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Basil (*Ocimum basilicum* L.) harvest and plant replacement methods in aquaponia

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SUMMARY

The aim of the study is to investigate the potential of basil leaf mass production under aquaponic conditions with different harvest and plant replacement methods. Aquaponics is a combination of soil-less crop production hydroponics and aquaculture and it is can use and clean the wastewater of intensive aquaculture systems. Three groups were established in the 6 units during the six-week harvest and seedling rotation cycles. Group 1 individuals remain in the units throughout the breeding season. Group 2 individuals were replaced every 12 weeks, while Group 3 individuals were replaced every six weeks, at the same time as harvest. Data from the experiment were analysed to determine how the harvest and replacement protocol of basil plants influences the amount of leaves harvested, the percentage of leaves harvested relative to the plant stem, and the changes in plant height, SPAD and NDVI during harvest and replacement. A continuously maintained and harvested healthy basil stock under aquaponic conditions can provide a consistent leaf mass all year round without the extra cost of replacing and producing seedlings.

Keywords: *Aquaponia; basil; leaf mass; plant replacement methods*

INTRODUCTION

The human population is growing rapidly. It recently passed the 7 billion mark and 8.5 billion by 2030 and 9.7 billion for 2050 was predicted (Saha et al., 2016). With the global population growing at this rate, agricultural production has to keep pace, while the proportion of usable land is steadily declining in favour of urban sprawl. New challenges such as soil degradation, drought and the development of urban areas can be managed by modifying and improving agricultural systems (Lehman et al., 1993; Lal, 2013). New alternative food production systems that require little space, soil and water, and can be located in urban environments, will certainly play a significant role in the agriculture of the future (Medina et al., 2016).

Today, aquaculture has become one of the fastest growing food sectors, suppllies nearly half of the growing population's demand for seafood (Rastegari et al., 2023). Aquaculture is the farming of various freshwater and marine fish, crustaceans and molluscs under controlled conditions. Maintaining good water quality, providing good quality food, promoting reproduction and minimising disease and predators are essential for successful production (Shang, 1981).

Since 2015, global aquaculture production has exceeded 160 million tonnes per year, with inland aquaculture playing a prominent role (FAO, 2022). This is accelerated by the demands of a growing population and the depletion and limitation of natural water resources (Wang et al., 2021).

Run-off water from intensive aquaculture systems could be a potential environmental problem (Piedrahita, 2003), which can be reduced by aquaponics technology (Schneider et al., 2005). Aquaponics is a combined technology system that can increase the profitability of monoculture aquaculture while reducing its environmental impact (Rakocy and Hargreaves, 1993).

Today, the logistics of producing food and getting it to cities require the use of intensive polluting technologies. Aquaponics can also be a response to these factors, with the supply of locally produced vegetables and fish, especially in smaller settlements, providing social and economic development in urban farming (Love et al., 2015; Santos, 2016).

Aquaponics is a combination of soil-less crop production hydroponics and aquaculture (Seawright et al., 1998; Rakocy et al., 2006; Csorvási et al., 2014). This is also how the Anglo-Saxon name originated (Peley and Gönczi, 2013). In a form that can be used in the modern food industry, it was created nearly 30 years ago by researchers at the New Alchemy Institute and North Carolina State University. In Hungary, it was first set up on an experimental basis in 2003 at the Research Institute of Fisheries and Irrigation in Szarvas. Aquaponics, as part of agriculture, can be classified as both livestock and crop production because of its combined system (Peley et al., 2012).

According to Mchunu et al. (2018) aquaponics is a complex fish farming and plant production system that can contribute in a productive and innovative way to solving today's agricultural problems such as drought, soil pollution and climate change. Especially, because aquaponics can generate high yields per unit area using limited land, water and soil (Saha et al., 2016).

The benefits of aquaponics, in addition to aquaculture and hydroponics, are that it minimises the amount of fertiliser needed, the environmental impact of agricultural run-off and filters water as a biofilter for

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the fishes (Rakocy et al., 2006). Plants obtain their nutrients from fish faeces, microbial decomposition of organic waste and uneaten fish feed (Roosta and Hamidpour, 2011).

