61
Papaya	142	0.32	45.44
Physallis	214	0.01	2.14
Musa fruits *(Bunches)*	17	8.1	138.38
Aloe Vera (leaves)	1.109 (144 Plants)	0.22	250.1
Aloe Arborescens (leaves)	494 (13 Plants)	0.072	35.48
Eletaria cardamomum (leaves)	50	0.52	27.41
Ginger Galaga	6	0.105	0.63
Total			**517.19**

The most notable producers in terms of mass were Aloe, Musa and Papaya. It must be noted however, that the value of the crop may be very different. Keeping that in mind, for now the discussion will focus on some mass parameters.

Overall, the PGH will deliver a harvest of 517 kg on approximately 200 m^2 of cultivated area in the period from September 2020 (initial planting) to June 2023 (end of project), about **2.6 kg per m^2**. It must be noted however, that most of the time was taken up by the planting and establishing period. The peak harvest is only now being achieved by papaya, ananas and many others. The way this year's harvest and fruit set is developing, the PGH would be on route to produce about 1,000 kg of output this year alone, meaning 5 kg per m^2 per year even though there are many sub-optimal plots like Ananas or brine-water affected areas. If the whole PGH was filled with only the most successful crops in terms of mass, the harvest output could most likely be increased considerably, probably doubled. The most profitable mix of plants is yet to be determined and depends on real market prices and partnerships with clients that will consider their preferences. However, as shown in **Table 5.3**, the corresponding KPI for HYDRO5 was successfully achieved, as 517 kg of tropical fruits were harvested during the HYDROUSA project.

Table 5.3: KPI set and achieved for HYDRO5

HYDRO5 KPI	Jun-23
> 1.5 tons tropical fruits per ha > 30 kg for 0.02 ha	**517**

Looking at individual crops:

Banana: cash crop plantations are established with planting densities of 2.500 plants per ha which works out to 4 m^2 per plant. In the PGH, due to sparse space, 25 plants were planted in about 60 m^2, which leads to almost **2.5 m^2 per plant**. Yields in commercial plantations, for example in Ecuador (one of the worlds prime exporters of fruit bananas), vary a lot, with harvests of exportable products between 20 and 40 tons per ha which results in 2 - 4 kg per m^2 per year (in mature conventional plantations, not counting the establishment years)[8]. This year, the expected harvest of bananas in the PGH in Tinos is expected to be equal to 150 kg on the 60 m^2 devoted to the crop. That means a yield of almost 2.5 kg/m^2/year, corresponding to the range in Ecuador. Since the crop is not yet fully mature, this number seems quite good. High individual care was given to each plant, which may have compensated for shortfalls due to organic cultivation. Very long sunny days on Tinos in summer with unimpeded sunshine (compared to ≈12-hour days in the tropics with frequent cloud cover) and enough water supply may be another factor for boosting yield, regardless of winter dampening. Finally, non-exportable fruits (too small or too big, discoloured, wrong shape) are often discarded and used as pig-feed in the exporting countries and may not be included in the final statistics. On Tinos all fruit qualities could be easily valorised at a higher level than animal feed. Considering that this crop yield was achieved under organic cultivation and despite the inexperience of handling the crop in Tinos-winter months, the results were agronomically very satisfactory.

[8] National Institute of Agricultural Research of Ecuador, 2020. https://www.iniap.gob.ec/banano-platano-y-otras-musaceas/ and https://www.cfn.fin.ec/wp-content/uploads/downloads/biblioteca/2020/ficha-sectorial-4-trimestre-2020/FS-Banano-4T2020.pdf

Papaya: Cultivation densities of 2,000 plants per ha are often used in tropical production areas. Harvest statistics or expectations vary greatly. Some country averages are close to 30 tons/ ha, others indicate 50 tons/ha and for Spain, under intensive PGH cultivation, yields of over 100 tons/ ha/year] are given (but here with higher planting density)[9,10]. Highest numbers are for conventional, high input monocultural cultivation.

Under this project only 8 papayas trees were planted, of which 7 survived the establishment phase. These 7 plants are expected to produce almost 100 kg of harvest this year, which results in **14.3 kg per plant**. Based on the commercial yield numbers given above, this results in 15 to 33 kg per plant per year. In this case, the Tinos harvests came in at the lower end of the comparison. This may be because the poor soil and the limits of organic fertilization were not able to supply the plants with adequate nutrients to sustain their impressive yield per plant. Winter may have also influenced fruit development (size) and the lack of good pollination during cold and closed PGH conditions may also be a factor. Furthermore, the mixed cropping where the papaya was always combined with other crops, may have also limited its nutrient availability, and prevented it from achieving its full potential in comparison to conventional monoculture. Finally, careful selection of the planted material to use only hybrid sex types, which are the most productive, would help. More experience with the crop under the particularities of Tinos would certainly offer more room for improved yields.

For many of the other crops, not enough numbers or harvest is available for solid comparisons, but the visual inspection would indicate that for the plants listed as successful, satisfactory harvests can be achieved on Tinos under organic farming practices or with low input of conventional agricultural chemicals.

Finally, it is noted that these yields were achieved with an irrigation level of 1.6 to 1.9 L/m^2/day during summer and less than 0.5 L/m^2/day in winter. On average, it was between 1.3 and 1.5 L /day over the whole year resulting to 110 m^3 of irrigation water that was consumed per year for the 200 m^2 PGH. For the current year, with an expected harvest of about 1,000 kg, this results in 110 L of water per kg of harvestable market produce. That would be 0.11 m^3 of water per kg of product. Since the approximate cost of tap water or drinking water is about 2€ per m^3 as an overall average in Europe, about 0.22 € worth of tap water is used per kg. Tropical fruits in the supermarket in Tinos or Europe usually cost much more than 0.22€ per kg, usually about 2€ -12€ per kg in conventional quality (bananas being the cheapest). It is noted that irrigation water in most agricultural activities is considerably cheaper than tap water (and usually of lower quality). In any case, these calculations should give an idea of the value proposition of the tropical PGH-crops on Tinos under the real project results, where the aim was to add value to the good quality fresh water produced by the Mangrove Still system.

5.5 Valorisation and derived products

For HYDRO5 Tinos, the main idea was to valorise the fresh water produced by the Mangrove Still system into higher value agricultural products. A tropical fruit Greenhouse was selected as the pathway that it would have

[9] Revista Mexicana de Ciencias Agrícolas, 2019. *Rendimiento y rentabilidad de genotipos de papaya en función de la fertilización química, orgánica y biológica.* Vol 10 no3. https://www.scielo.org.mx/pdf/remexca/v10n3/2007-0934-remexca-10-03-575.pdf

[10] Horticultura, 2020. *Mayor rendimiento en el cultivo de papaya gracias a novedosas técnicas.* https://www.interempresas.net/Horticola/Articulos/298561-Mayor-rendimiento-en-el-cultivo-de-papaya-gracias-a-novedosas-tecnicas.html

the potential to create high value products, while introducing new and interesting crops to Tinos, which is developing its national and international tourist interest. These tropical fruits could contribute to that effort.

During the project, all harvested plants and fruits were offered to the local community. The future valorisation of the tropical crops would be direct sales to business clients in the tourism and hospitality sector such as restaurants and hotels. There, they could be offered as fresh fruits, juices or included in salads, desserts, or drinks. The non-edible products like Aloe Vera would be sold to cosmetics and soap processors, who in turn could sell to the tourism sector, next to the general public. Aloe vera is also included in jams and marmalades after some processing from the same client.

Since the cultivation process on Tinos was strictly along organic farming guidelines, and the PGH would allow very short time and transport from harvest to end-consumption place, the tropical fruits from Tinos are expected to have a very high quality, in terms of taste, environment, sustainability and human health parameters. The fruits are harvested when they are ripe on the plant. This means a short shelf-life, but best possible taste development. Restaurants and bars are then able to turn the fresh fruits into a variety of drinks, cocktails, desserts, salads, etc. and sell them with a good profit margin to customers.

The tropical fruits themselves are basically a demonstration and proof of concept. A big result from this effort was to demonstrate the successful cultivation and distribution, to entice interest and investment from private actors, who could expand on the technologies and benefits that can be achieved. In this context, the Mangrove Still system and the tropical PGH have received numerous visits, including schools and municipal functionaries, as well as many private citizens from Tinos and even some visitors from outside the island. The didactic and learning benefit of the PGH is quite palpable. School students can get to learn firsthand some of the exotic crops they may have eaten, but never seen the plant (**Figure 5.8**). Moreover, HYDRO5's community engagement wasn't limited to market exploitation and educational activities. Ripe bananas were offered to the local social kitchen, thus contributing to the support of vulnerable residents and hence to the strengthening of the local community.

Finally, the soap and cosmetics manufacturer on Tinos along with the local traditional stores are actively selling their products made from local Aloe Vera from the PGH all year round. To be profitable, the tropical PGH would need to be bigger and have larger quantities on offer. The main valorisation for now would be to find actors, who will learn and gain from the experiences and knowledge gained through this project and want to push these business opportunities further.

Elementary School on-site visit

Aloe marmalade production

Aloe gel extraction

High School on-site visit

Bananas' offer to the local social kitchen

Aloe soap production

Bananas' offer & presentation to local Kindergarden

Ripe Bananas

Bananas offer to Tinos social kitchen

Bananas offer to Tinos municipal services

Environmental groups'on-site visit

Bananas offer to local citizens

Figure 5.8: HYDRO5 Community engagement and valorisation

6. HYDRO6

6.1 Demo site overview

HYDRO6 is a micro scale implementation site for a whole set of interacting nature-based solutions proposed, developed, implemented, and tested within the HYDROUSA project. The demo site is located at Potamia, Akeratos, on Tinos Island on the premises of the Tinos Ecolodge (ELT) (**Figure 6.1**). The premises cover an area of 6000 m^2 and have a hosting capacity of 13 customers. While there are two annual seminars organised that increase the hosted customers to 26 people for a period of four weeks. The site is exclusively supplied with electric energy by an off-grid production and storage system. The water supply is assisted by an extensive rainwater catchment and storage system able to harvest and retain 180 m^3 of service and irrigation water. All wastewater produced within the facility is treated by vertical flow constructed wetlands and reclaimed in a buffer tank for irrigation. This reclamation process contributes approx. 50 m^3 of irrigation water to the system. Alternative sanitation concepts as dry composting toilets with urine separation are part of the solution set.

