Interreg
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Hy4Dense
European Regional Development Fund

Technical Economic Social Feasibility study

Of a novel hydroponic system for densely sown crops

Written by the Hy4Dense partnership

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2 Introduction

Hydroponics benefits growers through increased productivity and improved, efficient management of crop cultivation while controlling diseases that impact yield and revenue. More than 90% of greenhouse cultivation of fruit vegetables has shifted to hydroponics. However, for densely sown leafy crops such as lamb's lettuce, spinach and rocket, a suitable hydroponic system is still not widely available or taken up by growers and the sector in general. Therefore, in the **Interreg 2Seas project Hy4Dense** (project no. 2S05-030) a novel hydroponic system for densely sown crops has been developed.

The need for less residues and desire to increase production leads worldwide to a shift towards hydroponics. In addition, soil bound cultivation faces different challenges. There is increased pathogen pressure due to more resistant pathogen strains for which currently allowed pesticides are not always effective. Furthermore, targets set by European Commission to reduce the use and risk from pesticides by 50% by 2030 together with strict demands to reduce pesticide residues on fruits and vegetables by the retailers will make it nearly impossible to grow densely sown crops in soil in the future.

This **technical economic social feasibility study** aims to compare the traditional in soil cultivation to the novel hydroponic system developed in the project. Results from this study will provide growers and manufacturers data on investments, operational costs, yield prospects and potential revenue of the different systems. This will allow growers and manufacturers to gain insight on the benefits of the system, but also on potential areas in which optimisation is still needed.

The two systems will be compared for different aspects like yield, time usage, operational costs and investments costs. This will include data for lamb's lettuce, spinach and rocket studied in the Hy4Dense project. Each of the different aspects will be evaluated from different perspectives:

- Technical perspective: is the level of technical difficulty increased or does it require more technical knowledge?
- Economical perspective: what costs are associated with the new system?
- Social perspective: does the new system bring more or less uncertainties for growers, is the new form of growing and exploitation more stressful,…

Figure 1 Traditional in soil cultivation of lamb's lettuce

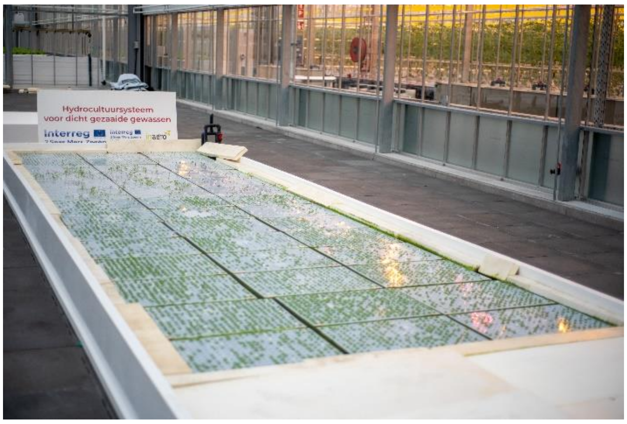


Figure 2: Novel hydroponic system for densely sown crops

3 Methodology

In this technical economic social feasibility study a comparison of a traditional in soil cultivation of lamb's lettuce, spinach and rocket is compared with the new hydroponic system developed in the Hy4Dense project.

The **data on the in soil cultivation** is collected by the partnership's own **farmers' network**. Data presented in this document are an average of their responses.

- Lamb's lettuce: data from Belgian growers. Lamb's lettuce in Belgium is overall grown in glass and plastic greenhouses. The data therefore is a reflection of these types of growing conditions.
- Spinach: data from Dutch growers. Spinach in The Netherlands is overall grown in open field. The data therefore is a reflection of this type of growing condition.
- Rocket: no data could be collected by the farmer network in the UK

The **data on the new hydroponic cultivation** is collected by the partnership during **trials on the pilot systems**. The data presented in this document are an average of multiple harvests of different experiments. It should be noted that the new systems were developed in a research setting and therefore scale effects, automatization and further optimization are not fully taken into account in this analysis.

- Lamb's lettuce: Data from lamb's lettuce trails during the project and with the pilot system at Inagro (Agrotopia) – pilot system 2 in §4.
- Spinach: Data from Spinach trails during the project and with the pilot system at Vertify – pilot system 1 on §4.
- Rocket data: Data from Rocket trials during the project collected on the two pilot systems at NIAB – see also pilot system 3 and 4 in §4.

4 Capital expenditure: Hydroponic systems

Four pilot systems were set up. Three of them consists of two main parts: (i) a deep float bins in which water with nutrients is added; and (ii) floaters to support the seeds during germination and cultivation until harvest. Additionally, a modified ebb and flow system was also tested during the project to support the floaters.

All of the pilot sites use the same floaters designed during the first years of the project. The deep float bins are slight different in design and structure, because they were adjusted to the location and were provided by local suppliers.

The systems are still small scale pilots. Therefore, scale effects are not taken into account in this study and the costs can differ from a large scale system. The costs of the floaters are the cost of a small scale production of an upscaled prototype. Upscaling and adjustments to the floaters can possibly lower the costs.

More detailed descriptions of each system are listed in the growers guide of the project.