Aquaponics technology is constantly evolving Suhl et al. (2016) have developed an aquaponics system that uses water from fish farming – in their research – in a separate system for hydroponic crop production, supplemented by conventional nutrient supplementation. As the DRAPS (double recirculating aquaponic system) fish rearing and plant production units they have developed operate in two separate systems, the nutrient replenishment and plant protection used in plant production does not adversely affect fish production.

In soil-less systems, the selection of plants for cultivation is extremely important. Culinary herbs are the best choice for aquaponical plant production, because they are capable make the highest level of income per unit of culture area and per unit of time (Rakocy, 2012). Basil (*Ocimum basilicum* L.) is an annual plant whose fresh and dried leaves are commercially important for food industry (Chalchat and Ozcan, 2008). Basil is a characteristic, essential oil-containing, well-known and popular ornamental, herbaceous medicinal plant (Ahmed et al., 2014) and also used in perfume compositions (Nguyen et al., 2010). It is used for its diuretic and stimulating properties and in traditional medicine against bronchitis, coughs, and sorethroat, in foods and flavorings worldwide (Vieira and Simon, 2000). It is marketed in raw and dried form and as an essential oil – rich in phenolic compounds – used worldwide in the pharmaceutical and perfume industries (Bernstein et al., 2010). It is a constituent of several tea blends, including cough suppressants, appetite stimulants, diuretics, diaphoretic and milk secretion enhancers. Its alcoholic extract can be used in mouthwashes and gargle liquids. It is a well-known flavouring (pizza, soups, salads, egg preparations) and is an important flavouring in fish preserves, soft drinks and liqueur recipes. Its essential oils are also used by the food and perfume industries (Bernáth, 2000).

According to Love et al. (2015), basil was the most frequently used crop under commercial aquaponic production. In Rakocy et al. (2004b) investigations the production of the plant was measured in an outdoor commercial-scale raft aquaponic system in the Caribbean, by the University of the Virgin Islands (USA) with a mean yield of 2.0 kg m^{-2} in batch production (Rakocy et al., 2004a) or an annual projected basil yield of 25.0 kg m^{-3} (Rakocy et al., 2004b). Basil is suitable for soilless production, and particularly beneficial as aquaponic or hydroponic crop (Rakocy et al., 2004a; Roosta, 2014; Mangmang et al., 2016). It is make better yield under soilless systems than conventional systems. Rakocy et al. (2004a) measured higher yield (1.8 kg m^{-2}) with aquaponic than field basil (0.6 kg m^{-2}).

MATERIALS AND METHODS

The aim of the study is to investigate the potential of basil green mass rearing under aquaponic conditions. To this end, three groups were set in four repetitions in six units. 150 plants were placed per unit and divided in two, giving an average of 75 plants per repetition. The first group stayed in the units from the first planting through the entire growing season, cutting back at harvest. The plants in the second group were rotated every 12 weeks, so that after the first six weeks they were harvested by cutting back. Plants in the third group were rotated at every six-week harvest.

The first sowing took place on 4 February. 14 basil seeds of the Genovese variety were sown in 14 seed trays with 84 holes at a depth of 1 cm. With this quantity of nearly 1,200 pieces, taking into account the potential loss. We planted the seedlings in the aquaponic units on 1 April. 150 were placed in a unit, in 6 rows of 25 plants per row, with a row spacing of 24 cm and a spacing of 22 cm.

Three groups were established in the 6 units during the six-week harvest and seedling rotation cycles. Group 1 individuals remain in the units throughout the breeding season. Group 2 individuals were replaced every 12 weeks, while Group 3 individuals were replaced every six weeks, at the same time as harvest. The groups were randomly paired per unit, so they were set up in four replicates. Basil plant height, SPAD (Konica Minolta Chlorophyll Meter SPAD-502 Plus) and NDVI (Trimble GreensSeeker Handheld Crop Sensor, Model No. HCS-100) were measured weekly in 10 samples per replicate and per group. The temperature and humidity of the air in the tent were also recorded daily (PCE-THB 40 Humidity/Baro/Temp. DATA RECORDER).