Figure 6.1: Location and overview of HYDRO6

The basic agricultural activities of ELT are a market garden which produces a high variety of fresh vegetables, a mixed herbs cultivation which aims at fresh herbs and raw material for essential oil production, respectively creams and dedicated workshops. A vineyard produces fresh grapes and derived products, such as natural wine and Raki (a local spirit) for in house consumption. Also, different fruit trees, prickly pears and artichokes were planted to enrich the Market Garden and for onsite production of conserved foods such as marmalade, juices and pickled goods.

As ELT is a small company, the design of the agricultural site had to keep in mind the long-term workload created by these new business activities and compliance with the strong focus on ecological sound practices of the company. While designing a site, many assumptions and simplifications must be made, and many unknowns have to be carefully managed. HYDRO6 took the decision to try different cultivations and agricultural practices with many different species to test which ones are suited and outperform others within the micro conditions of the site. Room was given to increase or decrease the balance between the different agricultural activities for future adaptation to available market opportunities and the operating experience and preferences of the managing crew.

The overall logic in the planting layout and composition of the agricultural site was to create sub areas with different characteristics. One of the main goals was to identify plant groups that can be managed from extensive to intensive, while providing an economical, ecological, and esthetical benefit. The market garden has the highest management cost considering the overall inputs such as maintenance, nutrients, water etc. but also creates the highest economic output. On the other hand, cultivations like grapes and artichokes have a medium input requirement. The herbs mark the other side of the ladder with very little input after the establishment phase. From the viewpoint of the ecological impact, the herbs as part of the local vegetative ecotype of the island and designed in a polyculture layout contribute greatly to the surrounding ecosystem.

The total allocated area for agriculture is 2,230 m^2 and is subdivided by intensively managed crops with 544 m^2, medium with 550 m^2 and extensively with 680 m^2. The different plant species are shown analytically in **Table 6.1.** The variety of over 30 cultivated species is high and for reasons of simplification the table only shows the vegetable families that are grown and not the real species count. Which would add more than 40 additional plants and are analysed in the following chapters. This segmentation of the cultivation's accommodates on the one hand the workload on site, the possible financial output, and the ecological constraints within regenerative agricultural practices.

Table 6.1: Overview of plant selection

extensivly managed agriculture			medium managed agriculture			intensively managed agriculture	
Herbs & Cactus		Plants	Grapes		Plants	Vegetable crops	Area
Sage	*Salvia pomifera*	92	Vitis vinifera	*Potamissi*	100	*Solanaceae*	
	Salvia triloba			*Monemvasia*	30	*Crucifers*	
Thyme	*Thymus capitatus*	40		*Sultanines*	10	*Amaranthaceae*	
	Thymus citroidorus		**Total number of plants**		**140**	*Alliums*	
	Thymus vulgaris		**Total area in m^2**		**205**	*Asters*	
Lavender	*Lavandula dentata*	40	Artichoke			*Umbellifers*	
	Lavandula *angustifolia*		*Cymara scolymus*	*x local*	100	Lamiaceae	
Rosemary	*Salvia rosmarinus*	50		*x local spiky*	30	*Cucurbits*	
	Salvia x Blue rain		**Total number of plants**		**130**	*Amaranthaceae*	
	Salvia x Boule		**Total area in m^2**		**250**		
St John's wort	*hypericum perforatum*	60	**Trees**			**Total area in m^2**	**540**
			Plum	*Prunus domestica*	4	**Micro Greens**	
Oregano	*Origanum vulgare ssp. hirtum*	92	Pear	*Pyrus*	2	high variety of different types	
Savory	*Satureja montana*	51	Apricot	*Prunus armeniaca*	2	Total area in m^2	**4**
Caper	*Capparis spinosa*	150	Fig	*Ficus carica*	1	**Agricultural Area**	
Elychrisum	*Helichrysum italicum*	60	Pomegranate	*Punica granatum*	2		
Dictamus	*Origanum dictamnus*	68	Almond	*Prunus dulcis*	2	Herbs & Cactus	680
Prickly Pear	*Opuntia ficus-indica*	60	Mulberrey	*Morus alba*	1	Grapes & Artichoke	455
			Cherry plum	*Prunus cerasifera*	2	Trees	550
Total number of plants		**763**	**Total number of plants**		**16**	Vegetable crops & Microgrens	544
Total area in m^2		**680**	**Total area in m^2**		**550**	**Total Agricultural Area in m^2**	**2.229**

ELT was able to establish most of the cultivations within the first and second year of the project, which gave the plants enough time to establish and thrive. This also gave the on-site crew time to learn and refine different management practices, as well as to adapt the plant plan to the reality of the micro conditions of the site and to take corrective steps in underperforming designs.

Throughout the years, the market garden became a focal point in the development of agricultural production. While it initially was designed to supply the customers and local staff with a farm to fork concept, it slowly grew into a continuous high surplus generating operation. The first end-user approached was a local

This project has received funding from the European Union's Horizon 2020 Research and Innovation Programme under Grant Agreement No 776643

restaurant absorbing the surplus. Over time, it was possible to produce enough vegetables to supply six restaurants and build a constant relationship for the “Veggie Box” delivery scheme that was created.

The Vineyard has also been established (**Figure 6.2**) well and started to produce in the third year its first mention able harvest (**Figure 6.3**). Which was further processed into a natural wine and “Raki” for ELT customers. The Herb cultivation has reached full maturity and produces very satisfactory harvests (**Figure 6.4** and **Figure 6.5**). Some of the herbs are performing better than others, which is normal due to micro conditions of the site. A firstly unseen market outlet for the herbs was discovered through the cooperation with the restaurants which by now absorb part of the harvest as fresh kitchen herbs.

Figure 6.2: Timeline of grape evolution

Figure 6.3: Timeline of grape evolution and first harvest

The production of essential oils with a home sized distiller and the further processing of the oils and hydrosols into face and body creams was successfully tested. ELT's customers are the end users of these derivative products. The same is true for the conserved artichokes and the marmalades that are produced from the fruit trees and prickly pears.

Overall, it can be stated that the agricultural activities of HYDRO6 are successful and well anticipated by the different end-user groups.

Figure 6.4: Timeline of herb evolution

Figure 6.5: Timeline of herb evolution 2

6.2 Plant selection

Site Description

ELT is situated in a mountainous landscape at 200 m over sea level. The landscape is greatly over formed by anthropogenetic activities throughout the centuries mainly characterized by a terraced landscape used for agriculture and animal husbandry. The former forests consisting out of Valenian Oak trees, and the typical Maquis shrub land exist today only in minor patches incoherently distributed over the island. The plot is localised within such a patch. The climatic conditions are defined by zone 10b after USDA (United States Department of Agriculture) hardiness zone categorization or Csa hot and dry after Koeppen. The rain distribution pattern follows the typical Mediterranean climate with dry summers and humid winters. The overall participation in the last ten years is between 220 mm and 570 mm with an average of 366 mm measured at the island’s capital Chora.

The soil is shallow with around 20 cm at the shoal end of a terrace and up to 120 cm at the deep end. Due to the degradation of the vegetative ecotypes by forest clearance followed by high grazing rates the conditions are poor. Described by typical characteristics such as low soil organic matter content, low biomass input, exposed soil, low water holding capacity and compact soil structure.

In 2019 a soil sampling campaign was carried out with 10 sampling points located at the different agricultural sites to obtain indicator values of the physical and chemical properties of the soil. The results are heterogeneous due to the different micro conditions of the plot. The average soil is described as sandy loam with 2.3% SOM (soil organic matter), a pH of 7.4, an EC of 367.7 µS/cm and fairly good availability of macro and micro plant nutrients. A full discussion of all soil samples can be found in D4.3 (Catalogue of selected plants, description, availability and product development options).

These soil tests provided a good starting point for the decision-making process on what cultivation method was suitable and what basic parameters should be in the focus of the soil improvement effort. Due to the narrow terraces forming the foundation for the design it is not possible to rely on bigger machines like tractors needed for tillage-based agriculture. The soil conditioning and field preparation usually done by towed implements behind a tractor had to be completely avoided. This meant developing a productive agricultural system localised to the constraints and requirement of HYDRO6.

The first decision was to kick start microbiological activity in the soil to improve structure, health and SOM to achieve long term beneficial effects. This was done by amending the soil with vermicompost and compost derived from Posidonia sea grass. High amounts were supplied to the vegetable garden and greenhouse with rates of 40 L/m^2. The rest of the plants received a rate of 5 L/plant while planting. A base fertilization of organic N-P-K fertilizer was applied per cultivation according to the recommendations of the consulting agronomist. The effort of increasing SOM is maintained throughout the whole project and is considered one of the key driving factors of successful agriculture within the described setting. The advantages include increased water holding capacity, increased biological activity, continuous positive restructuring and the slow mineralization process supplying nutrients to the plants while fostering a healthy soil biome. Organic matter cycling is also one of the loops that must be addressed in every organic driven production system. The composting schemes used are described in detail further down.

<u>The plant selection process and criteria</u>

The plant selection was driven firstly by their adaptation to local conditions and appearance on the island. As better the plants are adapted to the locality the lower is their external input demand like water, fertilizer, pest control and overall management effort. Also, their local appearance and their condition is a very good indicator for potential profit or loss of the specimen. Secondly the long-term water demand and the stress resistance were considered. The water demand can be divided in roughly two phases, establishing phase where water stress can lead to die off and mature demand that must be supplied periodically through their lifespan. Water availability is the major limiting factor for ELT's activities. In the selection and planting, the design made use of this change in water demand by establishing the herb, grape and artichoke cultivation first, because their water deficit resistance is low in the establishing phase but increases greatly after the second year. The vegetable garden has the highest water demand and was kept smaller in the first two years where more water was demanded by the other plant types. In the second year the water not utilised by the already established plants could be used to increase the vegetable production area.

