

Development of a new hybrid aquaponic system for increasing chilli production efficiency

Tamás Mester^{1*}, Gergely Csákberényi-Nagy², Gábor Türk¹, István Lázár³ Nóra Balog², Zsuzsa Pálfi² and Tamás Tóth³

¹Department of Landscape Protection and Environmental Geography, University of Debrecen. Egyetem tér 1. H-4032 Debrecen, Hungary. ²Renewable Energy Park, Kishegyesi út 187. H-4031 Debrecen, Hungary. ³Department of Meteorology, University of Debrecen. Egyetem tér 1. H-4032 Debrecen, Hungary. *E-mail: mester.tamas@science.unideb.hu

Abstract

One of the concerns regarding aquaponic systems operating without conventional soil is the limited selection of plants available for cultivation. For a wider use of aquaponic systems increasing yields are inevitable. The aim of our research, started in 2017, was to eliminate the drawbacks of aquaponic systems using alternative solutions in order to remain in the framework of sustainable agriculture. In order to meet the above challenges, a hybrid, automated aquaponic system was installed in which the soil was not removed completely from the systems that are not completely closed as fish receive fresh water as well as keeping in this way hormones impeding growth at a low level. Crucians and African catfish were placed into two tanks of 7 m³. Further novelty of the system is the application of quail dung in a quantity determined specially for increasing the natural efficiency of the system. Three methods of cultivation were used and plant macro- and micro-elements were measured. Results indicate that the system is suitable for growing different chilli types while quail dung input contributes to increase yield significantly therefore it can be integrated into aquaponic systems excellently.

Key words: Sustainable agriculture, Jalapeno chilli, quail dung, Crucian, African catfish

Introduction

Demand of food for the increasing population puts increasing pressure on natural resources and natural systems (Delaide *et al.*, 2017). Based on UN data, the population of Earth could increase up to 9.6 billion people by 2050 (UN) resulting in the increase of demand for animal protein. Traditional intensive agriculture has to face numerous problems. Climate change, decrease of arable lands, soil degradation, chemicals applied in agriculture, pesticides and other environmental damage caused by cultivation increase the concern for sustainability of agricultural food systems (Kingler and Naylor, 2012; Okemwa, 2015; Nuwansi *et al.*, 2017).

One of the primary characteristics of aquaponic systems combining conventional aquaculture with hydroponics is that they form a closed nutrient system resembling natural ecosystems, and therefore these systems have a major role in sustainable food production (Francis *et al.*, 2003). Integrated production is enabled by aquaponics systems in relation to a wide range of plant and fish species (Nelson, 2007; Diver and Rinehart, 2010; Kristan *et al.*, 2019).

The most common form is the integration of hydroponic beds in the water circuit of a recirculating aquaculture system (RAS) (Goddek *et al.*, 2015). The aim of the integration is to transform nutrients not used by fish into valuable plant biomass. This enables the use of smaller amount of water and significantly reduces the environmental effects of fish farming and hydroponic plant growing (Delaide *et al.*, 2017; Minya *et al.*, 2018).

Aquaponic plant growing designed in accordance with climatic and geographical conditions and taking local market demand

and environmental protection aspects into account could become a true alternative of traditional agricultural cultivation forms (Bindraban *et al.*, 2012; Al-Tawaha *et al.*, 2017). Although, these factors cannot be generalized completely, controlled and standardized systems shall be designed that could be managed easily and viable economically (Sirakov and Velichkova, 2018). In order to make aquaponic systems widespread, increasing the yield is essential.

Traditional aquaponic systems are capable of growing plants without soil. Although this is the primary advantage of the system, it also limits significantly the plants that could be cultivated. Recognising the drawbacks of the systems numerous research projects studied the possibilities to eliminate the drawbacks (Goddek *et al.*, 2015; Bernardino and Fernandes, 2016).

In the present research the ways to eliminate drawbacks of aquaponic systems with alternative solutions are studied staying in the field of sustainable agriculture and increasing the income of the system. In the research, a hybrid aquaponic system is designed in which soil is not removed completely and aquaponic systems are not closed. Fish receive fresh water continuously keeping the level of hormones impeding growth low.