Figure 1 shows the temperature and humidity conditions during the 24 weeks of the experiment (1 April to 21 September). Temperatures averaged around 20 °C for the first four weeks, rising steadily as the summer progressed, often approaching 40 °C. Humidity fluctuated between 40 and 70% throughout the experimental period.

Water was replenished in the units once a week. This was carried out every 5–5 units on Tuesdays and Thursdays, as it was not feasible to change the entire water of the 10 units at once for the maintenance recirculation fish rearing system with a useful water volume of 12 m^3, in which single-fin carp production was carried out. The average population density in the basins was between 20 and 25 kg m^{-3}. We introduced 2–2.5 cubic metres of water per unit from the water we took off the fish.

Harvests were on 13 May, 30 June, 10 August and 21 September. Then, in group 1 and, if not replaced, in group 2, the plants were cut back to the first leaf buds on average, to the first branching where the plants developed new shoots and stems. The group 3 stock was replaced by a full harvest. In each group and in all four replicates, the total green weight cut off was measured with and without the stem. In addition, the individual weight, leaf weight and leaf percentage of

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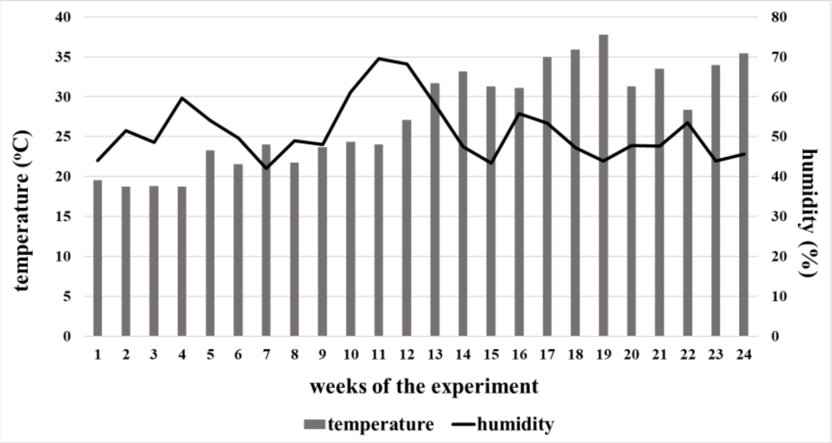
the harvested plants were measured in each group and replicate sample of 10 plants, calculated using the previous two parameters. The leaves were removed by hand from the stems of the plants and then collected in nylon bags and frozen.

Figure 1. **Average weekly temperature and humidity during the experiment**



In the experiment, we wanted to find out whether, under aquaponic conditions, maintaining and continuously cutting the plant population, changing the stock from time to time or from harvest to harvest can produce a higher leaf mass, and how the air temperature and humidity of the foil greenhouse influence this.

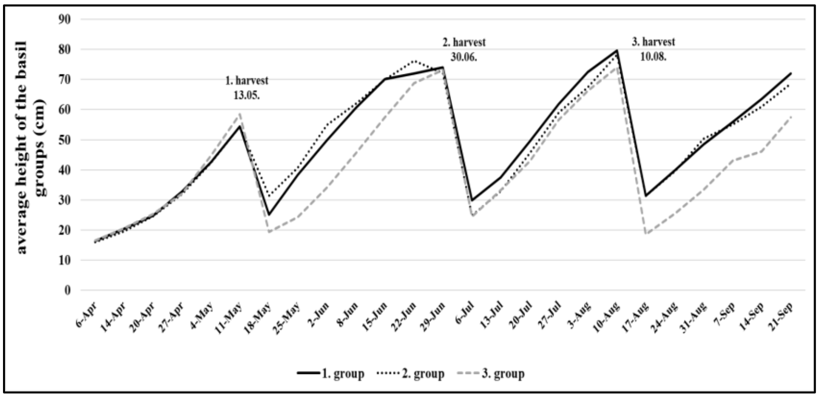
An analysis of variance was used to interpret whether there was a significant difference in the amount of leaves harvested between the different plant groups. Pearson's correlation analysis was used to investigate the effects of age group assignment, increase in the number of harvests, changes in average temperature and humidity during the six weeks prior to harvest on basil plant physiological parameters (SPAD, NDVI and height) and yield (green weight, leaf weight, leaf percentage) measured at harvest. In addition, correlations between the measured parameters of the dataset were analysed too.