It was important in the beginning of the project to assume that the reclaimed water potentially would have a restriction on where to use it according to the monitored quality parameters. In the water balance this was addressed by also integrating fruit trees and designing the irrigation system in a way that certain zones and cultivations could be irrigated with restrictions, mitigating the risk of low water availability.

Partly the crop selection was predefined in the project proposal in a more generic way describing the long-term perennial plants such as herbs, grapes, artichokes, caper and prickle pears.

In the purchasing process, a general rule for the plant selection was their availability at close by nurseries or the availability of propagation material on the island. Most of the Herbs were purchased from a nursery from the close Island of Kea. This has the upside that the seedlings or cuttings was from already adopted plants to similar conditions. The artichokes were propagated on site from propagation material found on the island. The prickly pears while existing on the island were imported from the mainland because the characteristics of the local variety were not favourable due to the high number of spikes and seeds within the fruits. The grapes were propagated by a specialised nursery using scions from a local variety and grafted on to an American root stock to create an immune plant against phylloxera. The trees were mainly selected to produce marmalade and fresh fruits, while still considering the above-described parameters.

Vegetable crop and variety selection

The vegetable production plant and variety selection has been a complicated and slowly evolving process throughout the project. In the first season ELT followed mainly the recommendations of the agronomist, who wisely chose to order all plants from nurseries in order to reduce complexity and workload on the managing crew.

A wide diversity of different plants where tested, evaluated and growing experience gained. ELT decided that within a serious organic setting, the use of F1 hybrids is problematic and it was observed that many plants from the nurseries were already infected by various diseases. Another problem is that seedlings are grown in special potting soils that are sterilised and optimised for germination. This ignores all the beneficial relations between bacteria, fungi etc. that a seedling must be infected with in order to become a healthy plant. By now all seedlings are produced in house and the seeds are bought from propagators with the highest organic standards, protections of old varieties and open pollination varieties. The in-house production allows minimizing shipping, produce on time, freedom of varieties and fast adaptation to on-site needs.

By gaining experience in cultivation methods, available tools, and market situation on the island, a matrix was established to benchmark the different crops and their suitability and profitability. The market garden approach tries to maximize crop production for a small area with a limited tool set consisting out of mainly non mechanized but human powered hand tools. In order to be able to maximize production, two main factors come into play, a very dense planting and a very high crop rotation rate optimizing space and time throughout the growing season.

Driving this system means carefully selecting the main crops, their varieties and compiling them for certain main characteristics described in **Table 6.2**. The table shows an exemplary extract of the whole vegetable variety tested to show the selection process.

Table 6.2: Crop selection criteria

Crop	Days to Maturity	Days in Garden	Season in months	Where	Management Effort	Vulnerability to Pests	Water demand	possible market penetration	Turnover	Profit
Arugula	35	60	8	GR+GH	low	low	low-medium	high	high	high
Beet root	60	70	8	GR	medium	low	medium	medium	medium	medium
Lettuce	60	30	10	GR+GH	medium-high	medium	high	high	high	medium-high
Tomato	120	150	6	GR+GH	high	high	medium-high	medium	medium	medium-low
Broccoli	120	120	7	GR	medium-low	medium-low	medium-low	medium	medium	medium-high

Timing is crucial and expressed by three main factors:

1. The days to maturity (DTM) is the time a plant needs to mature. Counting from the day the seeds are planted. This is the period where a plant bed is occupied, but not productive till the first harvesting event. Included are the period non direct seeded vegetables needed in the nursery.
2. The days in Garden (DIG) describe the number of days the crop can be harvested or in other words the productive period.
3. The seasonality accounts for the overall period the specific crop can be grown under local circumstances including the green house.

For example, Arugula is a direct seeded crop that needs 35 days to maturity and has 60 days in the garden, so the harvesting window is 25 days of production. The plant bed will be occupied for 60 days, and the growing season is 8 months giving a frequency of 4 full production cycles on this bed. Of course, this is a theoretical value because considering that crop rotation is needed, the place must change. Also, the values for DTM and DIG change throughout the growing season considerably.

Where the crop is grown has a high impact on the profit because the greenhouse, due to its higher initial investment cost, must have crops that can perform with a high profit rate per square meter. Accordingly, the garden can perform at lower rates while generating higher profits.

The management factor considers different aspects like how much time is needed to prune and harvest a crop, how precise different cultivation practices must be carried out before negative effects occur, how much effort is spent in the propagation process and how high are the loss rates. These very different aspects are summarised in an assessment driven by on-site experience and classified from low to medium to high. This factor directly impacts the financial potential of a certain crop.
Vulnerability to pests expresses the rate at which pests are observed. Some crops are susceptible to express the same infections every year, others and especially different varieties show less or no liability. Also, the occurring pests and their pressure is different from growing season to season. In many cases cultivation methods can be adapted, different plant protection strategies can be applied from mechanical to biological to chemical. These strategies usually increase the management effort, increase the cost for products and have a negative impact on profit.

Water demand is of high concern due to the generally limited amount of available water. A careful balance is established in every crop plan between profit and water demand and possible alternative cultivation. The possible market penetration tries to evaluate where the HYDRO6 products can out compete, or not compete with the available products on the market. It identifies niches and local advantages over other products and production methods like conventional versus organic or shelf life and freshness of imports versus locally grown.

Turnover and profit are the final criteria that have a high impact on the crop planning strategy. While the turnover can be high, as shown in the previous table for lettuce, the profit can be medium-high. This results from the medium-high management effort, the losses to pests and the high-water demand. This is balanced by the high demand for fresh harvested, high quality and high cultivar diversity of the local market. As shown by this example, every crop and cultivar have its own multi criteria analysis for evaluating its turnover and profit range. Also, different distortions must be considered resulting from "must have product" like e.g., tomatoes that are demanded by the end-users, but have mainly unfavourable overall ratings. The crop plan must account for this by identifying cash crops that can compensate for less well performing crops.

Another limiting factor is the available area and the tool set being used which prohibited crops that only make economic sense in greater scale or mechanised production methods. These crops include grains, maize, potatoes and other typical high carbohydrate ones.

6.3 Agricultural production

The intensive agricultural system of HYDRO6 has evolved throughout the project and consists at the time being of a poly cropping approach with a high number of different species and cultivars in a densely cultivated manner and a high crop rotation per plant bed. Also, it follows a no till approach to propagate a healthy living soil. This system was evaluated through the experience gained from season to season. The extensive agricultural systems consist of grape, herb, prickly pear, artichoke and caper production. These cultivations are well suited for the environmental conditions on the island and need less input.

Overview of the growing seasons 2019 to 2022

In the first Season in 2019 ELT tested a high variety of different crops and cultivars in order to analyse the suitability of every species for the specific conditions within HYDRO6 and its market potential within the restaurant and private customer range it is targeting. Also, the variety composition of the overall production was tested. This initial test setup was refined from season to season according to yield, quality, workload, and suitability within an organic growing setup (**Figure 6.6**).

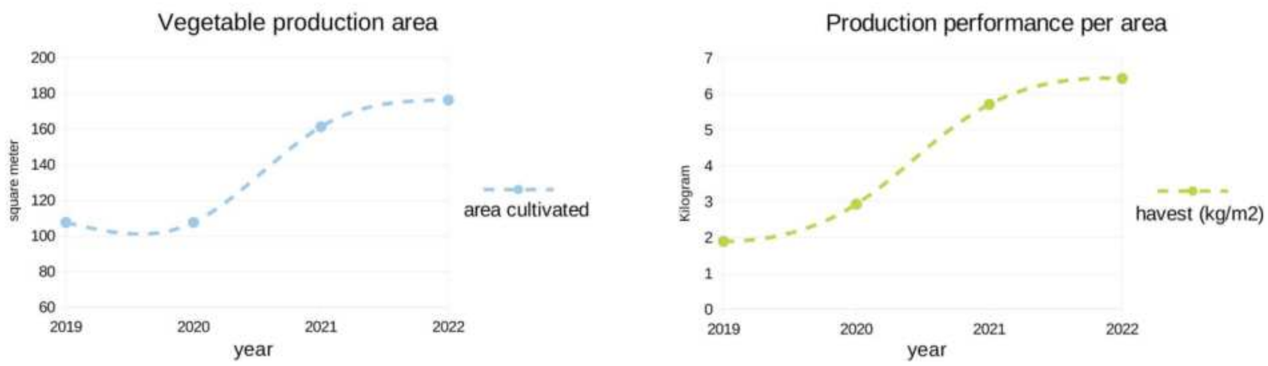

Figure 6.6: Increase of vegetable production and performance.

In **2019** the first garden was established with the market garden system as a design foundation. This system focuses on small scale farming with high yields per area and direct market outlets. The first growing season was mainly dedicated to learning with the main goal of establishing a baseline scenario (**Figure 6.7-6.9**). The theoretical setup was tested in practice and a workflow was established. All plants were bought in and consisted mainly of F1-hybrids suggested by the consulting agronomist. In terms of production, the season was unsatisfactory mainly due to the lack of experience that is needed to control a complex and highly interdependent agricultural system. **A total harvest of 1.89 kg/m² was achieved**. The main conclusions defined the need for addressing pest pressure control, pest monitoring, better adapted varieties, specific task planning, time management, parameters to monitor, systematic approach to field data acquisition and the need of a specific crop plan addressing the potential market.

Figure 6.7: Setup of the first vegetable garden

Figure 6.8: First growing season

Figure 6.9: First Growing autumn

In **2020** ELT, after analysing the shortcomings of 2019, approached vegetable production for the first time in a systematic planned and monitored way. In the winter season special tools were bought, a first crop plan was established, monitoring lists were designed, a small nursery was built, and the first seeds were ordered. The experience about time needed to perform certain tasks helped a lot in organising a structured day and task plan (**Figure 6.10**). The bought in plants could be reduced to around 60% and many experiments were conducted with directed seed cultivation. The first relations to restaurants were established and a first careful market outlet was started. This led to an understanding of the needs that are related to direct marketing within the catering sector. Overall, the season went a bit better with a **total harvest of 2.93 kg/m^2**. But many old and new problems were identified. The in-house production of good quality and well-timed transplants in the nursery was much harder than initially anticipated. It is a specialised job which needs focused attention and specialised equipment within a dedicated area. The importance is immense because it builds the backbone of the overall production.