4.1 Floater design

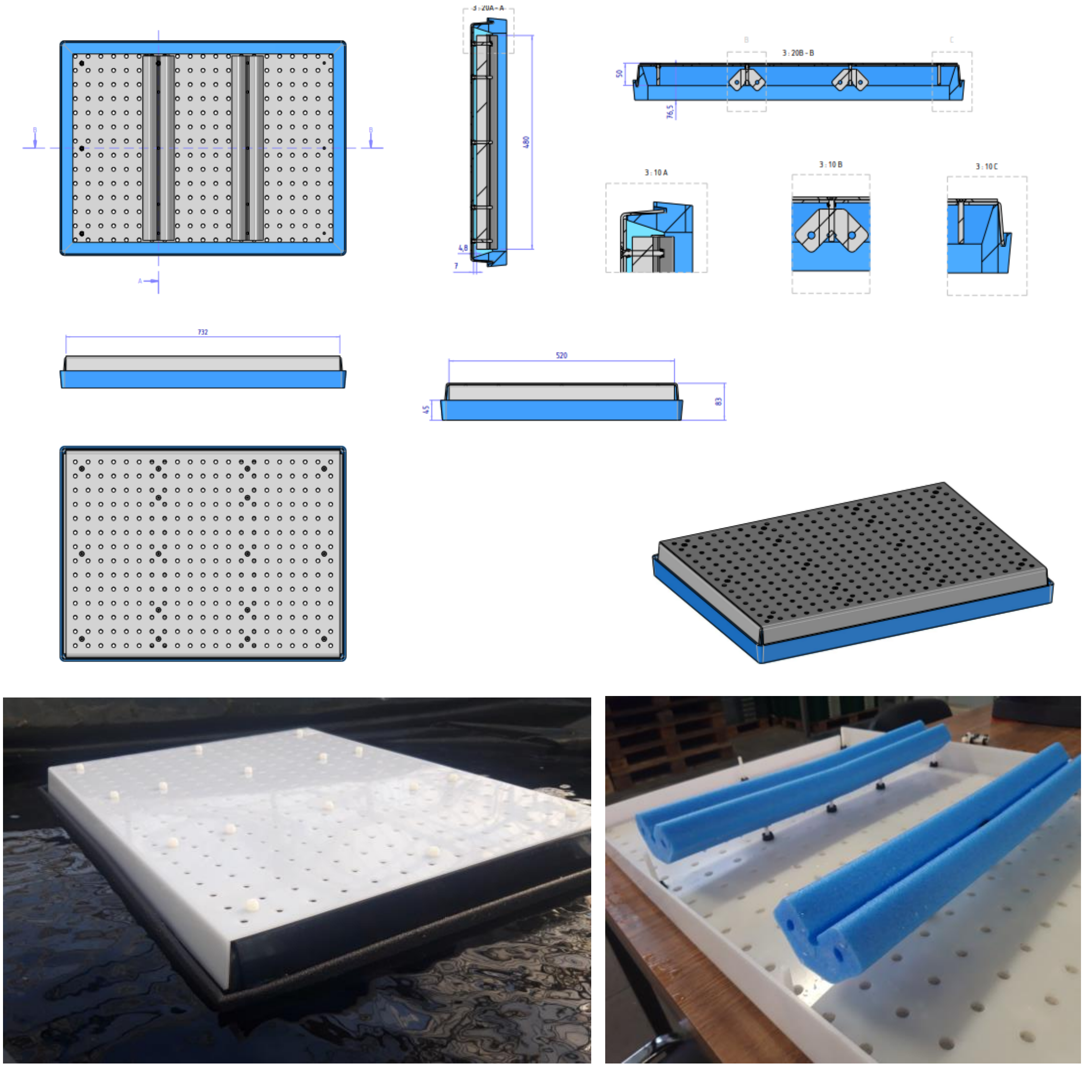


Figure 3: Floater design

The base design for the floater consists of two high density poly ethylene (HDPE) plates: a white one on top and a black one on the bottom. In between the plates there is mesh on which the seeds are sown. The size of the seeds and the thickness of the roots determine the meshsize (more detail in growers guide 2.1). The plates are supported by low density polyethylene (LDPE) profiles to make the whole able to float on the watersurface. No substrate is needed which makes this technique less costly as no substrate must be purchased or disposed of.

Trials with the floaters were too short to make an exact estimate on the expected life span of the floaters and the mesh. But based on the lifespan of similar products the estimation is that the floaters could have a lifespan of around 10 to 15 years. The mesh however is one of the weakest parts of the current design, here it is possible that the lifespan is lower than that of the rest of the floater parts. The price of the current floaters seen below are the result of a development process and semi-automated production lines. All these factors increase its pricing. For comparison the price of other leafy vegetables floaters are around 30 – 50 euro/m². With an optimised production line prices of the floaters for densely sown crops could be similar.

What	Cost (euro/m²)
Floaters	397,83

4.2 Pilot system 1 – climate chamber + DWC greenhouse (Vertify)

This system consists of two separate installations for two cultivation stages. The first stage, germination, is being done in a climate chamber (10,8m²) with artificial lighting and a misting installations to allow for sufficient humidity. After this the floaters are transferred to the greenhouse into four deep water culture bins (3,65 m x 2,03 m=7,4 m²) with no extra artificial lighting. However the last stage can also continue in the climate chamber as well.

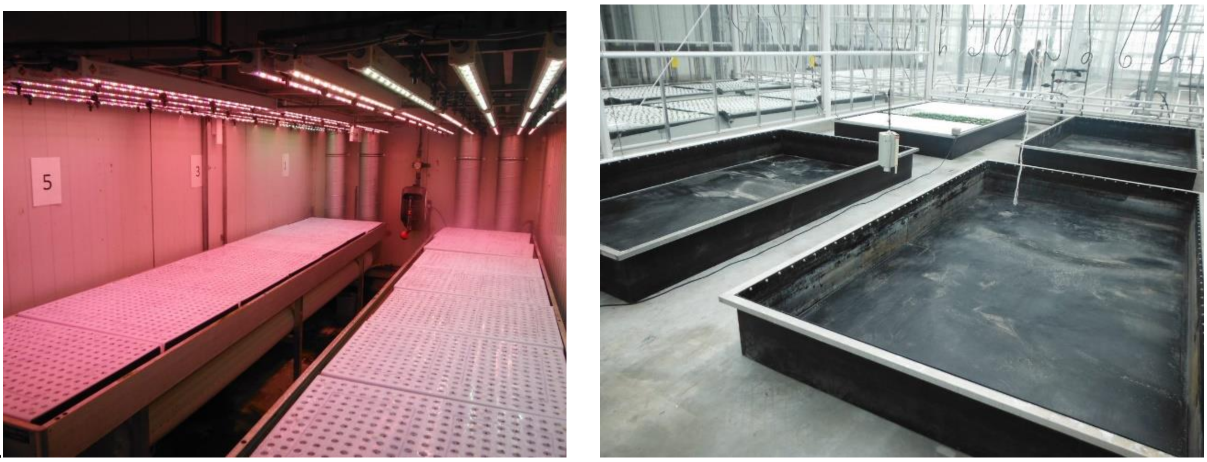


Figure 4: Base infrastructure pilot system 1- climate chamber and deep water culture bins in the greenhouse. Location: Vertify, Zwaagdijk, Netherlands

What	Cost (euro)	Cost per m²
Climate chamber with mist installation and artificial lights	/	1000*

** installation cost of multi-layered system with misting and artificial lights*

4.3 Pilot system 2 – DWC greenhouse (Inagro)

This system consists of two bins without any extra overhead irrigation or misting. The smaller one is 6.25 m² and used for germination using just rainwater. The second larger bin is about 24 m² and is set up for controlled fertigation. Both are white to reduce heat gain in the summer and contains a circulation system to maintain aeration of the water and nutrient mixture. Above the system there are Full-led toplight fixtures installed. They have a maximum output of 90 µmol/m²/s with a red/blue ratio of around 90/10.

Figure 5: Base infrastructure pilot system 2- two deep water culture bins in the greenhouse. Location: Agrotopia, Roeselare, Belgium

What	Cost (euro)	Cost per m²
Small DFT bin (6,25 m²)	2 356,20	377,99
Large DFT bin (24 m²)	7 186,80	299,45
Installation costs	1 050,00	Fixed cost

4.4 Pilot system 3 – DWC polytunnel

This system consists of 4 deep water bins (5,76 m² each) with overhead lighting and irrigation situated in a polytunnel with climate regulation done by heat pumps. The bins and overhead irrigation weren't installed by the producer but were built by the technical personnel what makes this a low budget option. However before starting the building process expert advice is advised.

Figure 6: Base infrastructure pilot system 3- deep water culture bins in in a polytunnel.
Location: NIAB, Eastern Agri-Tech Innovation Hub, United Kingdom

4.5 Pilot system 4 – ebb and flow polytunnel

This system consists of multiple ebb and flow tables (6 x 16m² = 96 m²) with overhead lighting. This novel approach was designed together with hydroponic suppliers to be easily installed by farmers. The goal was to build these in existing premises such as this plastic polytunnel, using accessible, locally sourced materials and resources. The ebb and flow tables are filled with a layer of gravel.

Figure 7: Base infrastructure pilot system 4 – ebb and flow tables in a polytunnel.
Location: NIAB, Eastern Agri-Tech Innovation Hub, United Kingdom

What	Cost (Euro)	Cost per m²
DFT + technique	14340,00	120,00

4.6 Comparison

Most growers cultivate densely sown crops in open field or in low-tech options like plastic tunnels and don't always own greenhouses (glass or plastic). For an optimal cultivation environment for hydroculture and year-round production, a greenhouse or protected environment is recommended. Therefore an investment regarding infrastructure may be needed. As the infrastructure costs of a greenhouse are outside the scope of this study, we do not take these into account in the analysis.

The investment cost of the system is highly dependent on the system itself and the amount of extra features that is desired. For example the surface area of the deep float bins, an additional climate chamber, adjustable or non-adjustable led light fixtures.