A typical plant produced in soil free aquaponic systems is salad. Growing herbs and chilli types is a novelty of this study. Production of processable chilli types with higher added value that could be stored longer was started. The system is completed by adding quail dung in order to increase the efficiency of production. The study may contribute to the development of integrated and sustainable food production with an analysis of new method applications.

Material and methods

Site location and characteristics: The hybrid aquaponics system is situated at Renewable Energy Park Research Centre (External Department of the University of Debrecen), Debrecen (Fig. 1). The study area is located in Hajdúhát microregion in the eastern part of the Great Hungarian Plain. The once alluvial plain microregion covered with loess and loess silt has heights between 93.4 m and 161.3 m. Around 95% of the soil cover is calcareous chernozem with high fertility developed on loessy sediments. Based on the international soil classification of WRB the soils are Chernozem and Phaeozem (Balla *et al.*, 2015).

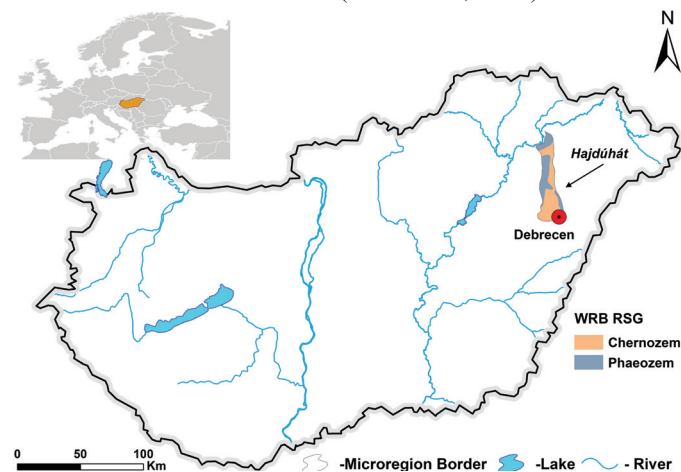


Fig. 1. Location and the Reference Soil Groups of the study area.

The micro-region is moderately warm and dry with 1850-1980 sunny hours annually. The annual mean temperature is 9.7-10.0 °C while that of the summer half year is 16.8-17.1 °C. Daily mean temperatures exceed 10 °C on around 195-196 days from 2nd April to 18th October. In general temperatures would not fall below freezing between 10-13th April and 18-20th October (187-191 day in a year). The annual precipitation varies between 520 and 550 mm in most parts of the microregion, out of which 310-330 mm fall in the growing season. The value of the aridity index is 1.28-1.33 while the depth of the groundwater table varies between 4 and 6 metres (Dövényi, 2010).

Due to the favourable pedological and climatological conditions the microregion is devoted to agriculture characterised by

PLANTING MODES		
1	45% potting soil, 45% normal soil, 10% quail litter	10L bucket
2	normal soil	10L bucket
3	normal soil	free standing
4	normal soil	free standing
5	45% potting soil, 45% normal soil, 10% quail litter	10L bucket
6	50% potting soil, 50% normal soil	10L bucket
7	clay granules	in granules
8	crucians	7 m ³ pool