RESULTS AND DISCUSSION

Data from the experiment were analysed to determine how the harvest and replacement protocol of basil plants influences the amount of leaves harvested, the percentage of leaves harvested relative to the plant stem, and the changes in plant height, SPAD and NDVI during harvest and replacement. The experiment was designed to find out whether the retention and continuous cutting of the crop, the occasional rotation of the crop, or the rotation per harvest could produce a higher leaf mass.

For height measurements, 10 randomly selected samples were used per group and per replicate. As can be observed, the first and second groups, if the latter was not replaced, always outperformed the third group, which was replaced at each harvest, in terms of height growth intensity (*Figure 2*).

Figure 2. **Average height of the groups**



When SPAD values were examined (*Figure 3*), all three groups showed large fluctuations throughout the experiment. The spike in week 12 can also be explained by the initial rise in temperatures and the humid air that eased it. The decrease in SPAD values observed since the beginning of August was observed for all three groups, which can be attributed to the average temperature approaching 40 °C in the first row.

The NDVI values (*Figure 4*) followed the rhythm of the harvests throughout the experiment, similar to the height values. However, the third group, which changes every six weeks, is also at a disadvantage compared to the other two. This suggests that a young seedling and a plant that has been cut back several times may have different growth abilities, which is caused, among other things, by the difference in the size of the root system.

Figure 3. **Average SPAD values of the groups**

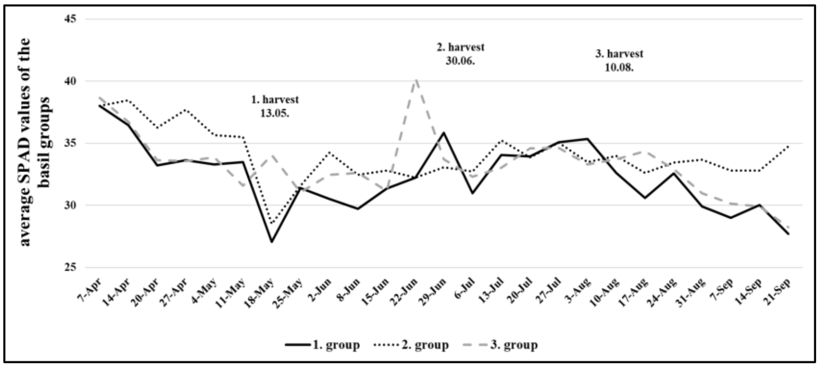
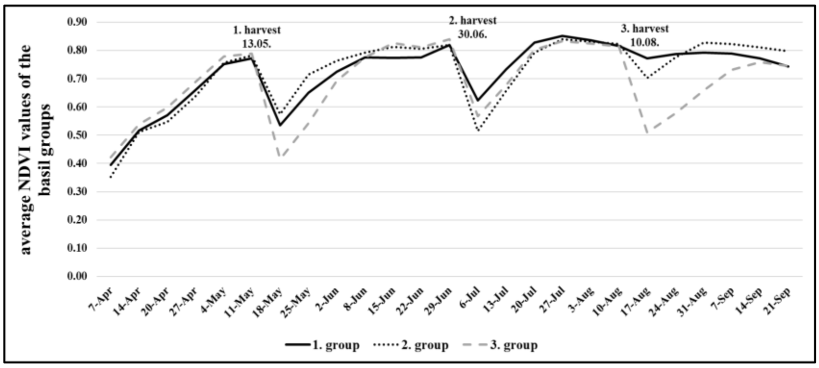
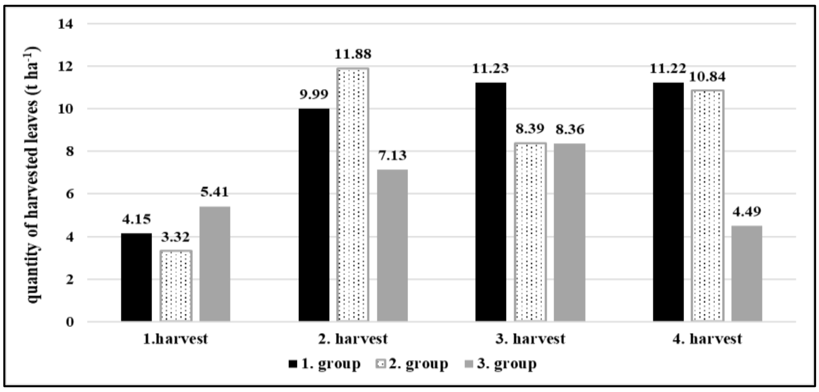