A DFT system inside a greenhouse allows the user to closely monitor parameters such as: air temperature, relative humidity, radiation, pH and EC of the nutrient solution. The additional cost is related to the desired level of control and the equipment that is already present (e.g. a climate computer). As these costs are highly user- and site-specific we only give an overview of the costs related to the pilots. For example a connection to the existing climate computer of pilot system 2 came down to 29 233, 60 euros.

5 Operational costs

5.1 Seeds

5.1.1 In soil cultivation

The choice for certain varieties is very grower-, season- and region-specific. In Table 1 an overview of these varieties and the average cost per hectare is given. However a generalization can be made per crop. For lamb's lettuce close to 90% of the cultivation today is done by the 5 varieties listed below. For spinach around 75% of production is done with the 2 cultivars.

Table 1: Overview seed variety choice in soil cultivation

Crop	Lamb's lettuce	Spinach	Wild Rocket	Salad Rocket
Cultivars	Bison Sonnet Audace Jazz Festival	El Tajin	Wasabi Sweet intensity Gusto Artemis	Uber Esmee Astra (Cheapest variety)
Average cost per ha (euro) *	150 to 170	180 to 300	100 to 300	100 to 300

(*) Cost dependable on sowing density see 3.Revenue

5.1.2 Hydroponic cultivation

The sowing density in this hydroponic system is around 75% higher for crops like lamb's lettuce (750 vs. 1400 seeds/m²). This means that more seeds are needed for sowing the same surface area which results in a higher total cost for buying seeds. So the total cost for seeds per surface area in a hydroponic system will most likely be higher without taken into account any increases in the actual seed cost.

Also varieties that are suited for the hydroponic cultivation differ from those used in soil cultivation. This is also a factor that can influence the cost of buying seeds. Typical costs now vary between 150 and 300 € per ha depending on the variety.

Another aspect that can increase the seed cost is any adjustments that could be made to facilitate automatization (such as pilling). This is discussed more in detail in *section 4 - Automatization and upscaling concepts*.

5.2 Labour costs

5.2.1 In soil cultivation

In the soil cultivation there are two ways to start the cultivation cycle: sowing or planting. The majority of densely sown crops growers chose to sow their seeds. Spinach and rocket are mostly sown. Most growers use a sowing machine for the start of their cultivation. However not every grower uses or owns an automatic harvesting machine and therefore still harvests by hand.

Having certain steps in the production automated has an enormous effect on the time use overall. In Figure 8 and Figure 9 an overview of how much time relatively is spend on certain cultivation steps is given: one time for fully automated sowing and harvesting step, one time with only the sowing step automated.

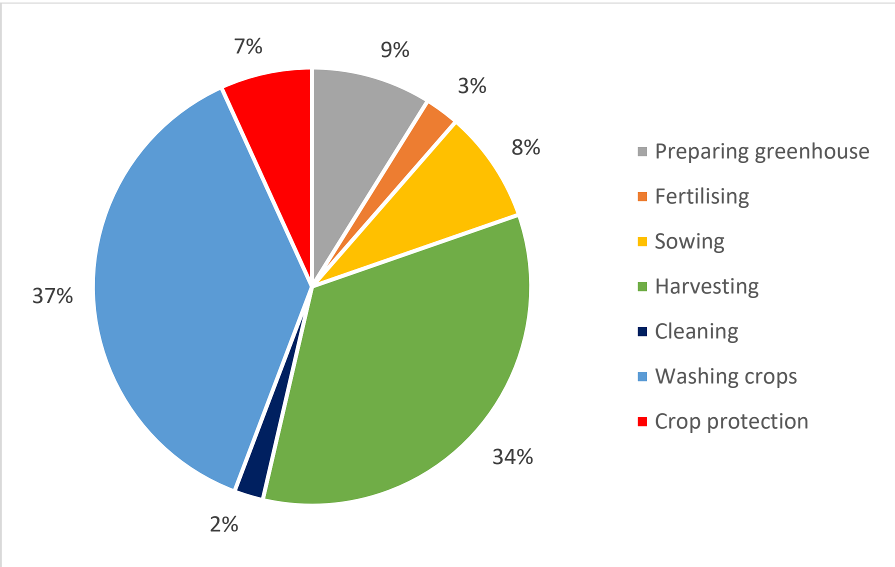


Figure 8: Overview time spent in soil production with automated harvest

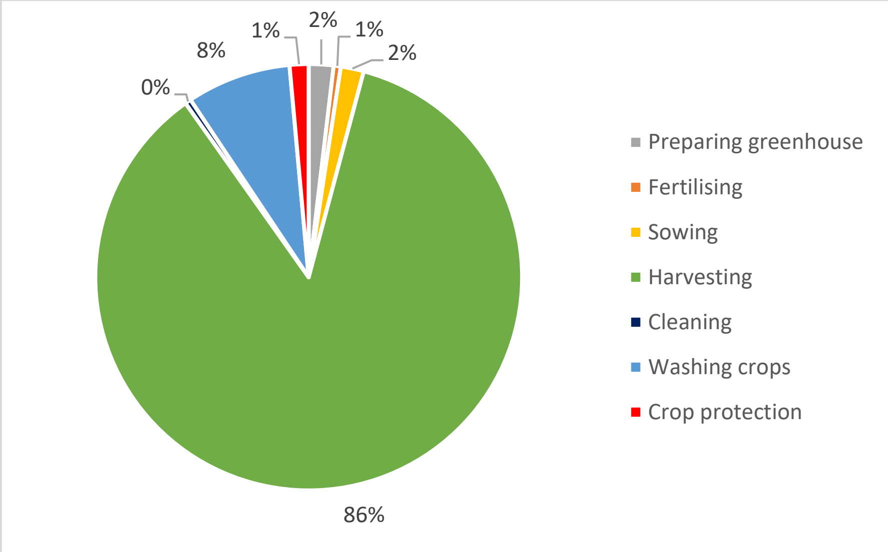


Figure 9: Overview time spent in soil production harvesting by hand

5.2.2 Hydroponic cultivation

The Hy4Dense system is a pilot system to showcase the potential of growing densely sown crops hydroponically. This entails that sowing, harvest and cleaning of the plates is still done by hand. An overview of the time spent on each task is given in Figure . There is **no usage of crop protection** products yet so there is no need for or time spent on crop protection applications and is therefore not taken up in the overview. Since this is a hydroponic system, the system and therefore the plants are totally free of soil particles, the plants don't require to be washed afterwards. However, there is always to option to add an extra washing step to enhance shelf life.

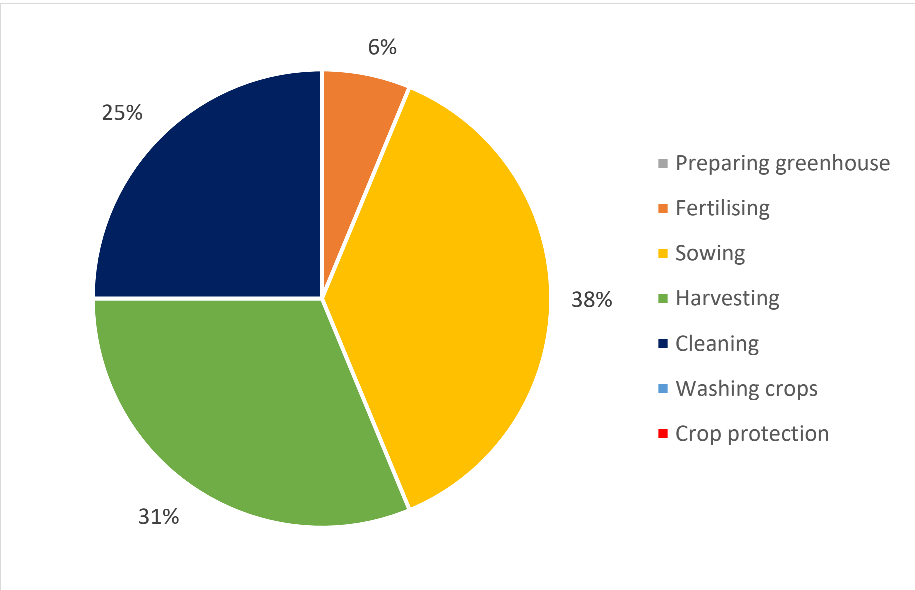


Figure 10: Overview time spent hydroponic cultivation by hand

5.3 Irrigation and water use

5.3.1 In soil cultivation

The water use presented in Table 2 is the water use of a covered in soil cultivation. The water sources presented in Table 3 and 4 are respectively from a covered and open field cultivation. It is important to note that the water source and it's storage capacity are very region specific and influenced by the infrastructure possibilities of the grower.