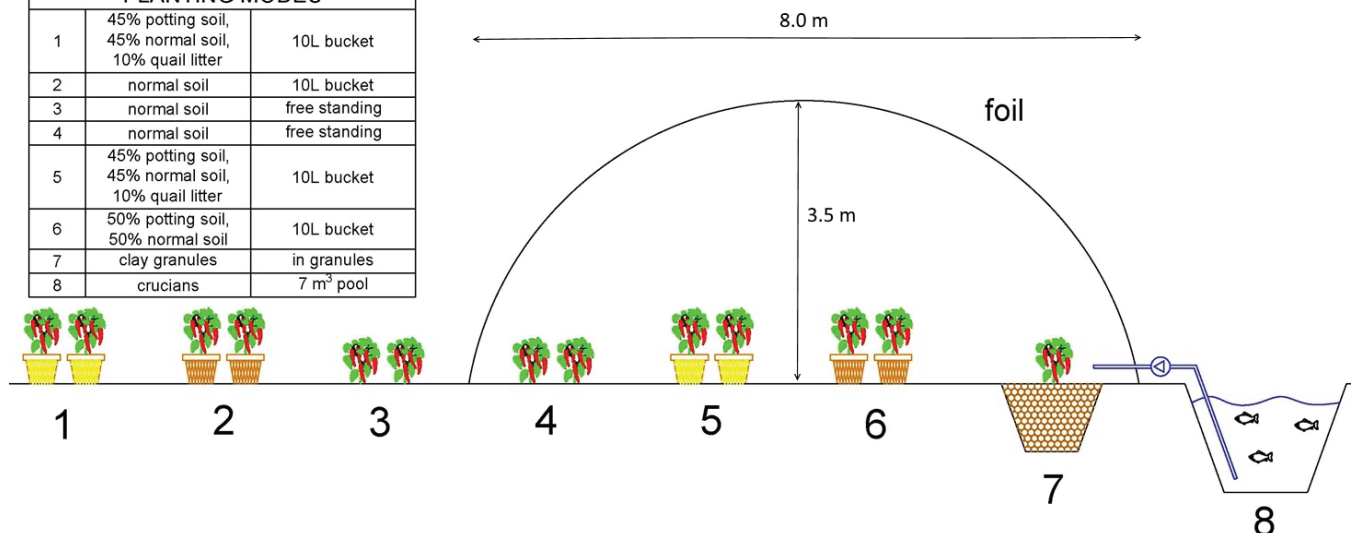


Fig. 2. Schematic outline of the installed hybrid aquaponic system.

intensively cultivated arable crops. Continuous growing is not possible over the year due to climatic conditions, however, diversity in the structure of cultivated plants is low while the environmental effects of chemicals and pesticides are significant that is why alternative plant growing methods are sought.

Design of the hybrid aquaponic system, cultivation methods:

In 2018 two foils with the size of 8 x 12 metres and with an internal height of 3.5 metre were involved in the study together with a third foil (for fish) with similar size in which 6 fish tanks were stored, the size of which was 1 x 7 metres with a depth of 1 metre. 100 kg and 30 kg of African catfish (*Clarias gariepinus* Burchell, 1822) and crucians (*Carassius auratus gibelio*, Bloch, 1782), respectively were installed in the 7 m³ fish tanks. Plants were under drip irrigation in 2017 while this was replaced by sprinkler irrigation in 2018 due to the frequent clogging of jets applied for drip irrigation caused by fish faeces. The system was controlled by a self developed remote control system with Raspberry PI 3 B+ control electronics and relay control. The system can control the circulation of the water supply for fish, gauge fresh water, monitor and control water temperature, influence the time of irrigation based on the external temperature and foil temperature, and determine the soil moisture for plants providing an ideal environment for both fish and plant. The schematic outline of the already installed systems and those to be installed shortly is presented in Fig. 2.

Measurements were performed by a HC2S3 sensor produced by Campbell Scientific Ltd. that detected temperature and relative moisture content. Regarding the operation conditions of the sensor, the temperature range of -40 – 100 °C and the accuracy of 0.1 °C (at 23 °C) are worth mentioning. The sensor was attached to a CR1000 data logger that sampled in every minute and averaged the obtained data by 10 minutes.

In the first year of the project (2017) three different cultivation types were applied. Jalapeno chilli pepper (*Capsicum annuum* 'Jalapeño'), artichoke (*Cynara scolymus*) and Arugula (*Eruca vesicaria ssp. sativa*) were involved in the study. In the first parcel plants were grown in potting soil and irrigated with fish tank effluent (type 1). In the second parcel to the potting and normal soil quail dung was mixed (10%), the plants were irrigated with groundwater (type 2). In the third parcel plants in bucket were

grown in potting soil and irrigated with groundwater (type 3).

In the second phase of the research (2018) two foil tents were involved with 500 jalapeno chilli (*Capsicum annuum* 'Jalapeño'), red cayenne (*Capsicum annuum* 'acuminatum') and Jamaican chilli. The water with fish dung was obtained from a 7 m³ fish tank with crucians. Production versions were increased from 3 to 7. The effects of quail dung to the flower and yield formation were studied separately.