Figure 4. **Average NDVI values of the groups**



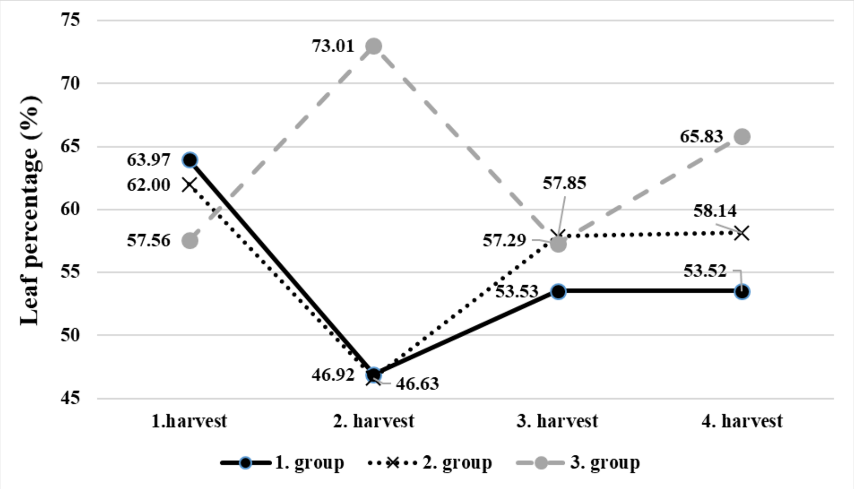
In terms of harvested leaf mass (*Figure 5*), the first group – not rotated – is characterised by continuous and uniform growth. A decline was observed for the second group after the replacements, while the third group, replaced at each harvest, failed to approach the other two in terms of quantity on any occasion. No statistically significant difference was found between the quantities of leaves harvested in the groups ($P_{5\%}$= 0.436).

Figure 5. **Quantity of the harvested leaves**



The percentage of leaves was calculated as a proportion of the total green weight cut. The third group achieved significantly higher values, except for the first harvest. Especially at the second harvest (*Figure 6*). This can be explained by the fact that when basil is cut, the plant develops several new stems, which reduce the percentage of leaves in the harvested green mass. However, as we look at the amount of leaves harvested, the leaf production capacity of cut-back plants that develop more stems is greater than that of young plants that have not yet been cut. No statistically significant difference was found between the quantities of leaves harvested in the groups ($P_{5\%}$= 0.219).

Figure 6. **Average leaf percentage**



Pearson's correlation analysis was used to examine the relationships between the measured plant physiological parameters (*Table 1*). A medium (r=0.699) positive relationship was found between plant height and NDVI values, while a loose (r=0.269) positive relationship was found with leaf weight per individual at 1% significance level. There is also a loose (r=0.289) positive correlation (P=0.01) between NDVI values and leaf weight per individual.

Table 1. **Correlations of plant physiological parameters**

	plant height	**SPAD values**	**NDVI values**	**leaf mass per individual**	**leaf percentage per individual (%)**
plant height	1	-0.059**	**0.699****	**0.269****	-0.029
SPAD values	-0.059**	1	-0.062**	-0.076	-0.002
NDVI values	0.699**	-0.062**	1	**0.289****	-0.010
leaf mass per individual	0.269**	-0.076	0.289**	1	0.123**
leaf percentage per individual (%)	-0.029	0.002	-0.010	0.123**	1

** significant at P=0.01 level, * significant at P=0.05 level

Temperature and humidity measured in a foil greenhouse influenced the measured values of the first group of basil through correlations of several strengths and signs (*Table 2*). The average temperature in the six weeks prior to harvesting is positively correlated with plant height (tight, r=0.806), NDVI (medium, r=0.697) and leaf weight per individual (loose, r=0.481) at the 1% significance level. The percentage of leaves per individual in the total harvested green weight is negatively related to the mean temperature in a loose (r= -0.258, P=0.01) way. Humidity, on the other hand, is negatively correlated with both plant height (medium, r= -0.614), NDVI (loose, r= -0.378) and % leaf per individual (loose, r= -0.273) at the 1% significance level.