The water use for a covered cultivation has a broad range this is because it is strongly dependent on a few factors like season, soil type (e.g. sandy soils require more frequent irrigation cycles) and irrigation strategy of the grower. This last one is sometimes adjusted by the growers to prevent the spreading of certain diseases as part of their IPM-strategy.

An open field cultivation is in contrast almost entirely dependent on the weather and the natural rainfall throughout the year so no averages can be made per season.

It is notable that there is huge loss of water due to drainage via the soil. Once the water infiltrates lower levels in the soil, the plant roots can't take up the water anymore and it can't be recuperated.

Table 2: Water use of covered in soil production

Season	Winter	Spring	Summer	Autumn
Water use (L/m²)	**between 10-70**	**between 15-185**	**between 30-170**	**between 15-45**

Table 3: Overview water sources covered in soil production (lamb's lettuce)

	Source	Storage (m³)	Use/year (m³)	Used for
Primary water source	**rainwater**	**3 – 2 500**	**/**	**Irrigation**
Secondary water source	**borehole water or drilling well water**	**/**	**250 -1 000**	**Washing plants**
Other water source	**tap water**	**/**	**500**	**Washing plants**

Table 4: Overview water sources open field cultivation (spinach)

( ) cost of buying, using, and maintance of surfacewater facilities is around 300 euro/ha*

5.3.2 Hydroponic cultivation

In a hydroponic system the amount of water needed throughout the growing cycle and by extension a year round production is significantly **less** than the in soil cultivation.

At the start of production a large volume of rainwater is needed to fill the DFT bins with nutrient solution. The average dept of which DFT bins are filled is around 20 to 25 cm deep which corresponds to 200 to 250 L of nutrient solution per square meter. However after that the nutrient solution is constantly being reused and recirculated. The only water that leaves the system is taken up by the plants or evaporated by the water surface which is also constantly being refilled.

However since the nutrient solution is constantly being recirculated it is necessary to treat and filter the solution before sending it back to the plants to avoid any contamination or diseases. Many treatments (physical or chemical) can be used for this purpose. Below a few techniques that could be used are listed:

- UV-installation
- Active carbon filter
- Use of hydrogen peroxide (further discussed in *2.5 – crop protection products*)

5.4 Electricity

Electricity costs highly dependent on the choice of hydroponics system. Choosing a high-tech system such as Pilot system 1 at Vertify consisting of a climate growth chamber (Figure 4) or a greenhouse equipped with overhead led lighting such as Pilot system 2 and 3.

In the case of a climate growth chamber most electricity is used for lighting. As led lights emit heat, a significant portion of electricity is used for climate control. Typical values for power consumption is 900-1000 kWh per m² per year for a growth container. For a greenhouse equipped with led lighting which supplies 90 µmol $m^{-2}s^{-1}$, electricity usage may be expected to be around 40 kWh per m².

Growing lamb's lettuce, spinach or rocket during winter months will take longer because of lower temperature and lower daily light integrals. However, by heating the greenhouse combined with adequate lighting, growing cycles can shorten. The additional costs for heating and overhead lighting depend on the installed power. An short summary of ideal supplemental lighting can be found in the Growers Guide §6.

5.5 Fertilisation

5.5.1 In soil cultivation

The amount of nutrients that need to be added for in soil cultivation is highly dependent on the current nutrient status, and soil texture. The primary nutrients that are added in the soil are N, P and K. Ideally, before every crop cycle a soil analysis is taken to calculate the amount of fertilisers needed. Typically, a cost of 1 500 € per ha for nutrients can be expected.

5.5.2 Hydroponic cultivation

In hydroponics all the macro and micronutrient need to be added. An example of the composition of a nutrient solution can be found in the Growers Guide (§7.1). As the fertilizers for hydroponics are pure, the costs are higher. Price for the nutrients in a hydroponics system vary between 3 to 5 Euro per m³ depending on the composition used. To adequately follow up the composition of the nutrient solution and avoid nutrient deficiencies, a frequent analysis is necessary.

During start-up the system and during seasons with strong growth this can be weekly. Later the amount of analyses can be lowered. Constant pH and EC monitoring and correction is advised to avoid nutrient uptake problems.

Measuring of the water temperature is also advised as this can affect the water uptake and oxygen concentration in the water. If an active carbon filter is used extra iron needs to added after the filter or an adjusted iron fertilizer needs to be used.

5.6 Crop protection products

The in soil cultivation faces more and more difficulties the last few years with persistent soil borne diseases (often fungi), pests and weeds. This is caused by a decrease in number of applications, number of allowed products that can be used and the changing climatic circumstances.

5.6.1 In soil cultivation

An overview of the currently allowed products for in soil cultivation of lamb's lettuce and spinach in 2023 is shown in Table 5 an 6. However, we strongly advice to consult with your local supplier or advisor on which crop protection product is suitable for your specific cultivation and region. The available crop protection products can differ a lot per region and per crop. Also the list of legally allowed crop protection is constantly in review and can change quite rapidly.

Table 5: Overview crop protection products used in soil cultivation of lamb's lettuce

Product (name)	**Signum**	**Ortiva/Amistar**	**Previcur energy**	**Luna privilege**	**Proplant**
Number of applications per year	1-6,5	1-7	2	1	2-7
Active compound(s)	pyraclostrobine boscalid	azoxystrobin	fosetyl propamocarb	fluopyram	propamocarb hydrochloride
Used as	Fungicide	Fungicide	Fungicide	Fungicide	Fungicide
Product (name)	**Decis**	**Tracer**	**Beloukha**	**Serenade**	
Number of applications per year	2-7	6,5	1	6	
Active compound(s)	deltamethrin	spinosad	Pelargonic acid	*Bacillus amyloliquefaciens*	
Used as	Insecticide	Insecticide	Herbicide	Biological product	

Tabel 5: Overview crop protection products used in soil cultivation of spinach

Product (name)	**Astrix**	**Centium**	**Goltix**	**Oblix**	**Karate Zeon**
Number of applications per year	1	1	1	3	1
Active compound(s)	Fenmidifam	Clomazone	Metamitron	Ethofumesaat	Lambda-cyhalothrin
Used as	Herbicide	Herbicide	Herbicide	Herbicide	Insecticide

Also non-chemical products can be used to protect the plant against pathogens. To avoid infection with the bacteria *Acidovorax valerianellae* some lamb's lettuce growers use **disinfectant products** like **hydrogen peroxide** during the cultivation. They do this by injection in their irrigation system or by adding it to the daily water supply. Important to note is that products like hydrogen peroxide aren't cataloged as a crop protection product (CPP) but as a biocide. The product is listed here since its purpose is to reduce disease.

5.6.2 Hydroponic cultivation

Till this day no crop protection products were used during the experiments with prototypes or during the pilot trials. However it is expected that in case of prolonged monoculture problems with diseases and pests may start occurring and crop protection products may be needed.

