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Analysis of Application of Aquaponic System as a Model of the Circular Economy - A Review

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ABSTRACT

In a time of limited water resources, climate change, and significant reductions in fish and plant species, aquaponics systems can play an important role in the future of ecologically and socio-economically sustainable smart cities. The paper aims to investigate the available literature that deals with the topic and current situation related to aquaponics systems - their application, effects of work, perspectives, and shortcomings, as a model of the circular economy. The exploratory method includes a literature review and the analysis of interviews with the pioneers in aquaponics in the Republic of Serbia. The main criterion for reviewing the literature was to find successful examples of aquaponics in the world and the Republic of Serbia. The result of the research is that aquaponics systems, due to the circular way of production, can be included as the model of the circular economy. Among a growing number of aquaponics pioneers, BIGH Farm, ECF Farmsystems, Urban Farmers, Bioaqua Farm, Tilamur, and Water garden currently have a successful implementation of the circular economy. These firms produce food with no waste production, they minimize energy input, and have a positive environmental impact, which are the main aims of the circular economy.

1. Introduction

Nowadays one of the most significant challenges in environmental management across the world is ensuring that human activities conform to the principles of sustainable development (Xu et al., 2014). The circular economy is a system developed for minimizing the use of energy, natural resources, and waste generation (Tura et al., 2019). A circular economy for food consciously emulates natural systems of regeneration so that waste does not exist, but is instead feedstock for another cycle (Ellen MacArthur Foundation, 2019). In the past few years, the current problems in agriculture include the lack of arable land and limited water resources (Mateo-Sagasta et al., 2017; Palm et al., 2018), specifically in developing areas (Joyce, 2019). In a bid to address these problems, the idea of aquaponic system emerged. The circular economy introduces sustainable technological advancements to aquaculture (Hochman et al., 2018).

The idea of applying aquaponics can be useful in countries that have limited resources of agricultural production, a high rate of urbanization, and exponential population growth (Mchunu et al., 2018). Aquaponics has gained momentum due to its superior features compared to traditional production systems because aquaponics seems capable of maintaining ecosystems and strengthening capacity for adaptation to climate change, extreme weather, drought, flooding, and other disasters (Yildiz et al., 2019).

This means that aquaponics is gaining new and increasing attention as an important factor in achieving sustainable food production in the fight against insecurity

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and poverty, both in cities and in rural areas (FAO, 2015). Also, aquaponics is known as one of the "ten technologies which could change human lives" due to its potential to provide essential food for the growing urban population (Van Woensel et al., 2015).

Also, aquaponics is recognized as a solution for sustainable food production as it follows a biomimetic natural system and the circular economy principles by reusing water and nutrients (Goddek et al., 2015; Asciuto et al., 2019).

Aquaponics is a sustainable way of food production that combines aquaculture and hydroponics into a single circular system that mimics natural production systems (Radosavljević et al., 2014), while drastically reducing the negative impact on the environment (Blidariu et al., 2013; Danner et al., 2019).

The parameters and factors that need to be controlled when projecting and managing aquaponic systems are various and represent a major challenge when striving for the highest possible yields and quality (Reyes Yanes et al., 2020). Aquaponics is a complex system in which three different biological systems (fish, plants, and nitrifying bacteria) must be combined into one working system. For this system to function successfully, aquaponics combines several disciplines, such as aquaculture, microbiology, ecology, horticulture, agriculture, chemistry, and engineering (Yep and Zheng, 2019).

This recycling system, due to its significant advantages, has stimulated increasing academic research in recent years and aroused the interest of members of the public, as evidenced by the large number of papers related to this topic (Junge et al., 2019).

In numerous papers, researchers analyze the basic factors and parameters that must be taken into consideration in these systems - system design (Palm et al., 2018), the proper pairing of plant and fish species (Knaus and Palm, 2017), welfare and health of fish (Yildiz et al., 2017), the impact of media on crops cultivated (Oladimejia et al., 2020), water quality parameters (Sallenav, 2016), etc.

