MODELLING THE SYMBIOTIC EFFECTS IN AQUAPONICS

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Introduction

Aquaponic systems are recirculating aquaculture systems that incorporate the production of plants without soil (Rakocy, J.E., 2012). 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 CO2, which the plants can utilize hence reduce cost on purchasing CO2 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. In this study the symbiotic effects from CO2 and heat contribution have been modeled to quantify their physical environmental impact and economic savings on the variable costs.

Materials and methods

Year round simulation were performed with the core of The Virtual Greenhouse^{TM} 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 m^2 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^{-1} and a peak water exchange of 0.58 m^3 h^{-1} 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 28C and a maximum of 32C 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-1 feed with 13608 J g-1 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^{-1}, 39.54 J g^{-1} and 17.15 J g^{-1} 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 Wm^{-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 22C year round. No distinguish between seasons, day and night and cultivation stage was done for model simplification. CO2 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} $year^{-1}$ (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} $year^{-1}$ 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 m2 aquaponic production. However, these fairly high variable costs 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 an aquaponic demo-plant. The model developed is planned to be an important tool in the future delivering input to contribution accounts in business plans promoting aquaponics.

References

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