Since most of the crop protection products used in soil are to battle soil borne diseases or weeds the amount of used crop protection products will **decrease drastically** in a hydroponic system. Using less crop protection products reduces the ecological footprint and meets increased consumer demands.

Even without the occurrence of soil borne diseases, it is still impossible to keep pests such as aphids out of greenhouses. In this regards the use of certain insecticide may still be needed. Additionally if the water surface is not covered properly from sunlight entering, algae may start to form. So a regular injection of hydrogen peroxide (disinfectants) can help to keep the system clean and relatively free from algae. This may not only be effective for algae but also for a pathogens like black root rot (*Berkeleyomyces spp.*).

6 Revenue (Yield)

Yield is one of the most important factors to look at when it comes to a profitable farming business. Yield is highly dependent on choosing the correct varieties, seed batch numbers and cultivation practices such as sowing density and germination method. In addition to the total yield will be the result of the percentage of germinated seeds which is connected to the aforementioned factors. An overview of the yield for the traditional soil cultivation and the new hydroponic system is given in the tables below. Different yield parameters for a year round cultivation are given of in soil cultivation as well as yield data collected during tests on the new hydroponic system. Data for soil-bound cultivation was collected from farmers.

6.1 Price

Pricing for example of lamb's lettuce can fluctuate during the year at the vegetable auction. On average for Belgium following prices were reached at the auction: 4.44€ per kg in 2021 and 3.12 € per kg in 2022. Some farmers can agree on long-term contracts with buyers and are therefore certain of a certain price for a given time.

6.2 In soil cultivation

Yield presented in Table 7, 8 and 9 represent optimal yield. Such yields are only possible without **yield loss** due to pests or **soil borne diseases**. Especially *Berkeleyomyces* spp. and *Pythium* spp. causes a lot of problems in the lamb's lettuce cultivation the last few years in the in soil production with a lot of crop and yield loss as a result. Some growers even decided to stop there production in summer seasons. Diseases influence the yield prospect greatly and causes a lot of uncertainties for the grower.

Table 7: Yield per season in soil cultivation of lamb's lettuce

Season	Winter	Spring	Summer	Autumn
Sowing density ($seeds/m^2$)	between 400-800 av. 700	between 400-800 av. 750	between 400-800 av. 750	between 400-800 av. 750
Cultivation period from sowing till harvest (days)	av. 90	av. 55	av. 32	av. 70
Total yield (kg/m^2)	1,2	1,2	0,9	1,1

Table 8: Yield per season in soil cultivation of spinach

Season	Winter	Spring	Summer	Autumn

Sowing density (seeds/m²)	**between 800-1000 av. 800**	**av. 800**	**av. 800**	**av. 800**
Cultivation period from sowing till harvest (days)	**av. 70**	**av. 55**	**av. 36**	**av. 42**
Total yield (kg/m³)	**1,15**	**1,15**	**1,15**	**1,15**

Table 9: Yield per season in soil cultivation of rocket

Season	Winter	Spring	Summer	Autumn
Total yield (kg/m³)	**1,0**	**1,0**	**1,0**	**1,0**

6.3 Hydroponic cultivation

Most soil borne diseases don't occur in a hydroponic systems, don't become infectious or are more easily controlled so most of the yield losses that the soil cultivation experiences can be prevented in a hydroponic system and a more constant yield can be attained. In the tables below yield data from the pilot trials in autumn is given as well as the average germination percentage achieved on the system for the different crops.

Table 10: Yield of hydroponic cultivation of lamb's lettuce, spinach and rocket during autumn

	Lamb's lettuce	Spinach	Rocket
Sowing density (seeds/m²)	**1400**	**1400**	**1400**
Cultivation period from sowing to harvest (days)	**av. 75**	**av. 35***	**av. 60-70**
Total yield (kg/m²)	**1,2**	**2,2**	**-**

**cultivation period included the pre-germination stage as well as the germination stage in the climate chamber*

Table 11: Average germination percentage of hydroponic cultivation of lamb's lettuce, spinach and rocket during autumn

	Lamb's lettuce	Spinach	Wild rocket	Salad rocket
Germination percentage	**Av. 70 – 90 %**	**Av. 80 – 90 %**	**Av. 65 - 90%**	**Av. 88 - 90 %**

** Germination percentage is heavily dependent on the variety, in the table a range of the best germinating varieties are given*

6.4 Comparison

In general the germination of lamb's lettuce seeds on the hydroponic system is a little bit slower than the traditional in soil production. Depending on the season this can be one or a couple of days. But the same germination percentage can be obtained as the traditional soil cultivation. The varieties with which this can be obtained can be different than our standard varieties we know in soil in cultivation as mentioned in *2.1 – Seeds*.

With the hydroponic system similar to slightly higher yields for lamb's lettuce can be obtained with both methods. Due to the higher sowing density on the Hy4Dense system a similar yield per square meter can be obtained even if the weight per plant is lower compared to in soil cultivation. The yearly yield can be optimized by adding lights and raising the temperature so more growing cycles can be achieved during the dark and cold months. For spinach a large increase in yield is possible using hydroponic system compared to traditional in soil cultivation. However the quality that can be obtained with a hydroponic system should also be taken into account. The harvested crops are cleaner and have no soil particles around them.

Any yield losses due to soil borne disease can be prevented in the hydroponic system which results in a more continuous harvesting schedule and yield prospect. Which is huge advantage when setting and maintaining contracts with buyers like retail chains and processors.

7 User Experience

This report outlines the user experience of the hydroponic cultivation system, with a focus on ergonomics, clothing considerations, plate quality, and cleaning. The aim is to provide feedback on how to improve the user experience of the system.

Ergonomics: The ergonomics of the hydroponic cultivation system could be better. The manual placement of floaters in and out of the basin is not good for the back, and assembling and disassembling the floater system is cumbersome. We recommend that the manufacturer consider designing a system that is easier to handle, perhaps by using automated systems or providing ergonomic handles that reduce strain on the back.

Clothing considerations: It is important to be careful about the clothing you wear when using the hydroponic cultivation system. Static electricity may cause the seeds to shift or jump out of the crevices of the floaters. We recommend that users wear clothing made of natural fibers and avoid synthetic fabrics that can generate static electricity.

Plate quality: Plates that are not perfectly flat can lead to non-uniform germination and growth retardation. We recommend that the manufacturer pays close attention to the quality of the plates used in the system to ensure that they are perfectly flat and of consistent thickness. This will help to ensure uniform germination and growth.