Because of the monitoring of the various factors, there is no complete and comprehensive critical analysis of aquaponics. The papers mainly focus on the analysis of one of these factors or on the possibility of improving existing systems and introducing new technologies (Suhl, 2020).

The number of papers and research in this field is limited for the territory of the Republic of Serbia (Radosavljević et al., 2014; Radosavljević et al., 2015; Blagojević et al., 2016).

Therefore, this paper aims to explain the basic principle of the aquaponic system, present its types, list the advantages and disadvantages, present examples from the world and the Republic of Serbia, and lay the foundations for further research of the aquaponic system in the Republic of Serbia.

2. Historical development of aquaponic system

Aquaponics is a hybrid name formed by combining the word aquaculture with hydroponics (Palm, et al., 2018). The earliest example of the use of aquaponics, according to some researchers, dates back to the time of the Maya and Aztecs, who grew plants on raised beams (rafts) on standing water surfaces (Jorge et al., 2011). The traditional name of this method of cultivation, among the Aztecs, comes from the word chinampas, which means an area surrounded by hedges or reeds, and today it is often translated as a floating garden (Figure 1), (https://fourstringfarm.com/2014/04/01/the-floating-gardens-of-aztecs). In addition to the Aztecs, the inhabitants of the area of southern China, Thailand, and Indonesia raised rice with the help of fish (carp, marsh eels, and river snails) and ducks (Figure 2), (McMurtry, 1988; Dai and Xuem, 2015). In China, rice production using aquaponic system dates back to the middle of the Han dynasty around 100 AD (Li, 1988).

Figure 1. Chinampas (https://fourstringfarm.com/2014/04/01/the-floating-gardens-of-aztecs)

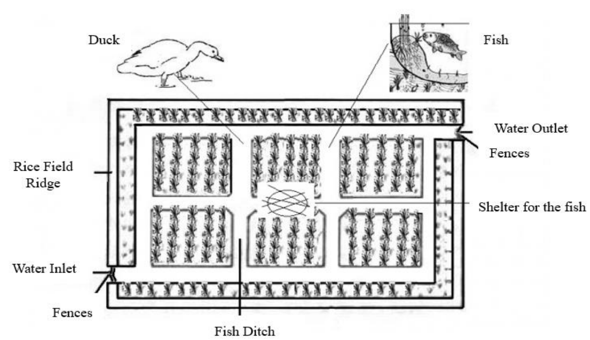

Figure 2. The symbiosis of rice, fish, and ducks (Dai and Xuem, 2015)

3. The operating principle of aquaponics

The circular process of the aquaponic system begins with feeding the fish in a fish tank. After a certain time, the fish excrete waste materials into the water, which are caused by the digestion of food. These products must be removed from the fish tank because their accumulation could be toxic for fish. The water with the fish's