Temperature and humidity measured in a foil greenhouse influenced the basal basil values of the second group through correlations of several strengths and signs (*Table 3*). In this case, the average temperature in the six weeks prior to harvesting was closely (r=0.824) positively correlated with plant height, while NDVI was moderately (r=0.690) correlated. Air humidity is negatively correlated with plant height (medium, r= -0.637), NDVI (loose, r= -0.308) and leaf% per individual (loose, r= -0.309) (P=0.01).

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Table 2. **Correlation of temperature and humidity with group 1 data**

	plant height	**SPAD values**	**NDVI values**	**leaf mass per individual**	**leaf percentage per individual (%)**
Average temperature in the six weeks before the harvest (°C)	**0.806****	**-0.354****	**0.697****	**0.481****	**-0.258****
Average humidity in the six weeks before harvest (%)	**-0.614****	0.184*	**-0.378****	-0.089	**-0.273****

** significant at P=0.01 level, * significant at P=0.05 level

Table 3. **Correlation of temperature and humidity with group 2 data**

	plant height	**SPAD values**	**NDVI values**	**leaf mass per individual**	**leaf percentage per individual (%)**
Average temperature in the six weeks before the harvest (°C)	**0.824****	-0.121	**0.690****	0.216**	0.030
Average humidity in the six weeks before harvest (%)	**-0.637****	0.073	**-0.308****	0.245**	**-0.309****

** significant at P=0.01 level, * significant at P=0.05 level

Temperature and humidity measured in a foil greenhouse influenced the basil values of the third group through correlations of several strengths and signs (*Table 4*). Mean temperature was positively related to plant height (close, r=0.855) and NDVI (medium, r=0.716), while SPAD values were negatively related (r= -0.324) at 1% significance level. Variation in humidity was negatively correlated with plant height (medium, r= -0.628) and NDVI (loose, r= -0.401) at the P=0.01 level.

Table 4. **Correlation of temperature and humidity with group 3 data**

	plant height	**SPAD values**	**NDVI values**	**leaf mass per individual**	**leaf percentage per individual (%)**
Average temperature in the six weeks before the harvest (°C)	**0.855****	**-0.324****	**0.716****	0.195*	-0.007
Average humidity in the six weeks before harvest (%)	**-0.628****	0.169*	**-0.401****	0.172*	0.063

** significant at P=0.01 level, * significant at P=0.05 level

CONCLUSIONS

Under our research we have investigated the basil leaf mass productive capacity with different harvest and plant replacement methods in aquaponics system. The height SPAD and NDVI valus of the three group of basil after every harvest was similarly. Only the adaptation abilities of plants of different ages showed minor, but not significant differences. Plant height increase and NDVI values are directly related (r=0.699, P=0.01).

The average temperature of the pre-harvest period had a significant positive effect on basil height and NDVI values for all three groups (P=0.01). In contrast, an increase in average humidity is negatively correlated with all of these. In order to increase the safety and efficiency of cultivation, especially in a system with a high water volume such as aquaponics, it is important to ensure regular aeration. This will ensure a healthy plant population while reducing the occurrence of potential plant protection problems.

As shown by the research of Rakocy et al. (2004a) (measured higher yield (1.8 kg m^{-2} = 18 t ha^{-1}) with aquaponic than field basil (0.6 kg m^{-2} = 6 t ha^{-1})), basil grown in aquaponic conditions can produce very high amounts of marketable green leaf mass in a harvest of up to 11.23 t ha^{-1}, compared to 36.59 t ha^{-1} with four. A continuously maintained and harvested healthy basil plant can provide a consistent leaf mass all year round without the extra cost of replacing and producing seedlings.

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