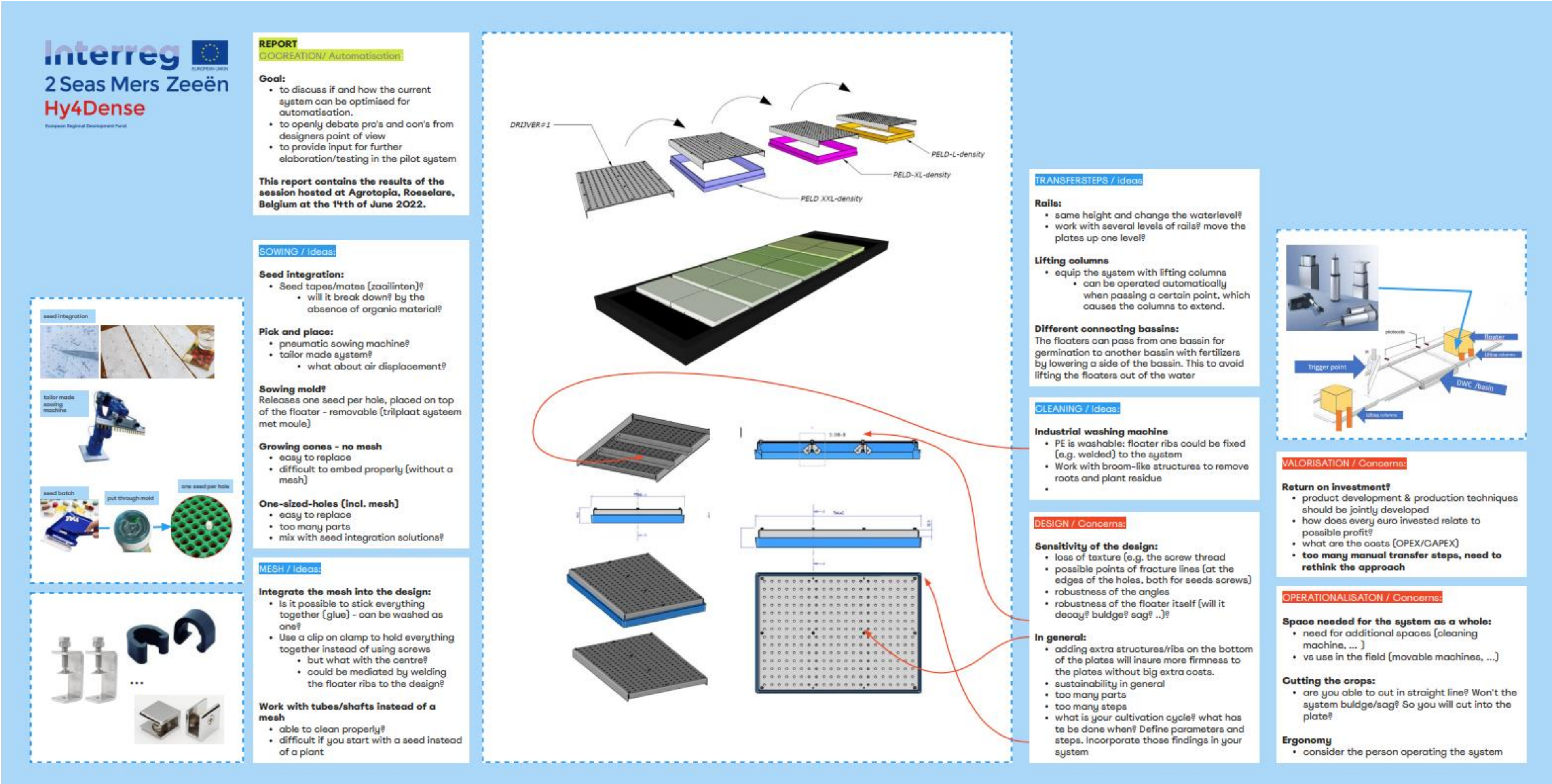
Cleaning: Cleaning of the floaters demands a lot of steps and time as it needs to be disassembled. We recommend that the manufacturer consider designing the floaters in such a way that they are easier to clean, perhaps by using detachable parts that can be easily removed and cleaned. Additionally, the manufacturer could provide detailed cleaning instructions to help users ensure that the system remains hygienic.

Conclusion: The hydroponic cultivation system has many benefits, including increased yields, reduced water usage, and more efficient use of space. However, the user experience could be improved by addressing the ergonomics of the system, providing guidance on clothing considerations, paying close attention to plate quality, and making the cleaning process easier. We recommend that the manufacturer takes these recommendations into account to ensure that the system is as user-friendly as possible.

8 Automatization and upscaling concepts

Even though the project ended with 4 pilot installations. Already multiple ideas of automatization were explored. These are mainly associated with reducing labour costs and enhancing ergonomy in handling the plates and harvesting. Additionally, the floaters can be redesigned to better accommodate the system for automatization. Different concerns but also possibilities were indicated below in the infographic.

Development of fully automated growing, harvesting and cleaning station of the produce is expected to cost up to 500.000 €. After development an investment cost of the system of 500.000€ is to be expected. By making this investment labour costs can be severely reduced thus making hydroponic cultivation economically viable.



Infographic on automatization and redesign ideas for the Hy4Dense system.

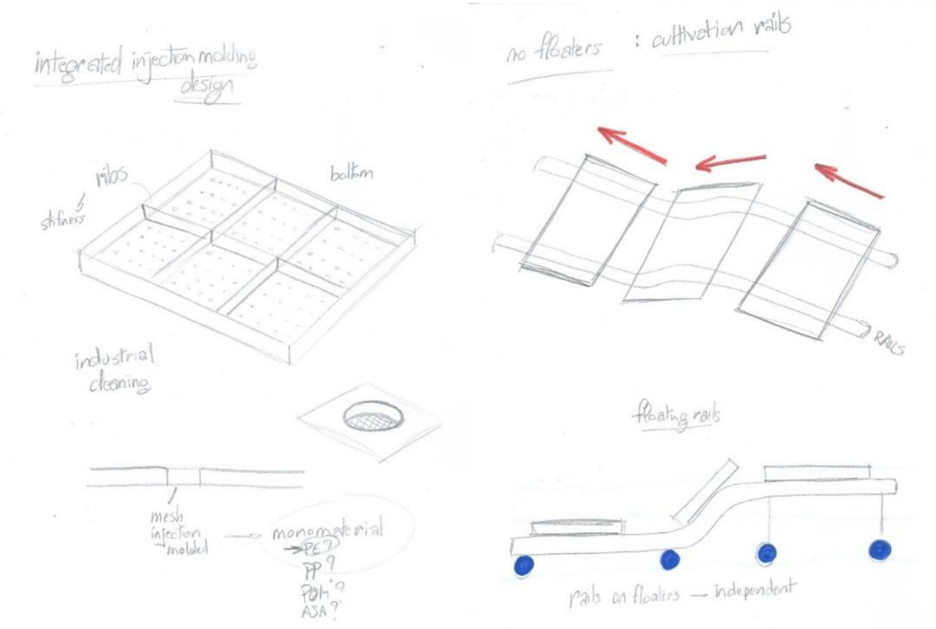
Based on the suggestions from the co-creation group and own experience using the pilots, we propose following adjustments to the pilot system.

8.1 Floater

suggestions for redesign/manufacturing: floater completely in injection molding.

Features:

- Ribs for stiffness on bottom side
- Top is completely flat
- Similar looking holes with mesh for seeds & growing. But the mesh is an integrated piece of the injection mold, not a separate layer of mesh (if damaged, plate is not longer useful)
- Cleaning is done on the complete part.
- No sharp inner corners for better cleaning (steaming, high pressure wash…)
- Monomaterial and monopart: PE or PP are probably the best choices
- Plate don't need to float on itself: on a carrier, rails… All features to keep it on the rails are integrated.
- Costly mold, so big investment for upscaling in large numbers
- Harvesting can be done with a long blade along the sides of the growing plate



8.2 Cultivation station: rails.

- Rail system so it is more or less stable in the water.
- Low position (germination) and a high position in 1 movement on the same rails.
- Movement can be manually done: pushing a new plate in, pushes a fully grown plate out on the other side