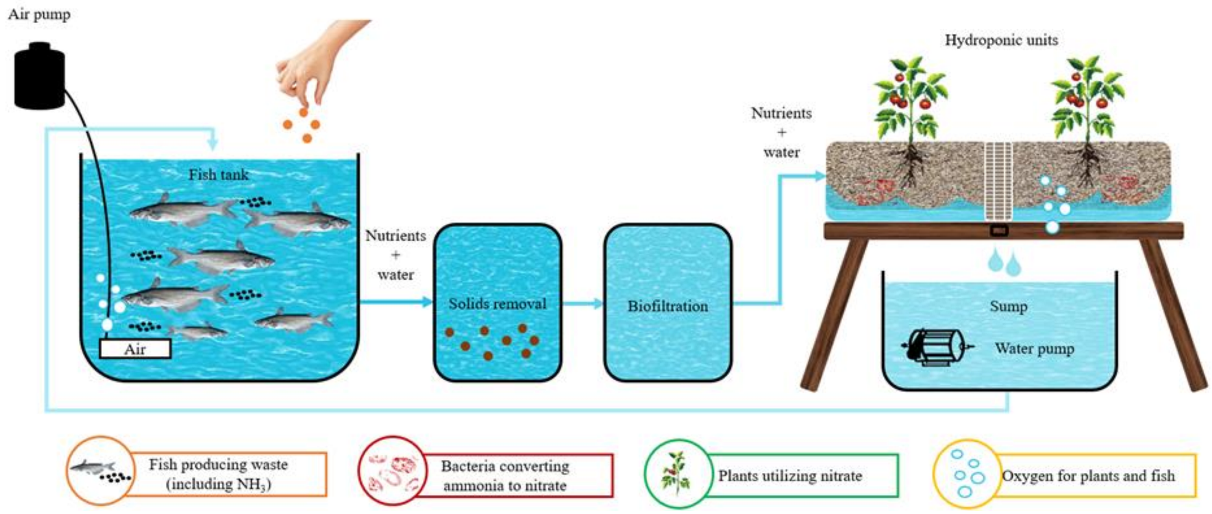

Figure 3. Schematic representation of the aquaponics system

metabolic waste goes to a mechanical filter that collects solid waste. The main task of this filter is to prevent the deposition of particles at the bottom due to the slow movement of water. After mechanical filtration, the water goes to the biofilter. The biofilter is designed to convert the ammonia (waste of fish) into nitrites and then nitrates; which can be consumed by plants. A biofilter is a permanent habitat for bacteria that convert fish waste into nutrients. From there, the water with dissolved nutrients is transported to the hydroponic unit in which the plants are placed, which absorb the nutrients from the water. Biofilters contain a medium such as gravel, sand, various plastic materials, etc. and their role is to ensure the "settlement" of bacteria (Turkmen and Guner, 2010).

At some aquaponic systems, there are no requirements for additional filter because the gravel, clay pellets, perlite, or some other internal substrates used, may act as a surface for bacterial colonization (Bernstein, 2011). The plants take all the nutrients from the water for their needs and act as filters. Namely, they purify the water and the clean water is pumped back to the beginning of the systems, to the fish tank. The process of nutrient removal prevents water from becoming toxic with harmful forms of nitrogen and allows plants, fish, and bacteria to live in symbiosis (Somerville et al., 2014). Thereby, all organisms work together to create a healthy environment for growth and development.

Products grown in aquaponics systems represent a closed cycle and thus avoid the generation of waste in agriculture (Proksch, 2019). The main component of these systems is water circulating between different elements (Krošelj, 2017). In a closed system, water is completely recycled. Plants grown in these systems consume only about 10 % of water (Bernstein, 2011). Figure 3 gives a schematic representation of the aquaponics system.

The crucial and most important part of the aquaponic system is bacteria, which serve as a bridge to connect fish waste with plant fertilizers. Namely, bacteria turn fish waste into fertilizer that plants use for growth. This two-step process involves bacteria of two genera (*Nistrosomonas and Nitrobacter*). Bacteria of the genus

Nitrosomonas, in the first step, oxidizes ammonia, dissolved in water, turning it into nitrite. In the second step, bacteria of the genus *Nitrobacter* converts nitrites to nitrate that plants use, (Figure 4). Many authors in their studies investigate the influence of bacteria on faster plant development. Thus, Eck et al. (2019) gave a global overview of the diversity of bacterial communities, microbial properties, and potentials they can have in plant care. Fanga et al. (2017) studied the introduction of a colony of algae bacteria into aquaponics systems and the improvement of nitrogen efficiency utilization.