Figure 6.10: Growing season 2020

The growing season of **2021** was very well prepared, and the lessons learned could be transformed into a very efficient crop plan that for the first time came close to the actual developments in the field. In the seasons before we saw that many plant diseases were imported with the transplants and that the transplant availability was not matching the planned successions (**Figure 6.11**). This led to the decision to focus on open pollinated organic varieties started exclusively from seeds and avoid any bought in F1-hybrids. On a conceptual level, ELT decided to stay true to agroecological and bio-intensive ways of farming and to resist the temptations of conventionalized organic farming, which relies more on external inputs. For the first time more than 90% of the varieties were produced on site. In a specialized area and build propagation tables in front of the greenhouse. All seeds were purchased from Demeter certified sources. Composting was integrated as a standard procedure and first test trials with different ways of composting were conducted. **The overall production was increased to 5.71 kg/m^2**. This increased production led to the need for new end-users. A vegetable box scheme for the local community was established and maintained.

Apart from the better organisation and evolved skill sets of the crew, also improved ecosystem services have played a major role in the progression of production. Regenerative practices such as constant addition of compost, mulching, flower strip planting, green manure seeding, herb plantation, the open water surface of the new rainwater cistern, no agrochemicals, and the no-till approach, slowly started to improve the overall conditions of the initially degraded fields. The new market outlet increased the pressure on the timings, overall production, composition of offered products and working schedule further. The monitoring was further improved and refined.

Figure 6.11: Growing season 2021

2022 started with a major drawback due to the loss of a by now well-trained crew member. However, the crop planning and the nursery was further improved, which reduced the pressure and enabled ELT to train a new employee. In the winter season, a lot of attention went into the composting process and more than 12 m^3 of high-quality material was produced and deployed to the plant beds. A lucky circumstance made this possible which was a Volunteer trained by Elaine Inghams school of the Soil Food Web who brought a lot of know-how and motivation into the activity of soil health improvement. The composition of the vegetable production was focused more on leafy greens for the restaurants and a rich mixture for the vegetable boxes. **The overall production was increased to 6.43 kg/m^2**, (**Figure 6.12**).

Figure 6.12: Growing season 2022

Crop Production Monitoring

The monitoring of the crop production is in its character a constant progression as knowledge and experience of the grower advances. ELT as manager of HYDRO6 had little experience in professional market crop production systems and had to cope with a steep learning curve throughout the project. Available resources for monitoring of small-scale farming are very limited and usually too broad or too localised to be transferable. The system that is now in place has defined the important factors to track and can be analysed in order to support evaluation of the past growing season and supports the decision-making process for the crop planning of the next season.

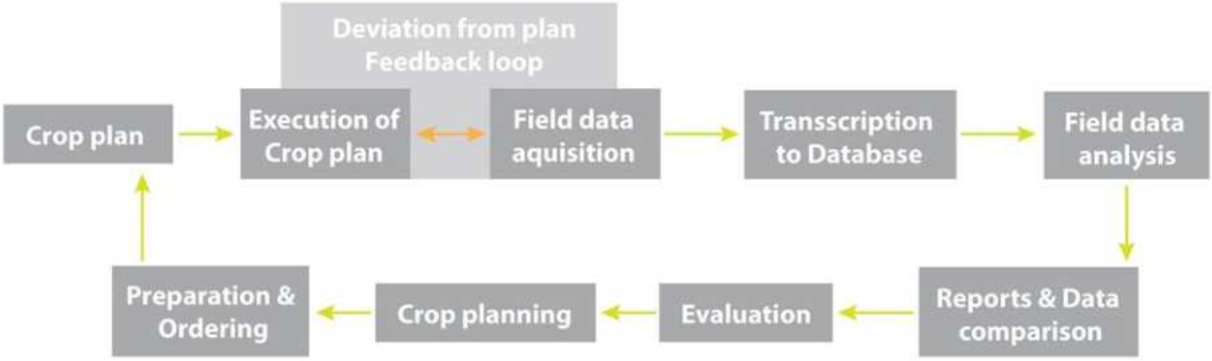

Figure 6.13: Monitoring system flow

The difficulty in the monitoring system consists mainly in the definition of parameters that need tracking. The target is to capture the main cultivation data without becoming too detailed or too broad. Too detailed means that the field data acquisition becomes time consuming, hard to execute by non-trained personnel and error-prone especially if data series depend on each other. Too broad means that the conclusions derived from the analysis are insufficient for optimising the production of the next season.

The crop plan is established in the winter season and describes the crop varieties, amount, place, transplant date, direct seeding date, succession per bed and targeted harvesting date as well as the expected harvest. In this way the whole growing season is predefined, and production is planned according to the market demand. In spring this plan is executed, and the gardens are established. From this point on, the production is monitored tracking the following parameters: crop variety=> harvest date=> harvest amount in Kilogram or pieces=> duration of harvest. Working with nature also means that a theoretically established crop plan will divert over time from the actual reality in the field. This is caused by unpredictable changes in weather conditions, seed quality, pest pressure, human error, market demand and reactions to observed problems. In order to maintain quality of the monitoring, a constant feedback loop between field data and updates in the crop plan is necessary. The field data is collected by filling out printed lists during the growing season which are transcribed in intervals to the according spreadsheets for further processing. The evaluation of the data happens three times a year. Once in the middle of the growing season to assess midterm performance and possible adjustments. Once at the end of season to assess overall output and in the winter a deeper analysis follows to further understand interconnection, shortcomings and improvements needed for the next growing season.

Also, many other parameters must be monitored as shown in **Figure 6.14**. An in-depth analysis of this would go beyond the scope of this report but are mentioned here briefly for the sake of completeness. Pest monitoring and intervention decisions are one of the most challenging parameters due to the knowledge required and often uncertain diagnosis of the problem cause. While it can have high impacts on the successes of the growing season. Further, time tracking is important to create production plans that don't exert excessive strain on the crew leading to mismanagement, a bad working environment and finally discrepancies from the two high set seasonal goals.

The monitoring for the agricultural site is challenging due to accuracy and continuity needed for consistent data sets (**Figure 6.14**). This antagonizes the working reality in the field where the problems tend to add up during the season and on the other hand mind and body fatigue steadily increases. We have observed the

This project has received funding from
the European Union's Horizon 2020
Research and Innovation Programme
under Grant Agreement No 776643

following reoccurring main issue: shifting attention from holistic to micromanagement of occurring problems. Which means that during the season it becomes more important to react for example to a failing crop, while failing proper monitoring due to the lack of time, which was invested in a more pressing problem. In a short-sighted view, this occurs to be correct, but it creates huge problems down the line when the monitoring data must be evaluated and analysed. Also, it slows down the overall progress of the farm due to the lack of an informed decision-making process. Another difficulty lays in the training of the employees, which in many cases starts without any education in farming. This leads to a high information density that must be learned in a short period of time and errors occur due to ignorance, misunderstandings, and personal evaluation of prioritizing tasks. Other problems are caused by mishandling, losing and unreadable monitoring lists.

Certain aspects of the monitoring system must change over time and parameters must be adjusted, which creates backwards inconsistencies. For example, the way certain crops are measured was changed from pieces to mass. This creates a certain error in the long-term data comparison. Adaptations in the monitoring system are necessary due to changing conditions and parameters but must be carefully evaluated for their impact on overall consistency.

Figure 6.14: Monitoring parameters

Measures and actions for soil improvement

In an organic growing setting soil health has to be seen as the foundation for most aspects related to long term successful crop production. HYDRO6 has in cooperated many of the widely recognised measurements to sustain and improve soil health. The overall management practices focused on techniques and principles to balance cultivation methods, variety and crop yields with the requirements imposed by organic soil management. The different methods are summarized in **Table 6.3**.

Table 6.3: Soil health management

Soil improvement measures	No-till to non-inversion tillage	constant soil cover	cover cropping, green manure	mulching	compost application	compost tea injection	fertigation
advantage	stimulates soil life, improves soil structure, increased capillary action, reduced fuel consumption, erosion reduction, increased water retention, decreased runoff, less compaction	increases soil biom, reduced erosion, complimentary to no-till, broad ecosystem support , increased biodiversity	increased bio diversity, increased mineralization, fostering natural accumulation of nutrients	weed suppression, reduced evaporation, nutrient release, insulating, reduced erosion, pest control, esthetical pleasing	enhances soil structure, mineralisation of nutrients, supports soil biom, increased water retention, carbon sequestration	increased soil water retention, improved soil fertility, reduced reliance on chemical pesticides and fertilizers	enhances nutrient use efficiency, fast response to deficiencies, reduces leaching, low work load
disadvantage	could promote fungal diseases, long term effect,steep learning curve	seed cost, another labor step, management	seed cost, another labor step, management strategy	can increase some pests	high work load, material need, land use, slow process	variations in quality per batch, workload, time critical	clogging of drip emitters, initial cost, increased maintenance
tools	broad fork	seeder, crop planning, tarps	seeder, crop planning	wood chipper, manual	compost piles	dosing pump, air pump, nets	dosing pump, drip irrigation

The main practices put forward are no-till or non-inversive tillage carried out with a specialised tool called broad fork, which has forks that are dunked into the ground and slightly tilted so that channels are opened, and oxygen can reach into lower soil layers. This is carried out two times a year on all the vegetable beds and as required at the herbs. A constant ground cover is maintained by either dense crop cover, cover cropping, green manure, mulching or in cases where necessary with tarps. All these practices point to a mimicry of an intact ecosystem, where bare exposed soil is solemnly found in nature contrary to prevailing agricultural systems. Fostering the complex interactions in the soil food web. By providing a diverse plant cover, consisting out of cash crops, crops with functions such as nitrogen fixation, loosening soil functions such as plants with tap roots, allelopathy functions such as Marry golds (tangetes erecta) against root knot Nematodes (Meloidogyne spp.), a generally divers root system releasing root exudates supporting different trophic levels of the soil biome and increasing carbon sequestration through constant plant growth.