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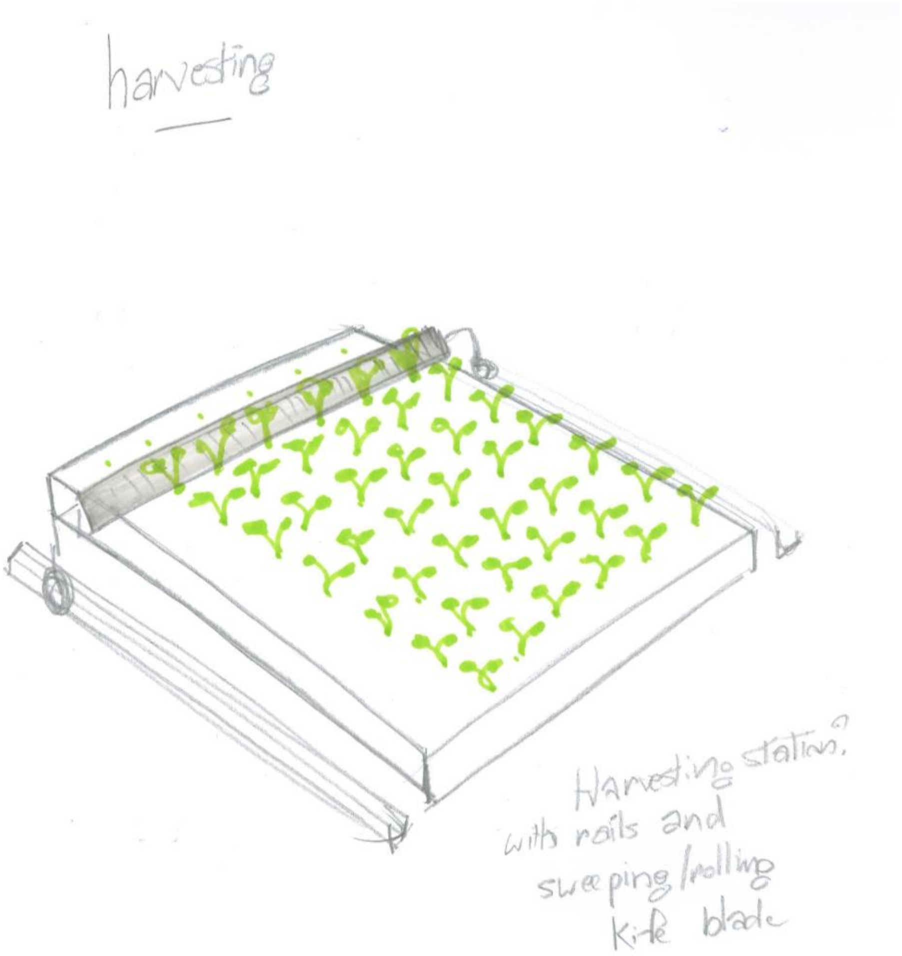
- To be researched where the incline should be and if the timing of growing & harvesting can be get right.

8.3 Harvesting station

- Can be in the length of the cultivation rails.
- Sweeping blade set to the height of the growing plates.
- Or: separate station. Lifting the plate out of the water (from the rails) onto a dedicated station of cutting and catching the crops.



8.4 Cleaning station for the growing plates.

- Comparable to industrial washing up machine.
- High temperature, high pressure, maybe steam, UV….
- Roots need to be pulled off or cut from the bottom. Ribs are in the way, but the surface including the meshes is flat.

9 Economic analysis: Case studies

The paragraphs above mainly focus on the separate costs and expected yields related to a transition towards a hydroponic cultivation system for densely sown leafy vegetables. Here, we will study some cases to getter a better overall understanding on the profitability of a hydroponic system.

We have selected following situations:

1. High tech growth chamber (with or without automatization)
2. Greenhouse with additional lighting (with or without automatization)
3. Greenhouse without additional lighting (with or without automatization), for this we expect to lose half a growth cycle per year

The parameters we have fixed can be found in the table below:

Parameter	Value	Unit
Crop	Lambs lettuce	
Available area	7500	m²
Hourly labor cost	12	€ per hour
Cost floaters	50	€ per m²
Growth cycles	6	per year
Electricity costs	0.16	€ per kWh
Average sales price for produce (€ per kg)	3	€/kg
Discount rate	4	%

As crop we have chosen Lamb's lettuce, because most information is available for this crop. An cultivation area of around 7500 m² can be expected for a farmer to switch to a hydroponic system. For the cost of the floaters we have chosen to use an estimate of floater prices if these would be produced on an industrial scale, this number is comparable to prices for other types of floaters for hydroponic cultivation in DFT cultivation systems.
Labour costs, energy and sales prices are subject to the economic market but an average price for the last years has been selected.

During the Hy4Dense project, no automated sowing, harvesting and cleaning station has been developed. To take the effect of possible automatization into account we assume an investment cost of around 500.000€ with write-off period of 20 years.

9.1 Case study: High-tech growth chamber

This case will take the high tech options with a germination in a growth chamber and subsequent transfer towards the greenhouse for growing until harvest. This case includes lighting in the growth chamber as well as in the greenhouse.

9.1.1 Case without automatization

Growth Chamber + greenhouse			Year		
Costs			1	10	% of total costs
	Operational costs	labour (no automation)	€ 918,000.00	€ 918,000.00	35%
		Electricity (lighting)	€ 1,080,000.00	€ 1,080,000.00	42%
		Nutrients	€ 7,500.00	€ 7,500.00	0%
		Seeds	€ 720.00	€ 720.00	0%
		Maintenance costs (1% of total replacement asset value)	€ 97,500.00	€ 97,500.00	4%
		Total operational costs	€ 2,103,720.00	€ 2,103,720.00	81%
	Investment costs	Total investment costs	€ 487,500.00	€ 487,500.00	19%
	Total costs	Operational + investment	€ 2,591,220.00	€ 2,591,220.00	100%
		Present value of total costs	€ 2,491,557.69	€ 1,750,535.39	
		Cumulative costs	€ 2,491,557.69	€ 21,017,115.36	
Revenue					
		Yearly yield (kg)	99000	99000	
	Revenu	Revenu	€ 247,500.00	€ 247,500.00	
		Present value of revenu	€ 237,980.77	€ 167,202.13	
		cumulative revenu	€ 237,980.77	€ 2,007,446.71	
	Profit	yearly profit	€ -2,343,720.00	€ -2,343,720.00	
	Cummulative profits	cummulative	€ -2,253,576.92	€ -19,009,668.66	
	ROI (10 year)	**-947%**			

9.1.2 Case with automatization

Growth Chamber + greenhouse			Year		
Costs			1	10	% of total costs
	Operational costs	labour (1.2 FTE)	€ 72,000.00	€ 86,046.66	5%
		Electricity (lighting)	€ 1,080,000.00	€ 1,080,000.00	61%
		Nutrients	€ 7,500.00	€ 7,500.00	0%
		Seeds	€ 720.00	€ 720.00	0%
		Maintenance costs (1% of total replacement asset value)	€ 102,500.00	€ 97,500.00	5%
		Total operational costs	€ 1,262,720.00	€ 1,271,766.66	71%
	Investment costs	Total investment costs	€ 512,500.00	€ 512,500.00	29%
	Total costs	**Operational + investment**	**€ 1,775,220.00**	**€ 1,784,266.66**	**100%**
		Present value of total costs	€ 1,706,942.31	€ 1,205,386.63	
		Cumulative costs	€ 1,706,942.31	€ 14,430,128.04	
Revenue					
		Yearly yield (kg)	99000	99000	
	Revenu	Revenu	€ 247,500.00	€ 247,500.00	
		Present value of revenu	€ 237,980.77	€ 167,202.13	
		cumulative revenu	€ 237,980.77	€ 2,007,446.71	
	Profit	yearly profit	€ -1,527,720.00	€ -1,536,766.66	

	Cummulative profits	cummulative	€ -1,468,961.54	€ -12,422,681.33	
	ROI (10 year)	**-619%**			

