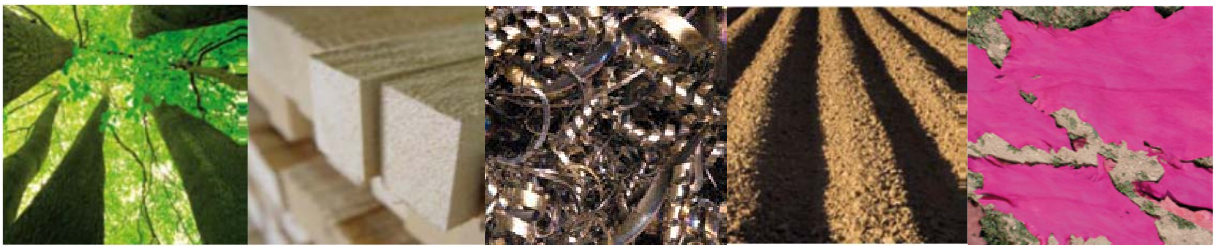

CIP Eco-innovation
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Report on production start and design D3.2

Ecoponics

Contract ECO/12/332783/SI2.656985

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Project website: http://aquaponics.is/ecoponics/

Facility

The IGFF test plant in Denmark was set up in the autumn of 2014 in an existing greenhouse research facility build autumn 2013, and owned and run respectively by Copenhagen University and the public-private innovation center for horticulture: AgroTech Ltd. The greenhouse itself is divided into 12 ‘cubes’ of each 50 m^2, and so has the prospect of making individual research in the large greenhouse itself. Each cube has a 24-hour data logging on temperature inside and outside, climate control on light, humidity, ventilation and heat. The aquaponic test plant is placed in one of the cubes, and uses excess space of 15m^2 outside the cube for the placement of bio-filter, sedimentation tanks, air-blowers and UV-system to secure as much plant growing area as possible.

Technical description

The aquaponic test plant inside the cube consists of six plant tables arranged in three pairs of 1.45 x 7.50 m and are covering three rectangular fish tanks (3 x 1 x 0.8 m) with a usable volume of 2 m^3 each. Plant tables produce horticulture products in pots with compost to open up for the prospect of getting an organic certification for the aquaponic system. To obtain an organic certification it requires that plants are grown in various specified types of soil.