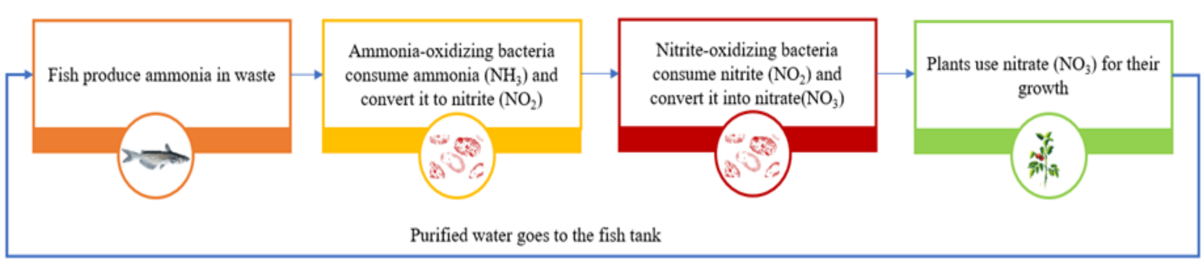

Figure 4. Nitrification process in the aquaponics system

When it comes to fish, the most commonly farmed species are carp, tilapia, ornamental fish, catfish, other aquatic animals, perch, pike, and others (Palm et al., 2019). In addition to these, in aquaponics systems, shrimp, crabs and the like can also be used (Love et al., 2015). Based on currently available research of aquaponics systems, it has not been determined whether the excretion of waste materials has a significant impact on the level of nutrients in the solution or on plant yield.

Further research in this field should help facilitate the selection of ingredients to be used in fish nutrition to improve fish growth and health and to increase yields of farmed plants (Robaina, et al., 2019).

To enable continuous and healthy plant growth in the aquaponics system, it is necessary to have ecological parameters of water and environment (Thorarinsdottir, 2015).

Water is also a very crucial element of the aquaponic system. Water quality and the chemical composition of water can affect each of the elements described above. Therefore, there is a need for continuous water quality and parameters monitoring. In Table 1 is given general water quality tolerances for nitrifying bacteria, fish (fish are grouped into hot and cold water fish), hydroponic plants, and ideal parameters for aquaponics as a compromise between all three organisms (Somerville et al., 2014).

Blagojević et al. (2016), analyzed the water quality in the area of Karlovac (Croatia), in the family home Ozimec, where a small aquaponic system of fish farming and food farming was made. The system was planted with river fish. Water quality was monitored during the breeding cycle. The authors monitored the values of the parameters: ammonia, nitrates, nitrites, and water, and established the optimal values of these parameters for this aquaponics system and determined how one parameter affects the others and vice versa. Tyson et al. (2008) analyzed how a change in pH value of water affects cucumber yield. It means that parameters and factors require a change, depending on the type of plants that will be grown. E.g., leafy vegetables are the most common type of plant grown in these systems because they grow well in concentrated water with nitrogen, have a short growth period, do not require a large number of nutrients and are generally in great demand in the world (Bailey and Ferrarezi, 2017). Commercial producers most often grow the following plant species: basil (Ferrarezi and Bailey, 2019), various types of lettuce, tomato, kale, paprika, and cucumber.

With additional care in these systems, eggplant and root plants, such as carrots (Bosma, 2017), onions, beets, and radishes (Somerville et al., 2014), can also be grown, as well as kale, thyme, barley, various types of flowers, etc. (Buzby et al., 2016).

Each element of the aquaponics system (plants, fish, and water) can be considered individually, also for each of them problems that may occur during the operation of the aquaponics system can be defined. Table 2 presents the problems that can occur with individual elements during the production process in an aquaponics system.

Table 1
General water quality tolerances for nitrifying bacteria, fish, hydroponic plants and ideal parameters for aquaponics as a compromise between all three organisms (Somerville et al., 2014)

Organism type	**Temp**	**pH**	**Ammonia**	**Nitrite**	**Nitrate**	**Dissolved O_2**
	[°C]	[mg/L]	[mg/L]	[mg/L]	[mg/L]	[mg/L]
Bacteria	14 - 34	6 - 8.5	< 3	< 1	-	4 - 8
Warm water fish	22 - 32	6 - 8.5	< 3	< 1	< 400	4 - 6
Cold water fish	10 - 18	6 - 8.5	< 1	< 0.1	< 400	6 - 8
Plants	16 - 30	5.5 - 7.5	< 30	< 1	-	> 3
Ideal parameters	18 - 30	6 - 7	< 1	< 1	5 - 150	> 5