9.2 Case study: Greenhouse with lighting

9.2.1 Case without automatization

Greenhouse with lighting			**Year**		
Costs			**1**	**10**	**% of total costs**
	Operational costs	labour (no automation)	€ 918,000.00	€ 918,000.00	88%
		Electricity (lighting)	€ 42,979.59	€ 42,979.59	4%
		Nutrients	€ 7,500.00	€ 7,500.00	1%
		Seeds	€ 720.00	€ 720.00	0%
		Maintenance costs (1% of total replacement asset value)	€ 12,750.00	€ 12,750.00	1%
		Total operational costs	**€ 981,949.59**	**€ 981,949.59**	**94%**
	Investment costs	**Total investment costs**	**€ 63,750.00**	**€ 63,750.00**	**6%**
	Total costs	**Operational + investment**	**€ 1,045,699.59**	**€ 1,045,699.59**	**100%**
		Present value of total costs	€ 1,005,480.38	€ 706,437.18	
		Cumulative costs	€ 1,005,480.38	€ 8,481,560.41	
Revenue					
		Yearly yield (kg)	99000	99000	
	Revenu	Revenu	€ 247,500.00	€ 247,500.00	
		Present value of revenu	€ 237,980.77	€ 167,202.13	
		cumulative revenu	€ 237,980.77	€ 2,007,446.71	
	Profit	**yearly profit**	**€ -798,199.59**	**€ -798,199.59**	
	Cummulative profits	**cummulative**	**€ -767,499.61**	**€ -6,474,113.70**	
	ROI (10 year)	**-323%**			

9.2.2 Case with automatization

Greenhouse with lighting and automatization			**Year**		
Costs			**1**	**10**	**% of total costs**
	Operational costs	labour (1.2 FTE)	€ 72,000.00	€ 86,046.66	35%
		Electricity (lighting)	€ 48,000.00	€ 48,000.00	20%
		Nutrients	€ 7,500.00	€ 7,500.00	3%
		Seeds	€ 720.00	€ 720.00	0%
		Maintenance costs (1% of total replacement asset value)	€ 17,750.00	€ 12,750.00	5%

		Total operational costs	**€ 145,970.00**	**€ 155,016.66**	**64%**
	Investment costs	**Total investment costs**	**€ 88,750.00**	**€ 88,750.00**	**36%**
	Total costs	**Operational + investment**	**€ 234,720.00**	**€ 243,766.66**	**100%**
		Present value of total costs	€ 225,692.31	€ 164,680.02	
		Cumulative costs	€ 225,692.31	€ 1,935,293.09	
Revenue					
		Yearly yield (kg)	99000	99000	
	Revenue	Revenu	€ 247,500.00	€ 247,500.00	
		Present value of revenu	€ 237,980.77	€ 167,202.13	
		cumulative revenu	€ 237,980.77	€ 2,007,446.71	
	Profit	**yearly profit**	**€ 12,780.00**	**€ 3,733.34**	
	Cummulative profits	**cummulative**	**€ 12,288.46**	**€ 72,153.62**	
	ROI (10 year)	**4%**			

9.3 Case study: Greenhouse without lighting

9.3.1 Data with automatization

Greenhouse without lighting			**Year**		
Costs			**1**	**10**	**% of total costs**
	Operational costs	labour (no automation)	€ 841,500.00	€ 841,500.00	93%
		Electricity (lighting)	€ 6,000.00	€ 6,000.00	1%
		Nutrients	€ 7,500.00	€ 7,500.00	1%
		Seeds	€ 660.00	€ 660.00	0%
		Maintenance costs (1% of total replacement asset value)	€ 9,000.00	€ 9,000.00	1%
		Total operational costs	€ 864,660.00	€ 864,660.00	95%
	Investment costs	Total investment costs	€ 45,000.00	€ 45,000.00	5%
	Total costs	Operational + investment	€ 909,660.00	€ 909,660.00	100%
		Present value of total costs	€ 874,673.08	€ 614,533.70	
		Cumulative costs	€ 874,673.08	€ 7,378,157.45	
Revenue					
		Yearly yield (kg)	90750	90750	
	Revenu	Revenu	€ 226,875.00	€ 226,875.00	
		Present value of revenu	€ 218,149.04	€ 153,268.62	
		cumulative revenu	€ 218,149.04	€ 1,840,159.48	
	Profit	yearly profit	€ -682,785.00	€ -682,785.00	

	Cummulative profits	cummulative	€ -656,524.04	€ -5,537,997.97	
	ROI (10 year)	**-301%**			

9.3.2 Data with automatization

Greenhouse without lighting			**Year**		
Costs			**1**	**10**	% of total costs
	Operational costs	labour (1.2 FTE)	€ 72,000.00	€ 86,046.66	35%
		Electricity (lighting)	€ 9,600.00	€ 9,600.00	42%
		Nutrients	€ 7,500.00	€ 7,500.00	0%
		Seeds	€ 660.00	€ 660.00	0%
		Maintenance costs (1% of total replacement asset value)	€ 14,000.00	€ 9,000.00	4%
		Total operational costs	**€ 103,760.00**	**€ 112,806.66**	81%
	Investment costs	**Total investment costs**	**€ 70,000.00**	**€ 70,000.00**	19%
	Total costs	**Operational + investment**	**€ 173,760.00**	**€ 182,806.66**	100%
		Present value of total costs	€ 167,076.92	€ 123,497.63	
		Cumulative costs	**€ 167,076.92**	**€ 1,440,852.88**	
Revenue					
		Yearly yield (kg)	90750	90750	
	Revenu	**Revenu**	**€ 226,875.00**	**€ 226,875.00**	
		Present value of revenu	€ 218,149.04	€ 153,268.62	
		cumulative revenu	**€ 218,149.04**	**€ 1,840,159.48**	
	Profit	**yearly profit**	**€ 53,115.00**	**€ 44,068.34**	
	Cummulative profits	cummulative	€ 51,072.12	€ 399,306.60	
	ROI (10 year)	**22%**			

10 Conclusions

Upon analysis of various cases, it is evident that **labor constitutes a significant bottleneck** in operational costs associated with hydroponic cultivation. This is due to the manual processes involved in sowing, harvesting, cleaning, and preparing the produce for market, which demand substantial labor input. These processes require a large team, leading to high peaks in labor demand during sowing and harvest periods. However, there is a considerable opportunity to enhance workflow automation, from sowing to harvesting and packaging, which could result in significant time savings. It is estimated that automation can be managed with a supervisory requirement of 1.2 full-time equivalents (FTE) for an area of 7500 m^2.

In addition to labor, the **profitability** of hydroponic cultivation is strongly influenced by the **technical level of the system**. One approach involves using a growth chamber for seed germination. However, investment and power costs are high, making this approach unprofitable unless customers are willing to pay **premium prices** or unless **electricity costs** can be substantially **reduced**. In contrast, greenhouses offer a more profitable option, provided that automation is a prerequisite for economic viability.

The use of **assimilation lighting** during cultivation significantly **impacts costs** related to LED investments and electricity usage. However, it has a relatively **small effect on the number of growth cycles** achieved using lights. During darker winter periods, these lamps may be employed to promote growth. Crops such as spinach, rocket, and lamb's lettuce are tolerant of low temperatures but grow more slowly. Therefore, it is estimated that the use of assimilation lights could enhance growth cycles by 0.5 to 1. Increased market prices for the produce could make it more economically appealing to use assimilation lights.

Overall, **hydroponic cultivation of crops such as lamb's lettuce, spinach, and rocket offers several advantages**, including efficient use of water and nutrients, limited use of pesticides, absence of soil-borne diseases, and absence of soil particles in the final product. However, the most significant challenge facing hydroponic cultivation is **automation**, particularly in the sowing and harvesting processes. Labor costs render the current model unprofitable. It is necessary to collaborate with the industry to develop and construct automated systems that enable the transition from soil-based to hydroponic cultivation.