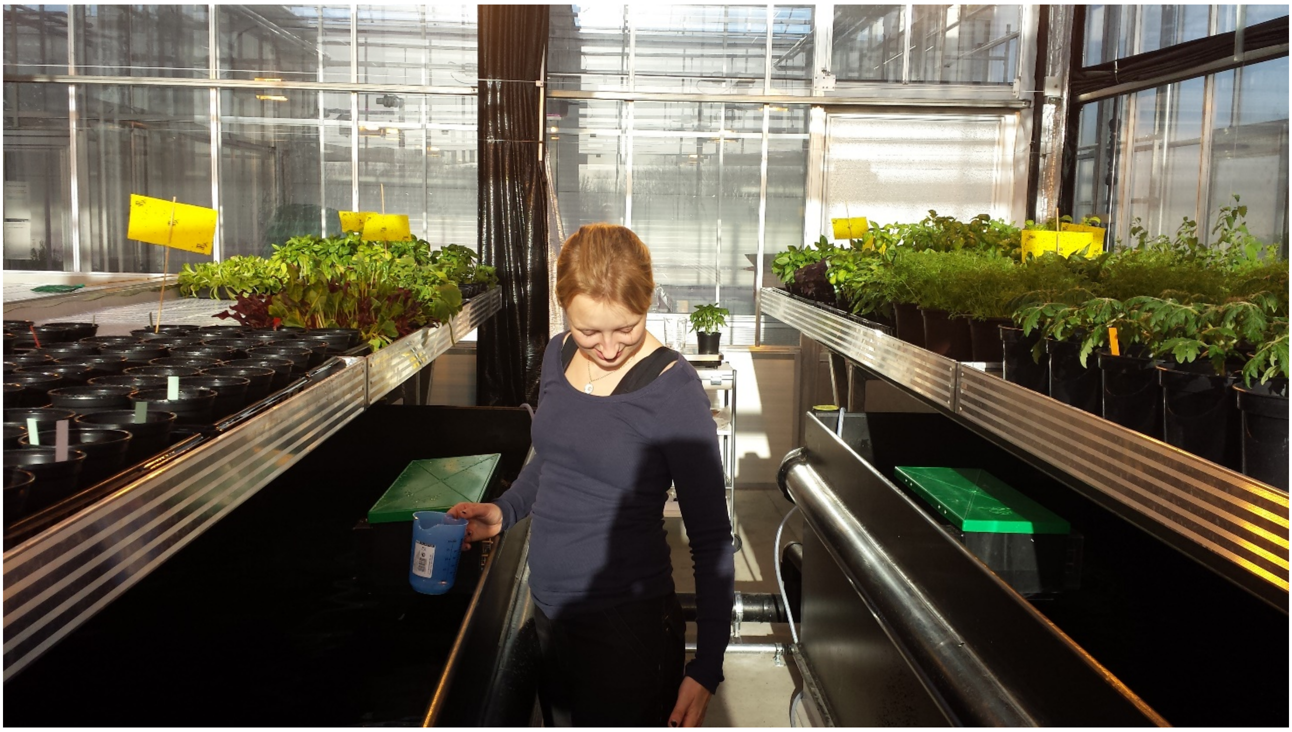

Figure 1. Mobile plant tables placed above the rectangular fish tanks.

Water to the plants is supplied by the ‘flood and ebb’ principle. To secure as much plant growing area in the cube, bio-filter, UV-lighting, air pumps, pH regulation and sedimentation tanks are placed outside the cube. The oxygen supply to the fish tanks are secured by three independent air blowers. The tanks are connected to a central water discharge line that ends in two sedimentation chambers. These chambers do not only serve as pre-filtration system but also as pump sumps. Each chamber is connected to one separate lift pump providing a pumping capacity of around 15m^3/h. The total water flow is split into two basically independent loops. In one of them, the fish loop, the pumps are supplying water to a bead-filter that acts as a mechanical- as well as a biological filter and one in-line ultraviolet disinfection system (UV-system) connected in series. From the UV-system the water can be led to the plant tables and/ or directly back to the fish tanks located beneath the plant tables. The water from the plant tables can also enter the fish tanks by gravity or can directly be discharged into the main discharge line and the sedimentation chambers. In the second loop (plant loop) the lift pump supplies the water directly back to the plant tables from where it will enter the fish tanks. Both lift pumps are frequency regulated, furthermore the plant loop pump is equipped with a timer that allows to pre-set pumping time and -duration to follow a “flood & ebb” watering schedule of the plant tables.

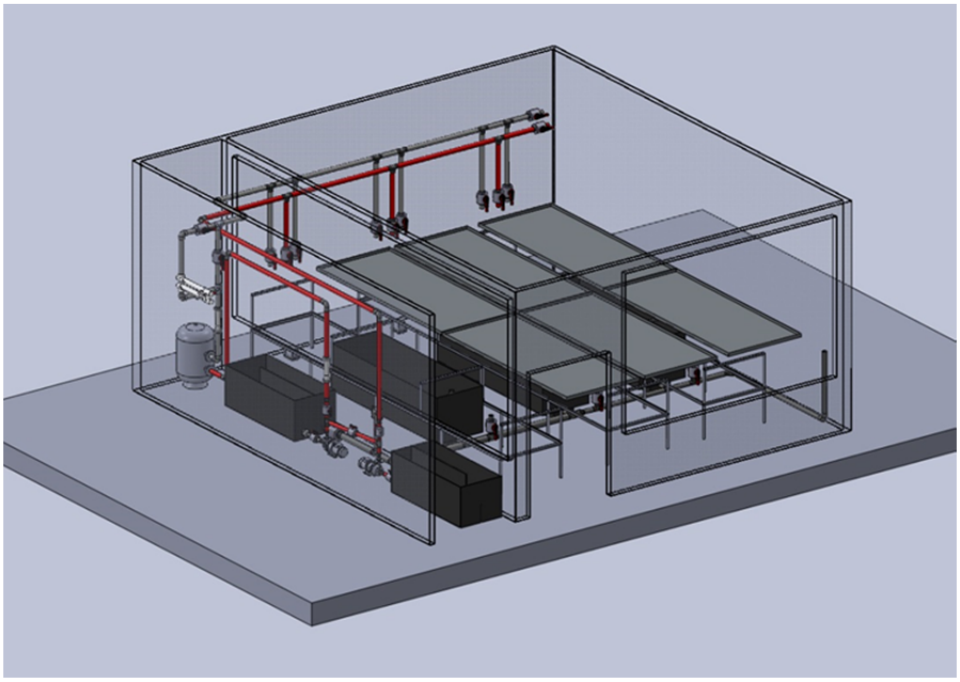

Figure 2. A principle sketch of the IGFF aquaponic system.