Another important practice is the on-site production of different composts. Considering the effort and importance of this action, a detailed description follows below. A derived product from the composting process is compost tea and extract. It is produced by extracting beneficial microorganisms like bacteria, fungi, protozoa, nematodes etc. from a mature compost through a so-called brewing process. The final product can be applied as foliage spray or for soil improvement by injecting it into the irrigation system with the help of dosage pump. With the dosage pump it is also possible to apply plant nutrients directly in water soluble form to the plant in case of any observed deficiency.

As described, most of the practices target a rich and diverse life in the soil and its supporting functions for a healthy thriving crop development. The idea is that management practices can be carried out on site with materials derived from the ecosystem itself. This reduces greatly the external inputs and reliance on specialised expensive imported products. Also, it supports the indigenous microorganisms adapted to the micro conditions on site rather than importing similar microorganisms found in agricultural products. Through the gained experiences and observation throughout the last four years, it can be stated that the benefits cannot be attributed to a single practice but to the complex interaction of the whole strategy.

Composting

Composting was an essential part of the ELT gardens also before the HYDROUSA project, but the intensified production of vegetables also called for improvements in the composting systems. Composting is the main part of the organic matter loop and matter input within the system. ELT established a pilot trial with one of the restaurant's owners to address the organic matter loss through the external outlet. The idea is to identify the parts of the crop that are really processed within the kitchen and the ones that are finally disposed. The unused parts are cut off at ELT to avoid unnecessary loss of organic matter and transport weight. Also, all kitchen scraps were recollected from the kitchen and reefed into the composting process. This created a good back flow of organic matter because the kitchen processes also non-ELT organic matter though the inflow was higher than the loss. This was possible due to an on-sight visit from the whole restaurant crew in early spring when many basic problems of organic production were discussed, and the kitchen team wanted to address the organic matter problem and organize a solution. It is basically the extension of the farm to table idea to the loop: "from farm to table and table to farm".

Another import comes as cow manure from a neighboured farm that gladly sponsors the material. As the whole HYDRO6 system develops the amount of bush, herb, grape, green clippings and other organic material produced within itself increases the yearly organic material for further processing.

All of these materials are processed in three ways or a combination of these. The first is a traditional hot composting pile system that is monitored for its heat development in every one of the three turning cycles (**Figure 6.15**). The second is a static pile process called Johnson–Su Composting Bioreactor and has the advantage of being less labour intensive with the downside of longer process time, around 6-12 months. The third is Vermicomposting which depends on the red wiggler (*Eisenia fetida*) earth worm to digest green material or already otherwise composted material into Vermicast.

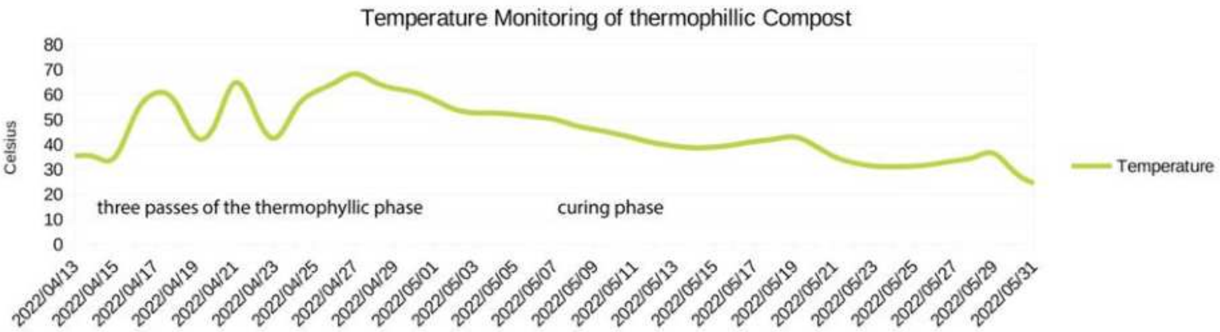

Figure 6.15: Thermophilic Compost Monitoring

Another important input is woody material that comes from neighbouring Olive and grape plantations. It is chipped on-site and used for mulching the pathways in between the vegetable rows and the herb plantation. It acts as a weed suppressor, reduces bare soil, and slowly decomposes, enriching the soil.

The overall compost production has increased significantly over the duration of the project. At the time being, it is fully integrated into the agricultural workflows allowing for a production in 2021-23 of around 10 m^3 of final compost, (**Figure 6.16**).

Figure 6.16: Compost production and application

Water usage

In order to increase the water efficiency, HYDRO6 agricultural area was designed to utilize drip irrigation to the biggest possible extent. The different agricultural plots are divided into irrigation zones that can be controlled independently. The plots with high water demands are subdivided into smaller irrigation zones to increase the irrigation precision. Especially in the market garden areas an irrigation control per bed is beneficial due to the constantly changing cultivation and usage pattern. The Greenhouse, Herbs, Grapes, and trees are automated and controlled by an irrigation computer. The open field vegetable plots are controlled by manual irrigation and fine-tuned with the help of daily observation and soil moisture sensors. The agricultural water consumption graph shows the monitored water demand of the different cultivations by month for 2022 (**Figure 6.17**).

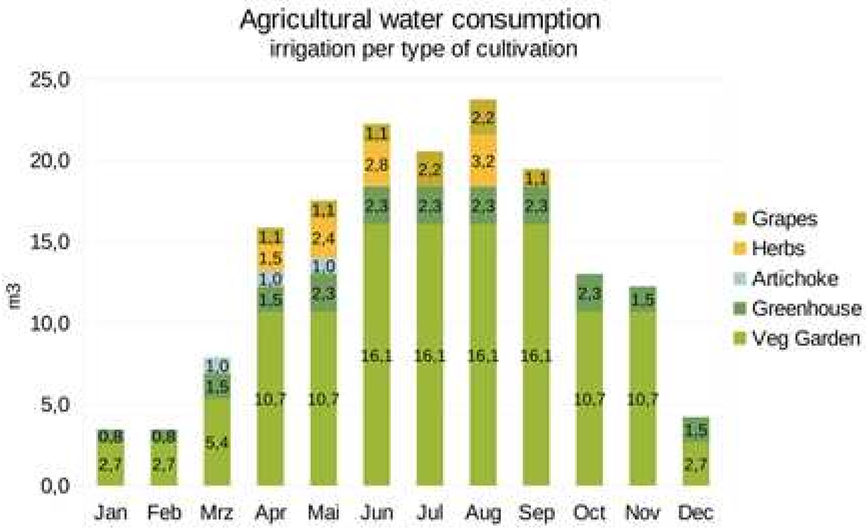

Figure 6.17: Water consumption of the different crops

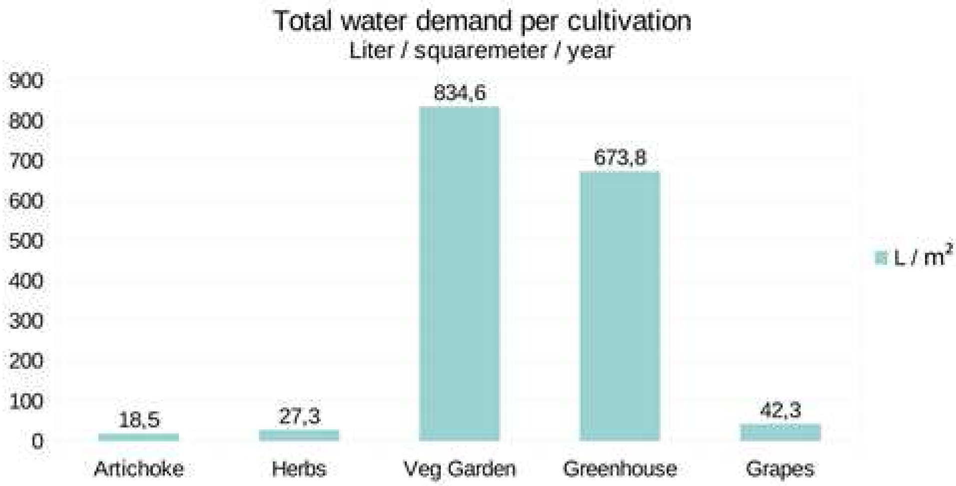

Figure 6.18: Water demand of the different crops by area

Vegetable production has the highest water demand within the agricultural system. The water consumption is even a bit higher because the plant propagation, the first days of direct seeding and the service water for cleaning and washing is not captured in the data. Due to the cash crop character of the vegetables, the soil moisture is kept at optimal levels to avoid water stress which could potentially reduce the overall yield and influence the crop quality. In the rest of the cultivation's a deficiency irrigation scheme was applied in order to reduce overall water demand. In the grape and herb sector this can be seen as beneficial to the derived product quality due to higher concentration of aromas and active substances. Also, the adaptation of these plants to water stress is much higher due to their origin.

Figure 6.18 shows the water utilisation per square meter in the main crops over the year. These results in a product water use (PWU) of 118 L/kg and a water use efficiency (WUE) of 0.0084 kg/L for the mixed vegetable production. Published data on PWU from water footprint network state for a mixed cultivation consisting out of tomatoes, cabbage, lettuce, cauliflower, spinach, and carrots an average of 160,3 litter/kg. This data is not especially for the Mediterranean region but rather a world average.

6.4 Comparative yields

Overall Crop yield

The overall yields were increased in every growing season from 2019-22 as shown in the **graph** below. The two main cultivation practices, consisting of open fields and greenhouse production, were monitored independently. Some crops were measured in grams and others in pieces or bunches (**Figure 6.19**) depending on the common local market unit.