Analytical investigations: Analytical investigation of groundwater supply providing water for the study was performed. Macroelements (Na, Al, Ca, Fe, K, Mg) and microelements (Ba, Cd, Cr, Cu, Li, Mn, Ni, Pb, Sr, Zn) of the water samples and soils used for cultivation were measured using an Agilent Technologies MP-AES 4200 device. Measurements were performed in three parallel repeats three times. Elements of the plant nutrient (NO_3^- , NO_2^- , NH_4^+ , PO_4^{3-}) were measured according to the Hungarian Standards (HS ISO 7150-1:1992. and HS 1484-13:2009). Water pH, electric conductivity and dissolved oxygen content were measured in an automated way using devices integrated into the Rapsberry system (SEN-10972, SEN-12908, EZO-DO™ Dissolved Oxygen Circuit).

Results

Although the hybrid aquaponic system was installed successfully, the installation and operation of sensors was not without problems reflected by the lack of data from time to time. Fig. 3 shows internal and external temperatures. Lack of data is caused by the repeated failure of the internal sensor. Based on experience from the studied period the ideal location and sealing of the sensors to avoid further lack of data were found. Fig. 3 shows daily mean temperatures calculated from data from every 10 minutes.

The annual distribution of external and internal temperatures is presented in Fig. 4. No significant negative difference could be detected in the studied period as only 1-1 days showed differences exceeding -2 and -3 °C. Negative differences could be observed in the mean temperature of 11 days in total, i.e. 4.7% of the studied cases (Fig. 4). Internal temperatures never reached freezing point

(Table 1) and this could be vital for plants. Difference values given in Table 1 represent the mean, minimum, maximum and standard deviation of external and internal temperature pairs. The average difference between the values of the two measurement points is 2.9 °C.

Table 1. Variation in daily mean temperatures during study period

	External	Internal	Difference
Mean	11.9	17.5	2.9
Maximum	30.6	31.9	9.1
Minimum	-13.1	2.7	-3.6
SD	9.3	8.1	2.0

Nutrient content of the groundwater, the crucian (*C. gibelio*) and the African catfish (*C. gariepinus*) water is presented in Fig. 5 while their macro-element and micro-element contents are summarized in Table 2.

In accordance with expectations, inorganic nitrogen and phosphorus content of the crucian and African catfish waters exceeded the values measured in the groundwater.

Data in the table reveal that the chemical parameters of the groundwater and waters from the fish tanks did not exceed the authoritative legal limits. Furthermore, K, Cu, and Na showed higher while Ca exhibited smaller concentration values in waters from the fish tanks than groundwater. To explain this difference, water from the fish tanks contain by-products of the metabolism of fish, while Ca depletion is caused by Ca intake by fish to make their bones healthy and increase their muscles.

Considering cultivation methods, highest phosphate and nitrate contents were measured in samples treated with quail dung (Table 3). Samples irrigated with water with fish manure showed higher phosphate and nitrate contents in all cases.

Higher average nutrient content was measured in the case of plants irrigated with type 1 and 2 water than in the case of plants irrigated with type 3 water. Comparing results with water, chemical concentrations presented in Fig. 5, higher nitrate and phosphate contents were measured in all three plant types in the