Introducing two separate loops, one for plants and one for fish, gives a very high degree of flexibility and safety of production. The system allows the gradual reduction of the independence of the loops up to a system solely depending on the mutual symbiotic relationship of plant- and fish production. If at any time there is an imbalance of the two components it is possible to (partly) separate the processes and stabilize the system again.

Figure 3. Bio-filter, UV-lighting, sedimentation tanks and airblower.

Discussion and conclusion

The test plant integrates already well-known technologies and production systems applied in large scale modern aqua- and horticulture production systems, and hence designed to eliminate a pre-barrier of insecurity when introducing aquaponics as a commercial option in the two industrial sectors. The test plant has also been designed to minimize the mutual dependency risk in aquaponics by introducing separate (but integrated) nutrient loops in the event of problems or failures in either the aqua- or horticulture section to avoid a complete shut-down of the whole aquaponic system. Likewise, to reduce the higher fixed costs in aquaponics the test plant has applied ‘economies of space’ (fish tanks underneath the mobile plant tables), and together with the symbiotic effects with savings on variable costs on nutrients, water and CO_2 paving the way for a commercial viable balance sheet when aquaponics go large scale.

Studies performed and goals

Studies have been done to measure the symbiotic effects of aquaponics in physcical terms on CO_2 and heating energy, to provide data for the economic analysis.

Studies related to the fish:plant biomass ratio and sustainable harvest strategies of the IGFF system, are yet to commence due to the newly start-up of the IGFF production system. However, once production has reach a steady state in a peak fish biomass, scientific analysis and measurements on biomass ratios will take place.

In the beginning of October 2014, 275 Red and 275 Silver Tilapia fingerlings between 0.2-0.5 gram were introduced to two of the three fish tanks. In late December, 175 Pike Pearch of 25 gram were introduced to the third and last fish tank.

Figure 4. Weighing Red Tilapia fingerlings for optimum feed calculation.

While the fish biomass is growing, successively testing have been done with a variety of horticultural plants. Since the IGFF aquaponic system applies nutrient based compost to the plants, short time cultures (4-5 weeks) such as herbs like Basil Genovese have shown a healthy growth when starting up the system. However, longer-term cultures like salad and further time-consuming cultures like tomatoes and peppers have shown potassium deficit after 8 weeks. There has been no pH regulation so far due to a very high pH 8.1 in the water, but one could consider adding potassium hydroxide for later testing on longer-term cultures such as tomatoes if missing out from the fish feed.

Figure 5 Testing a variety of short- and long term growing horticultural products such as coriander, red basil, basil Genovese, parsley, mint, and on the table in the back of the picture watermelon, passion fruit and chili peppers

The symbiotic effects of aquaponics

When integrating horticulture with aquaculture production, the benefits of various symbiotic effects will occur. These are, a) metabolic bi-products from the fish production are utilized by the horticultural plants to grow and hence clean the water as well as save cost on plant fertilizer; b) fish produce CO_2, which the plants can utilize hence reduce cost on purchasing CO_2 to boost plant production; c) the fish tanks, when placed in the greenhouse for horticultural produce, can act as heating buffers during night time and hence save cost on energy.

IGFF has together with AgroTech Ltd modelled the symbiotic effects in aquaponics on respectively CO_2 and heat energy to quantify their physical environmental impact and potential economic savings on the variable costs.

Year round simulation were performed with the core of The Virtual GreenhouseTM of AgroTech (www.dvv.infogrow.dk) (Körner and Hanssen, 2012), that consists of a compilation of physical and biological greenhouse simulation models. In connection to this an aquaponic system model was created consisting of a 1000 m2 Venlo-type greenhouse and growing area (4 m gutter heights, 2x25x20m area) volume of 65 m^3 water capacity separated in 6 circular tanks of each 10 m^3 plus system components as pipes etc. of 5 m^3 water. The rectangular fish tanks were placed under the mobile plant tables.