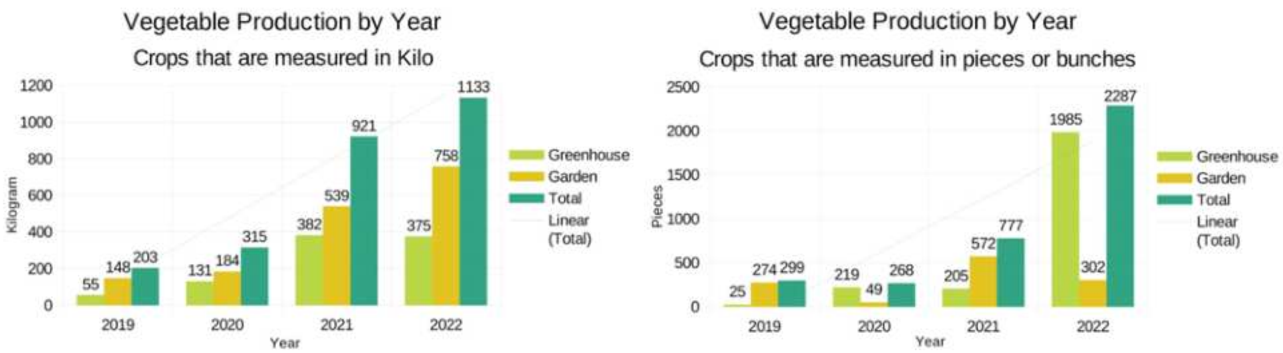

Figure 6.19: Vegetable production per year

Most crops that were recorded in pieces or bunches were grown outside and consist mainly of salad heads and fresh kitchen spices like parsley, chives, dill etc. and Mediterranean herbs like Oregano, thyme etc. Within HYDRO6 it was possible to increase the production by a factor of 5.5 compared to the initial overall production from 2019 to 2022. This shows that the gain of knowledge, the right crop type and cultivar together with the slow process of improving the overall conditions like soil, crop rotation, irrigation etc. led to an overall increase in production and plant health.

Figure 6.20 shows the total production over the entire growing season for the years 2019 to 2022. The Black curve shows an optimal production as anticipated by ELT, considering its current knowledge, market and available resources. Looking at **the first season,** production started late in May with a fast rise and peaked in June for a short period, then flattened out through July to mid-August and afterwards declined heavily from September to December. In both cases the lack of knowledge about production timing, time to harvest, harvesting time span and actual capacity lead to an unbalanced and insufficient timed production.

In **2021,** as described above, ELT managed to establish a crop plan based on the collected data and experiences from the previous seasons. The curve shows a nice steady increase from March to mid-June, peaking in July, decreasing fast in August, and picking up again from September to the end of the season. The decrease in August was caused by two factors. The first one was a heavy focus on the spring period with still inadequate experience of harvest time spans for certain crops that declining faster than anticipated and the second factor was the exhaustion of the crew after 5 months of constant hard work in the field. The positive part was that the declining production was realised early on, and new plants and seedlings could be established for a high autumn yield.

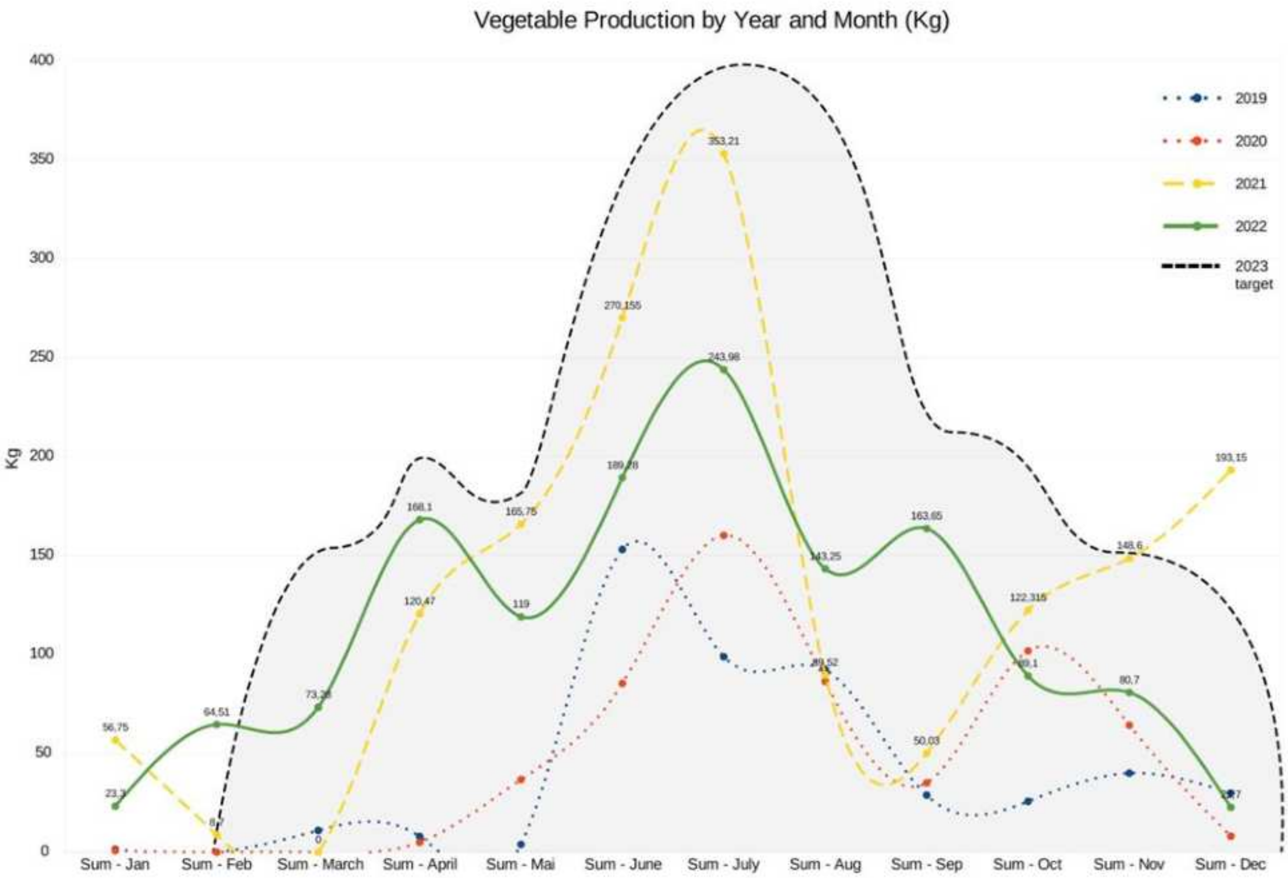

Figure 6.20: Total vegetable production by season and month

2022 shows the best growing season so far with a slow increase from January on meeting the first high production target for Greek eastern around April, lowering slowly till the start of the touristic season and picking up till July. Through August, production could not be maintained at this high level and decreased as in any previous season but not as dramatically. A fairly positive September was managed with a slow decrease as the tourist season ended and Vegetable Boxes maintained the market outlet. In every season it was observed that August is the most problematic month. In our analyses there come several factors into play such as difficult environmental conditions with high sun radiation, high water stress, low water availability, strong north winds and peaking pest pressure. Also, the crew fatigue on the physical level as well as the psychological exhaustion from constant trouble shooting, failing crops and pressure form set goals come into play. Nevertheless, for the first time the planned production could be achieved over wide periods of the growing season and real progress in the overall management where made.

Crop yield specifics

In this section the data monitoring is shown for the Tomato and Cucumbers cultivation as an example. In 2019, a total of 12 tomato varieties were cultivated with a production of 112 kg. In 2020 a total of 8 varieties were grown with a production of 90 kg. In 2021 only 6 varieties were cultivated with a production of 386 kg. **Figure 6.21** shows the production by tomato type and cultivar throughout the last three growing seasons and the totals per season in turquoise. So, an overall of 26 different tomato cultivars were tested and selected for yield, growth habit, plant health and taste as an important factor within a small-scale production.

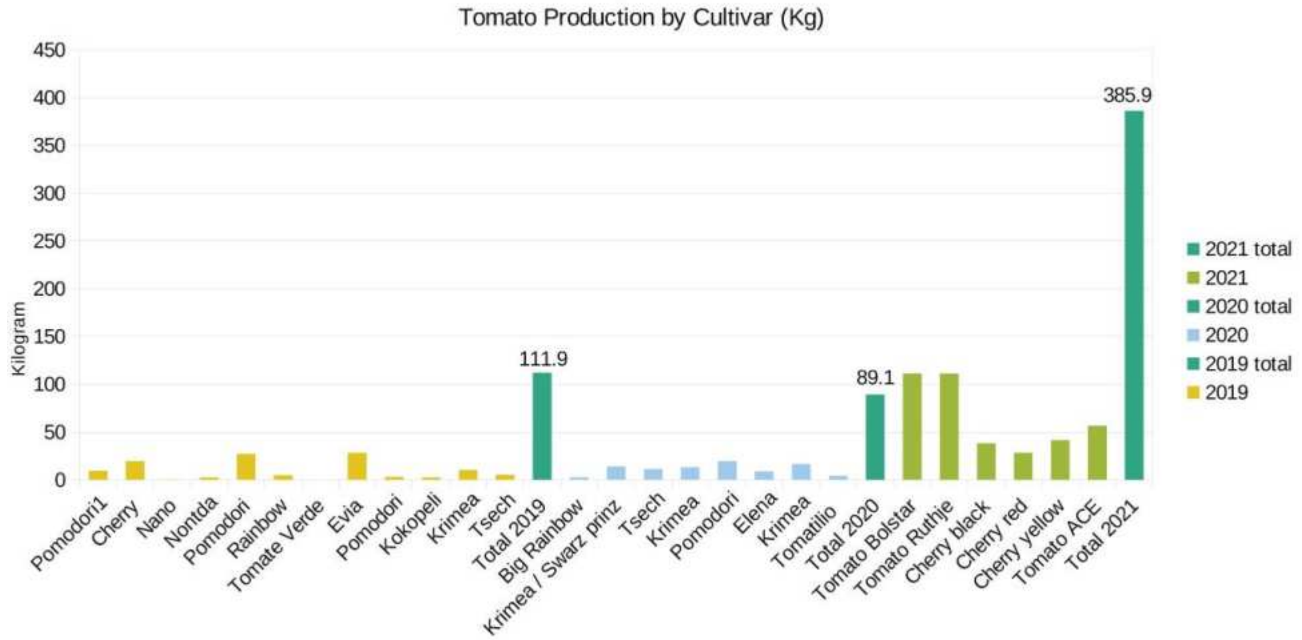

Figure 6.21: Tomato production by variety

Within tomato cultivation there are two different growing methods consisting of the Greenhouse and the open field production. Both methods were in use on site and were recorded separately due to their difference in possible production rate. **Figure 6.22** shows the total production by year in kilograms. The totals as performance indicator must be treated with care because it is not rendering the number of plants that produced the overall yield.