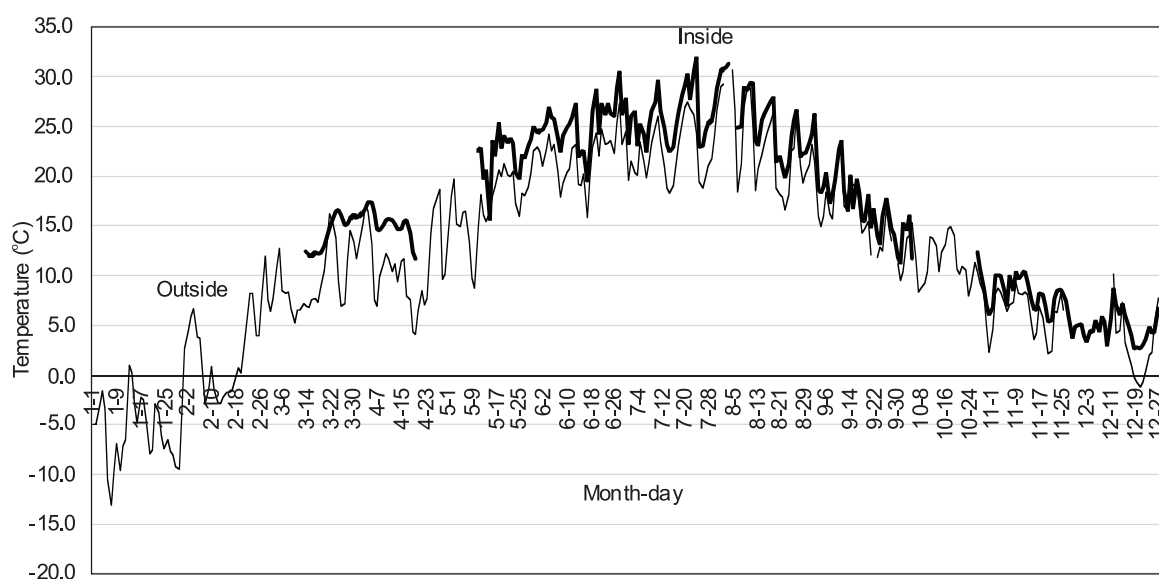


Fig. 3. External and internal daily mean temperatures in 2017

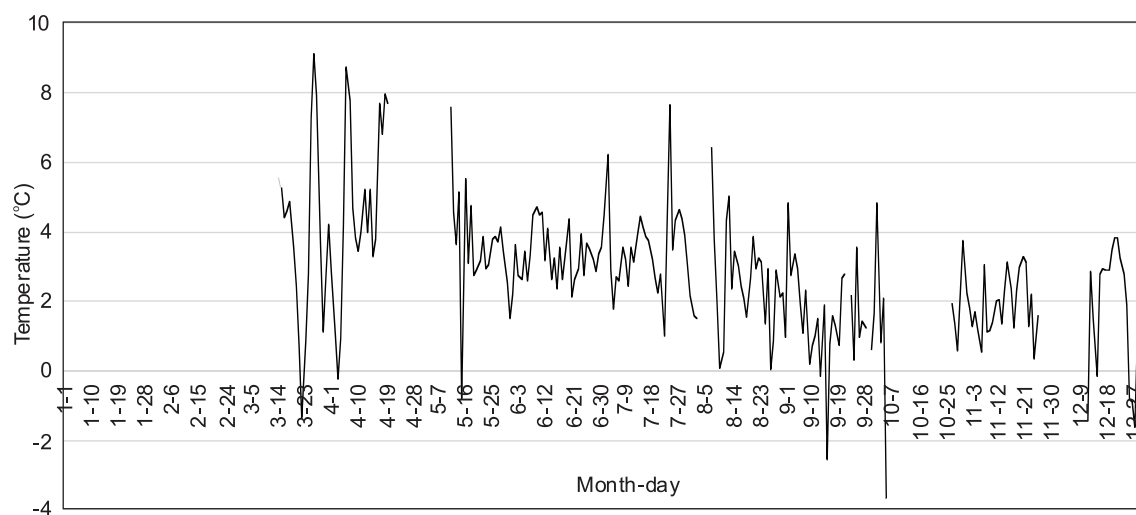


Fig. 4. Differences between external and internal temperatures.

Table 2. Macroelement and microelement content of water samples (mg L⁻¹)

Element	Ground water	Crucian water	African catfish
Na	205.53	214.68	216.57
Al	0.208	0.449	0.145
Ca	116.01	114.51	107.28
Fe	0.53	0.83	0.59
K	9.37	11.08	20.14
Mg	22.38	23.09	23.66
Ba	0.033	0.024	0.044
Cd	0.007	0.004	0.002
Cr	0	0.001	0.001
Cu	0.006	0.013	0.015
Li	0.005	0.005	0.006
Mn	0.718	0.414	0.055
Ni	0.002	0	0
Pb	0.005	0.006	0.006
Sr	0.157	0.165	0.152
Zn	0.029	0.03	0.111

Table 3. P and N concentrations (mg kg⁻¹) measured in the case of different cultivation methods.