The aquaponic system (AkvaGroup, Denmark) was dimensioned to produce 9 Mt tilapia fish yearly. For that a peak system biomass of 3000 kg fish was calculated. The fish feed was given to the optimum with a peak feed capacity of 40 kg/day and a peak water exchange of 0.58 m^3/h and minimum intake capacity of fresh water was calculated from transpiration and evaporation losses. Additionally, the needed water supply for keeping the desired water temperature at minimum of 28°C, and a maximum of 32°C was calculated from fresh water supply at pre-heated water. Energy supply to the water system was calculated by heat production through the fish calculated from an average oxygen consumption rate of 0.54 kg/kg feed with 13608 J/g feed. A rate of 51% of oxygen waste was assumed. Additional heat production was calculated by biological break-down of feces (1.3 MJ kg-1 feed) and feed. Feed composition was 38% protein, 10% fat and 20% carbohydrates. The rates of energy conversion was 23.64 J/g, 39.54 J/g and 17.15 J/g for protein, fat and carbohydrates, respectively.

The greenhouse was a standard greenhouse type with lettuce cultivation. The greenhouse was equipped with an energy screen (LS16, Ludvig Svensson, Sweden) and a shading screen (ILS60 Revolux, Ludvig Svensson, Sweden) under the roof and equipped with standard heating pipe system and passive roof vents. Climate control was done according to common practice with installed supplementary lighting of 80 W/m^2 (HPSL 400 W, Philips, The Netherlands) and sufficient dosage capacity of pure CO_2. However, temperature set-points for lettuce cultivation were set to 18 and 22°C year round. No distinguish between seasons, day and night and cultivation stage was done for model simplification. CO_2 was dosed to a maximum of 1000 ppm at daytime, but supply stopped when vents were opened with more than 10%.

For simulations, the Danish reference climate year (Lund, 1995) with hourly data was used as input. Simulations were done with a 5-min time step over a complete year. Two cases were simulated: 1) The greenhouse without aquaponic system using regular lettuce cultivation on benches (same climate setpoints as with aquaponics) and 2) the greenhouse with the combined 6-tank aquaponic system installed under the benches.

Results

The total energy consumption for greenhouse heating was less with the installed aquaponic system, a higher yield was achieved and additional CO_2 supply for the greenhouse was strongly reduced.

In addition, CO_2 supply for elevated CO_2 level could be reduced strongly by the supply from aquaculture. A regular dosage of 2.89 kg m-2 year-1 was needed, while this could be reduced to 0.35 kg /m^2 / year (Fig 1). In addition, due to the higher CO_2 level in the case with aquaponics (since active CO_2 supply stopped with vent opening at >10%), a fresh yield increase from 43 to 49 kg /m^2 was achieved, i.e. a 14% yield increase. Assuming an average lettuce target head weight of 250 g, 24 more heads per m^2 greenhouse were produced each year (i.e. 24000 more heads in total for the 1000 m^2 greenhouse). However, lettuce development time was not taken into account here, and a higher individual head yield would be another possibility.

The comparing simulations show that heating for greenhouse could be reduced from 1.0798 GJ /m^2 by 21% or 0.22 GJ /m^2 / year to 0.8569 GJ /m^2. In total, the aquaponic system could save 223 GJ heat energy. Both cases used electricity for lamp-light consumption of 0.637 GJ /m^2.

Discussion and conclusion

Based on the simulations for the Danish reference climate year, the symbiotic effects from aquaponics on CO_2 and energy were quite substantial. Economically the variable cost savings amounted to app. 6.500 Euro per year for the 1.000 m^2 aquaponic production. However, these fairly high variable cost savings would also have to be compared with similarly high fixed investment cost for the aquaponic plant and the included CO_2 dosage system. The modeling indicates though that an aquaponic production of this size will be better off relying on the CO_2 from the fish alone. Further scenarios are in the making and the model will be validated via tests in the IGFF aquaponic test plant. The model developed is planned to be an important tool in the future delivering input to contribution accounts in business plans promoting aquaponics.

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