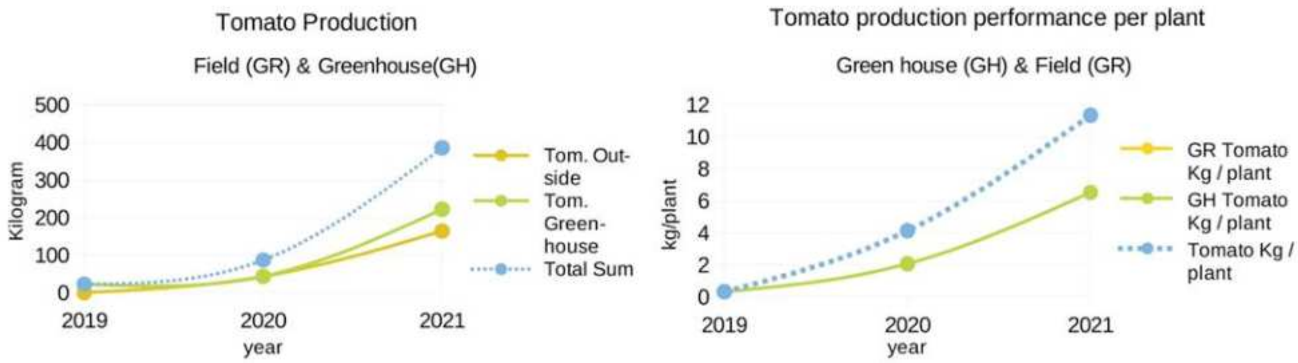

Figure 6.22: Tomato production performance

The best performance indicator is the yield per plant that is rendered in the graph above for the tomato cultivation in open field (GR), the greenhouse production (GH) and the combined value of both methods. In this way it shows that the yield increase was continuous, and HYDRO6 reached satisfactory levels with **6.5 kg/plant in the greenhouse, 1.4 kg/plant in the open field and an overall 2.5 kg/plant**.

Similar results can be shown for cucumber production where the production was unsatisfactory in 2019 with 0.67 kg/plant but was improved to good levels in 2021 with **4.8 kg/plant** as shown in **Figure 6.23** below.

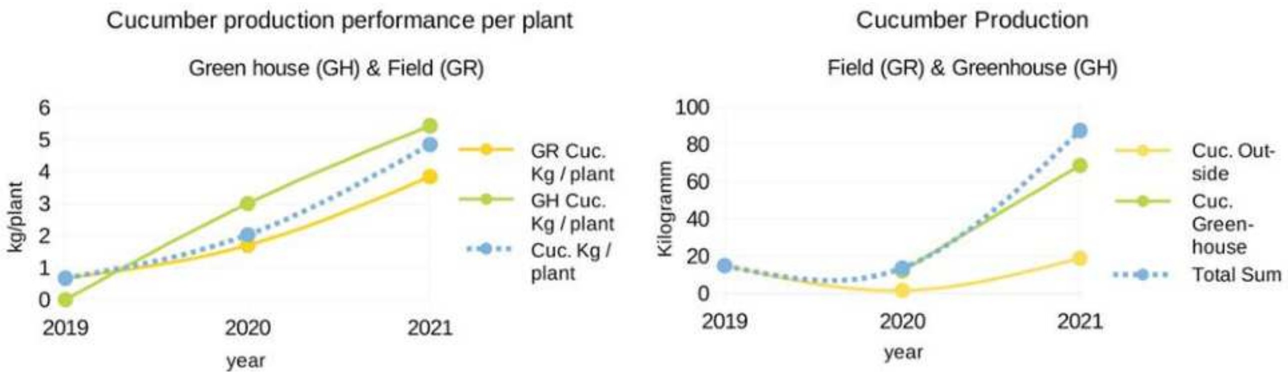

Figure 6.23: Cucumber production performance

In the market garden approach of HYDRO6, one of the most important and on the other hand most difficult parameters to achieve, is planning the availability of any given crop over the season and the right amounts that can be deployed through the market outlet of ELT. The different crops and cultivars were also recorded according to their productive period and the yield distribution within this time frame. Analysing this data is important for the yield planning for the season and the cultivar used within a given time. **Figure 6.24** below shows the production rate for all cultivated open field varieties in 2019 and 21 according to their productivity over the productive period.

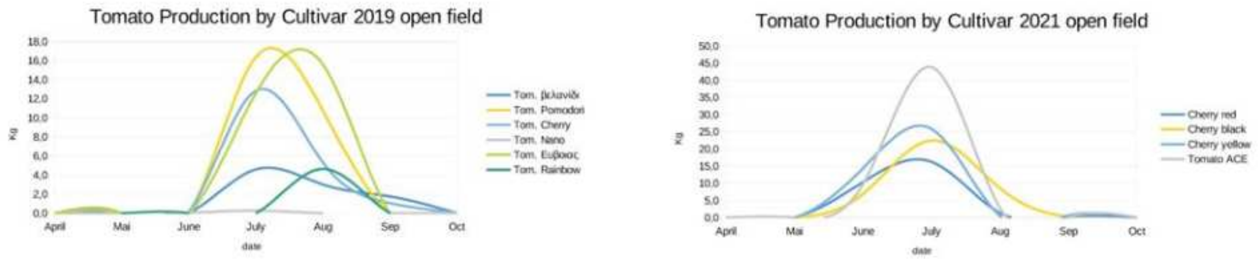

Figure 6.24: Tomato production by variety 2019 and 2021

It can be shown here exemplary for the tomato cultivation that monitoring of a certain set of parameters is favourable to analyse, learn and improve the cultivation methods in order to increase production, while maintaining a biointensive approach.

Yield comparisons with published data is difficult, since the intensive mixed cropping offers a good overall harvest quantity per m^2 with an average production of approx. **6 kg/m^2/year** for the market garden. Each individual crop by itself is less than in monocultural cropping systems and official statistical data reflect an average of open field and greenhouse production mainly from conventionally practices including hydroponics, aquaponics, artificial lighting, and heating. Taste and variety are valued over quantity. Off-season cultivation of mixed crops is practiced as well to ensure a steady supply year-round, which sometimes is not conductive for maximum harvest weight output. There is no specific KPI on the crop yields for HYDRO6.

6.5 Valorisation and derived products

The main valorisation path for agricultural production is the direct marketing and delivery approach ELT has chosen to market the variety of agricultural products. Here the beneficial relationship between consumer and producer is the main added value. This follows from the direct communication of the consumer needs like quality, variety, amounts, transparency in the cultivation methods and the resulting dialogue explaining the constraints of agricultural production within the given setting. Another benefit is the higher income stream caused by the elimination of the “middleman” like intermediary distributors and buyers. Another benefit that strengthens this relationship is the delivery of the ordered products, which gives a weekly possibility for ordering on demand and expressing positive and negative feedback. Many of the end-user comments can be directly evaluated and many times addressed within the next weeks leading to a participatory relation where both parties feel perceived and taken care of.

Figure 6.25: HYDRO6 Boxes with mixed selections

The vegetable box delivery scheme started out of the need to market an overproduction in winter 2020. The overall perception was so positive that it slowly increased. HYDRO6 has produced and delivered a total of 715 Veggy boxes to end-users (of around 30 people). The boxes are kept and returned by the end-users every time an order is placed. There is very little to no extra packaging material involved, reducing greatly the amount of plastic consumed compared to typical shopping from a supermarket. The number of boxes is constant and mainly limited by the production capacity of ELT **(Figure 6.26)**.

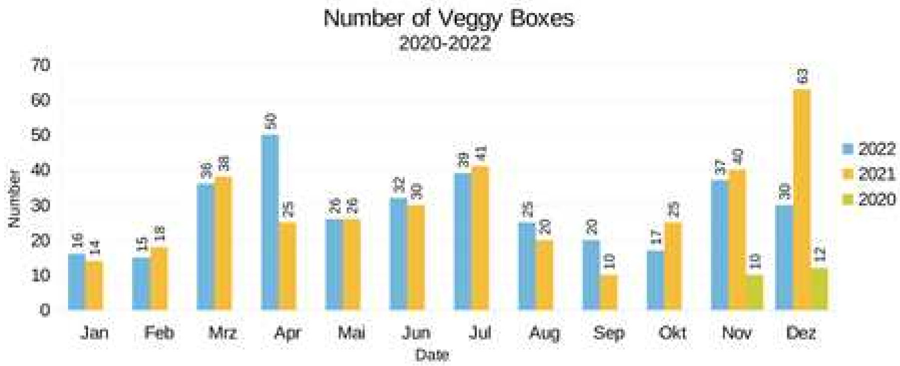

Figure 6.26: Veggie box deliveries in pieces for 2020 till 2022

The income generated by the boxes is on average 275 € per month for the period of 26 months that this activity takes place. The consumers show a certain fluctuation in their consumption pattern throughout the year, especially in the first two months of the year where many islanders take outside holidays. August and September are lower unassumingly due to the high workload of the main occupation of the islanders in tourism which reduces the time for daily fresh cooking. The turnover by month can be seen in **Figure 6.27** below.