Method	Crop	P	P _{ortho}	Nitrate
Type 1	Chilli	35.7	83.2	339.5
	Artichoke	24.3	56.6	63.0
	Arugula	55.5	129.4	377.9
Type 2	Chilli	56.0	130.5	152.9
	Artichoke	79.8	185.9	51.5
	Arugula	90.2	210.2	1535.1
Type 3	Chilli	43.6	101.6	36.0
	Artichoke	40.2	93.5	18.5
	Arugula	36.2	84.3	24.1

case of type 2 water. However, higher phosphate content in the African catfish water compared to that in the crucian water did not cause such degree of nitrogen demand in the case of chilli as indicated by the difference between the nitrate – phosphate content of the crucian water and the values measured in the plants.

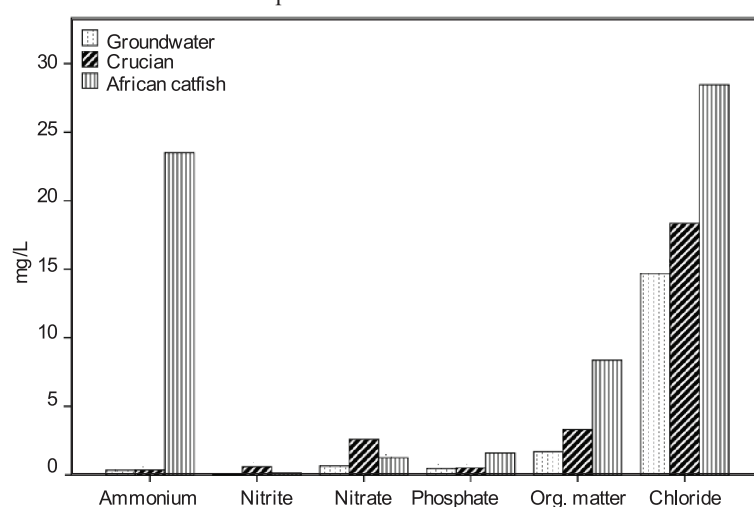


Fig. 5. Nutrient content of waters used for irrigation.

Regarding micro-element and macro-element concentrations, the results of the measurements in the vegetation period show that the mixture of quail dung resulted in a higher concentration of Ba, Zn, Cr and Al, Fe, K, Mg, Mn than the other two cultivation forms (Fig. 6). The samples with a mixture of quail dung contained nearly 50% less Na than the fish tank effluent irrigated samples. P, Sr, Cu concentrations did not show significant differences in the three cultivation forms. Based on the results, it can be stated that the quail dung contributes significantly to the trace supply so that it can be successfully integrated into the aquaponics systems. Table 4 summarizes the macroelement content of the plants in the three cultivation types.

Jalapeno chilli yields in the first year of the project: The first harvest was made on 25/08/2017 and the last harvest on 20/11/2017. Since quail dung significantly slowed the leaching process, the plants had larger leaflets and yield. The average yields of the different planting types are as following: Jalapeno chilli in buckets with quail dung had a yield of 285 g/plant; without quail dung it was only 205 g. Plants in clay granulate had a yield of only 95 g. It can be concluded that quail dung significantly increases yield.

In 2018, three fish tanks with a total volume of 300 m³ were established to be included in the study in 2019. Crucians, starlet and Siberian sturgeon were installed in one tank each. The number of foil tents increased as well to 6 from the current 2 and that enabled us to include 2000 plants in the study. Study on 7

Table 4. Macro element concentrations (mg kg⁻¹) measured in the case of different cultivation types

Method	Crop	Ba	Cd	Co	Cr	Cu	Na	Ni	Pb	Sr	Zn
Type 1	Chilli	242.3	4.8	0.0	95.5	288.3	5002.0	0.0	16.8	145.2	202.3
	Artichoke	245.5	0.0	0.0	103.5	85.5	2881.0	0.0	19.3	127.8	239.3
	Arugula	227.8	0.0	0.0	93.0	98.5	4634.8	0.0	19.3	149.3	246.0
Type 2	Chilli	320.0	0.0	3.5	130.5	74.5	2119.3	0.0	19.5	107.7	298.5
	Artichoke	312.5	0.0	0.0	129.0	78.0	1719.8	0.0	30.3	108.1	262.8
	Arugula	327.5	0.0	0.0	120.5	87.8	2712.0	0.0	18.8	167.7	276.0
Type 3	Chilli	61.0	0.0	0.0	20.3	23.8	1059.3	0.0	7.5	43.9	67.5
	Artichoke	56.3	0.0	0.0	25.3	23.3	1030.0	0.0	11.0	27.7	58.8
	Arugula	56.3	0.0	0.0	20.0	25.8	1517.5	0.0	8.8	40.1	86.5

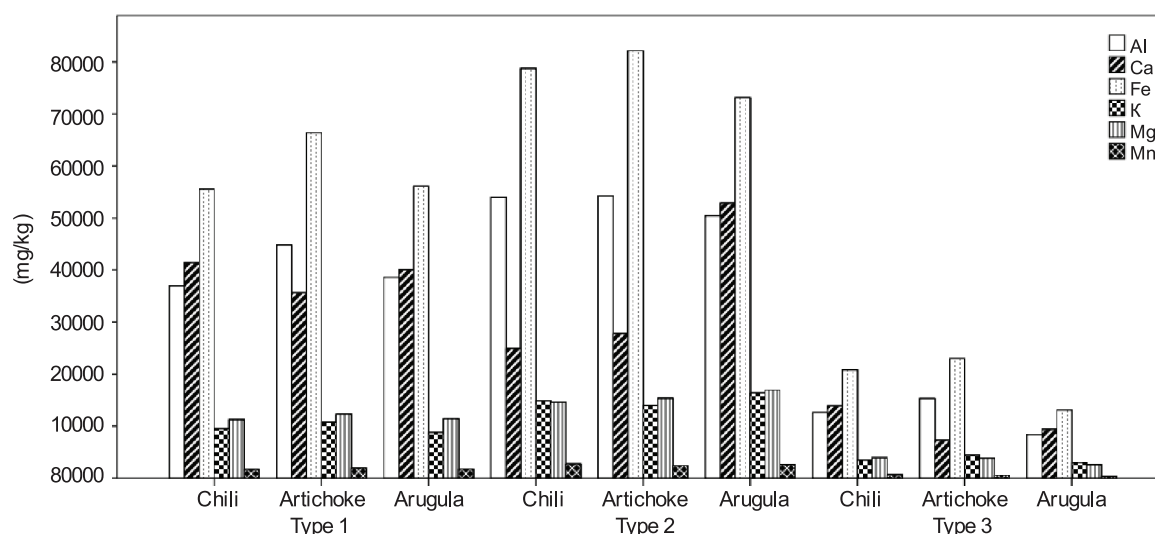


Fig. 6. Microelement concentrations measured in samples from the different cultivation types.

cultivation types carried out focused on the effects of quail dung. Another essential task was to reduce the amount of soil used for cultivation by applying alternative plantation media.

The study revealed that to eliminate the drawbacks of aquaponic systems, a new hybrid system may be adopted. The system is suitable for growing different chilli types. Yield increase can be achieved by adding quail dung to the system. Quail dung reduced the rate of leaching, and increased the amount of nutrients.