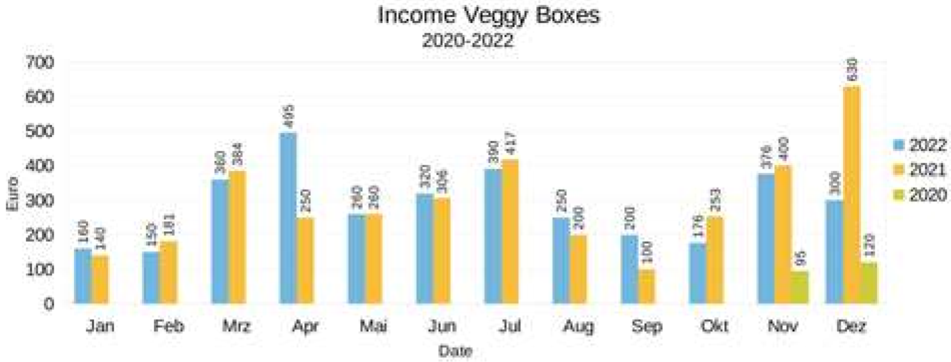

Figure 6.27: Turnover by boxes

The cooperation with the Restaurants has steadily increased from one during 2020 up to six in 2022. With the increased understanding of the market and the special needs of the restaurant supply it was possible to form very good trustworthy relationships throughout time. Special orders for certain crops are placed and considered in the crop planning in order to empower the end-users to serve certain dishes based on this crop variety.

The restaurants follow closely the pattern of the touristic season and increase their orders accordingly. Many businesses close for the winter period and restart in the beginning of spring. The average turnover generated by this activity was 507 € per month over a period of 18 months (**Figure 6.28**). The performance increase becomes clearly visible in the 2022 season, where it was possible to increase turnover to 792 € compared to 2021 with 378 €.

Figure 6.28: Turnover from restaurants

As described previously it was not only possible to increase the overall production of the market garden but also to find the according market outlets. The gross turnover could be increased by 540% from 2020 to 2022. Where a year-to-year growth would be 279% from 2020 to 2021 and 69% from 2021 to 2022 (**Figure 6.29**).

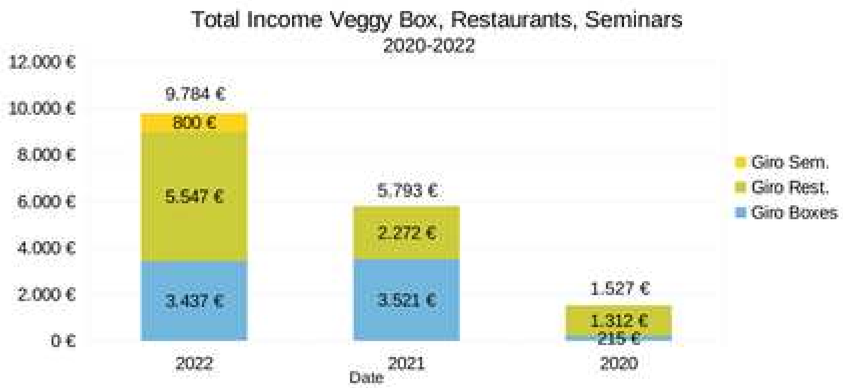

Figure 6.29: Gross income by market outlet

It seems also interesting to compare the gross income to the cultivated area over time to derive a value in euros per square meter. This allows us to observe the overall performance and gives a good indication of the area needed to fulfil certain financial targets. **Figure 6.30** shows the total cultivated area for vegetable production and the according €/m^2 for the duration of three years. In 2020 the gross income was 14.4 €/m^2 which is low but seems logical considering the new activity managed by a motivated but inexperienced crew within the difficult setting of the Cycladic environment. The gained experiences described earlier on, led to an increase in performance by 151% to 36.2 €/m^2 in 2021. The generally good reception of the produce by the market, the increased soil lives and SOM, the increase in diversity and the by now well-trained managing and ground crew made it possible to achieve in 2022 a total of 54.45 €/m^2.

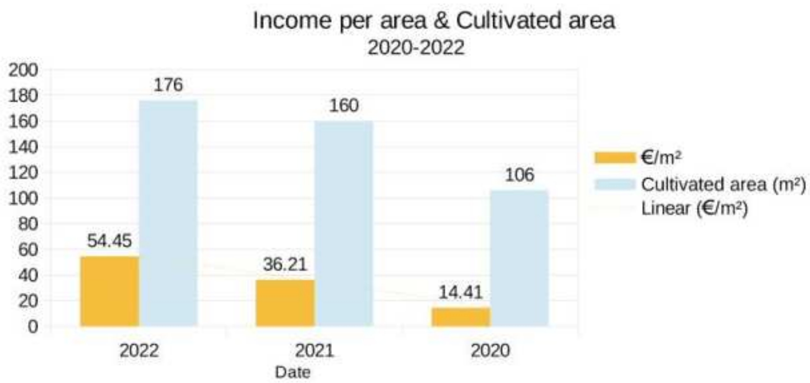

Figure 6.30: Performance indicator

It is difficult to find literature data on the market garden approach, which is important if trying to benchmark performance indicators for HYDRO6 with similar agricultural systems. Comparable data was found in a survey of Austrian market gardeners carried out by Bionet and FiBL in 2020. The survey states 2.7 € in the minimum and 37.2 € in the maximum income per square meter range. Another study performed by Kevin Morel showed after a two-year survey of the same farm a gross income of 54.3 €/m^2 could be obtained by the farmer. This comparative data shows that HYDRO6 is performing at the high end of the literature data after an initial setup time of one and a half years.

7. CONCLUSIONS

All the demo sites offered particularly interesting results. In general, the concepts of using sustainable water sources for agricultural activities proved to be technically feasible and agricultural production was successful. It is understood that some problems arose and sometimes some estimates and assumptions attempted at the beginning had to be corrected when practical issues arose or when unexpected contingencies (such as a global Covid pandemic) affected the demo site activities. The logistics of providing equipment, materials and plant material to some island locations proved to be a challenge that required quite some effort to overcome.

The cost analysis as well as return on investment studies may show that economically it may be difficult to compete against off-island imports produced with more favourable conditions and conventional practices. But there are definitely some viable opportunities that could be uncovered.

The challenge is rather twofold. Conventionally, grown production, often in monoculture and perhaps subvention agriculture externalizes environmental and human health factors. On the other hand, locally sustainably grown organic production needs to receive a premium price, so that in effect it internalizes the cost of reduced environmental harm and of practices that strengthen ecosystem services of the cultivated areas. One way to address this unfair competitive price disadvantage is to make the whole story behind the sustainable products visible to consumers, as well as pointing out the health and tastiness advantages. It is difficult to quantify the ecosystem benefits economically.

Policy makers and decision makers could also offer incentives and aids for sustainably grown local organic produce, especially if this means the stress on local freshwater resources is reduced, as well as the needs to invest in fresh-water provision infrastructure are reduced. There are some win-win strategies to be found between local administrations, public budgets and stimulating sustainable local farming practices with sustainable irrigation water sources. Benefits for climate change amelioration and resilience could also be derived.

The use of reclaimed water from municipal wastewater treatment plant effluents for agricultural irrigation proved to be highly successful and positive for nutrient balance. And this is no scientific mystery. It is just of great importance to monitor and eliminate biological health risks for workers and consumers. This is a manageable technical challenge. If this requirement is met, it can be wholeheartedly recommended that this practice be established as common practice. UN and EU recommendations or efforts already try to suggest this type of use for water resources. It is often national and regional regulations that still make this practice difficult or impossible and also public perception needs to be informed and educated better in this regard.

The rainwater collection and storage strategies may offer an affordable sustainable water strategy within reach of smaller farmers, that could extend the growing season of many summer-arid regions by some months and increase yield expectations. Having specialized companies offering advice, components or turn-key solutions could greatly enhance wider adoption with many benefits to the environment and society. A key contribution this project managed to provide in the HYDRO3 and HYDRO4 sites was to uncover some of the key challenges faced by Oregano and Lavender crops on Mykonos and showing viable solutions. The acceptance of the local market, driven by high tourism activity, for added value products based on these crops is also an important contribution for wider adoption of the production technologies.

The solar desalination technology called Mangrove Still System offers a sustainable and reliable freshwater source that conveniently has its highest output when it is sunny and hot in summer. Worldwide distribution is feasible, but the training of local technicians will be necessary. Proximity to the sea or other salty water sources is necessary for best cost effectiveness and reduced energy demand for pumping water over distances.

The organic mixed cropping strategies pursued by HYDRO2, HYDRO5 and HYDRO6 led to the production of a rich variety of crops. This appears very advantageous for islands catering to touristic activity that want to offer a rich and tasty culinary variety to visitors. That way the race for lowest prices can be contained. This also brings benefits in soil health, biodiversity and resilience of systems. Particularly the mix of trees and perennials with annual or vegetable crops like in the agroforestry system of HYDRO2 has great environmental benefits as it increases the ecosystem services of the cultivated land greatly and counteracts desertification. The organic mixed cropping practice of HYDRO6 in the otherwise rather baren hills of that Tinos Island location appears to actually contribute more biodiversity to the area and certainly improves soil fertility. This can be considered an example of human activity and human land management, including agriculture, that actually enriches an area that has suffered historical deforestation.

The tropical fruit production demonstrated in HYDRO5 shows that the agricultural production of Greek semi-arid islands can be enriched with some exotic tropical crops. The reliable sunshine even in winter is enough to keep a simple greenhouse within temperature ranges that are tolerable for tropical plants. This may help to add more touristic interest to the island, replace imports with a long transport tail and offer further business opportunities for locals. The need for fairly large greenhouses, sustainable water sources and irrigation infrastructure makes it a somewhat capital-intensive proposition and some training for farmers and technology transfer to adopters will be necessary.

The smart soil humidity-based irrigation system management from AGENSO used in different demonstration sites shows that the valuable and limited irrigation water resources can be used more efficiently thanks to this technology. Particularly if larger areas are put under irrigation and year-round production, the water savings offered by this solution are very meaningful.