References

- Al-Tawaha, A.M., M.W. Puteri Edaroyati and H. Siti Aishah, 2017. Requirements for inserting intercropping in aquaponics system for sustainability in agricultural production system. *Agronomy Research* 15(5): 2048-2067.
- Balla, D., M. Zichar, N. Barkóczi and O.G. Varga, 2015. Cognitive interpretation of different spatial databases in web environment. In: *Cognitive Infocommunications (CogInfoCom), 2015 6th IEEE International Conference* (pp. 159-162). IEEE.
- Bernardino R.J. and C. Fernandes, 2016. Growth performance for European sea bass fingerlings, *Dicentrarchus labrax*, reared at different salinities. *Front. Mar. Sci. Conference Abstract: IMMR [International Meeting on Marine Research]*.
- Bindraban, P.S., M. Van der Velde, L. Ye, M. Van den Berg, S. Materechera, D. I. Kiba, L. Tamene, K.V. Ragnarsdottir, R. Jongschaap and W. Hoogmoed, 2012. Assessing the impact of soil degradation on food production. *Current Opinion in Environmental Sustainability*, 4(5): 478-488. <https://doi.org/10.1016/j.cosust.2012.09.015>
- Delaide, B., G. Delhay, M. Dermience, J. Gott, H. Soyeurt and M.H. Jijakli, 2017. Plant and fish production performance, nutrient mass balances, energy and water use of the PAFF Box, a small-scale aquaponic system. *Aquacultural Engineering*, 78: 130-139. <https://doi.org/10.1016/j.aquaeng.2017.06.002>
- Diver, S. and L. Rinehart, 2010. Aquaponics—Integration of hydroponics and aquaculture (Appropriate technology transfer for rural areas: Horticulture systems guide). *NCAT*, 28 pp.
- Dövényi, Z. 2010. Inventory of microregions in Hungary. Budapest: MTA Földrajztudományi Kutatóintézet. [In Hungarian].
- Francis, C., G. Lieblein, S. Gliessman, T. A. Breland, N. Creamer, R. Harwood, L. Salomonsson, J. Helenius, D. Rickerl and R. Salvador, 2003. Agroecology: The Ecology of Food Systems. *J. Sustain. Agric.* 22: 99–118. https://doi.org/10.1300/J064v22n03_10
- Goddek, S., B. Delaide, U. Mankasingh, K. Ragnarsdottir, H. Jijakli and R. Thorarinsdottir, 2015. Challenges of sustainable and commercial aquaponics. *Sustainability*, 7(4): 4199-4224. <https://doi.org/10.3390/su7044199>
- HS ISO 7150-1:1992 Hungarian Standard Water quality. Determination of ammonium. Part 1: Manual spectrophotometric method
- HS 1484-13:2009 Hungarian Standard Water quality. Part 12: Determination of nitrate and nitrite content by spectrophotometric method
- Klinger, D. and R. Naylor, 2012. Searching for solutions in aquaculture: charting a sustainable course. *Annual Review of Environment and Resources*, 37: 247-276. <https://doi.org/10.1146/annurev-environ-021111-161531>
- Kristan, J., M. Blecha and T. Policar, 2019. Survival and growth rates of

- juvenile Grass Carp *Ctenopharyngodon idella* overwintered in ponds and recirculating aquaculture systems including a comparison of production economics. *Turkish J. Fisheries Aquatic Sciences*, 19(3): 261-266. http://doi.org/10.4194/1303-2712-v19_3_0
- Minya, D., L. Kovács, D. Homoki, M. Fehér, P. Bársony and L. Stündl, 2018. Effect of different weaning time on the growth and survival of Common carp (*Cyprinus carpio* L.) larvae. *Acta Agraria Debreceniensis*, 75: 55-59. <https://ojs.lib.unideb.hu/actaagrar/article/view/1646>
- Nelson, R.L. 2007. Ten aquaponic systems around the world. *Aquaponics Journal*, 46: 1-8.
- Nuwansi, K., A. Verma, V. Tiwari, C. Prakash and M. Chandrakant, 2017. Standardization of the stocking density ratios of Koi carp (*Cyprinus carpio* var. koi): Goldfish (*Carassius auratus*) in Polyculture Aquaponic Recirculating System. *Turkish J. Fisheries Aquatic Sciences*, 17: 1271-1278. http://doi.org/10.4194/1303-2712-v17_6_20
- Okemwa, E. 2015. Challenges and opportunities to sustainability in aquaponic and hydroponics systems. *International J. Scientific Research Innovative Technology*, 2: 54-76.
- Sirakov, I. and K. Velichkova, 2018. The Influence of aquaponically grown duckweed (*Lemna minuta* Kunth) used for composition of sustainable diets on hydrochemical and technological parameters in Carp (*Cyprinus carpio* L.). *Turkish J. Fisheries Aquatic Sciences*, 18: 1037-1044. http://doi.org/10.4194/1303-2712-v18_9_03

Received: May, 2019; Revised: May, 2019; Accepted: June, 2019