Table 2
Problems with individual elements in the aquaponics system

Plant problems	**Fish problems**	**Water problems**
- Deficiencies and toxicity of some nutrients (Rakocy et al., 2006), - Plants are not growing and/or leaves are changing color (Somerville et al., 2014), - Nitrate levels are high yet plants leaves are yellowing (Somerville et al., 2014),	- Fish are piping at the water surface (Somerville et al., 2014) - Fish are not eating (Somerville et al., 2014), - Accumulation of fish in the system, consumption of space and food (Tyson et al., 2008), - The water temperature is too high or too low (Somerville et al., 2014),	- Temperature (Somerville et al., 2014), - pH (Somerville et al., 2014), - Nitrate or nitrite level (Somerville et al., 2014), - Carbonate hardness (Somerville et al., 2014), - Algae (Somerville et al., 2014), - Low dissolved oxygen (Somerville et al., 2014),

4. Basic cultivation techniques in aquaponics systems

Hitherto, in practice, three cultivation techniques in aquaponics systems are used: Nutrient film technique (Castillo-Castellanos et al., 2016), Media bed technique (Kamauddin et al., 2019), and Deep water culture technique (Somerville et al., 2014). The nutrient film technique (Figure 5) is a hydroponic method that uses horizontal pipes (Somerville et al., 2014). Through each pipe, there is a shallow stream of nutrient - rich aquaponic water. This water provides the necessary amounts of nutrients for plant growth. It is necessary to install a mechanical filter at the beginning, to avoid the accumulation of solids at the root of the plant. The water flows by gravity from the fish tank, through the mechanical filter and flows into the combination biofilter/sump. Through a "Y" connector and valves from the biofilter/sump, the water is pumped in two directions. Water can be pumped directly back to the fish tank, or it can be pumped into a manifold that distributes the water equally through the pipes. Again by gravity, the water flows down through the grow pipes.

The water outlet is at the end of the pipes. From the grow pipes water is returned to biofilter/sump, where again it is pumped either into the fish tank or grow pipes, thus ending the cycle (Somerville et al., 2014).

Plastic pipes are usually used as a material for these systems. Pipes are with a flat bottom and are angled by 1 %, to enable the gravity fall of water. Pipes dimensions are defined, and, usually, they should not exceed 10 m to avoid the loss of dissolved oxygen. Each pipe has holes, and the dimension of the hole matches the size of the available net cups. The plants are planted into the net cups, which are placed into the holes. These systems are suitable for growing lettuce and herbs (Maucieri et al., 2019), as well as for growing crops on concrete floors or roofs.

The advantage of these systems is the recirculation of nutrients and the absence of substrates. Thereby, there is a great potential for system automation while reducing operating costs and managing the optimal density of plants during its cycle. On the other hand, the lack of substrate and low water level in these systems creates the possibility of failure of the pump, or pipe clogging (Thorarinsdottir, 2015).

Media-filled bed units are the most popular design for small-scale aquaponics (Mullins et al., 2015). Figure 6 shows the main components of an aquaponic system using media beds, including the fish tank, the media beds, the sump tank, and the water pump. The media bed system is filled with suitable growing media such as expanded clay pebbles, lava rock/pumice stones or gravel. The water from the fish tank is pumped over to the media filled beds, and the plants grow in the clay or rock media. Many materials can be used as a medium in a media-bed system.

The media must be organic and have an adequate surface area to allow bacteria to grow and water to flow to the plants' roots. The first function of the medium is to help the root of the plant to more easily take nutrients from the water, and the second function is to use it as a filter, both mechanically (particle removal) and as biological (bacterial colonization). Gravel, spheres, coconut trust, vermiculite, etc. are most often used as a medium. There are three growing zones, based on the medium, within the bed: surface or dry zone, root zone, and zone of solid particle collection and mineralization (https://gogreenaquaponics.com).

This aquaponics system design has a relatively low starting price and can be expanded relatively easily with certain limitations. However, although they are classified as the simplest systems of growing crops, these systems also have certain weaknesses, e.g., water evaporation is higher in these systems (Thorarinsdottir, 2015).

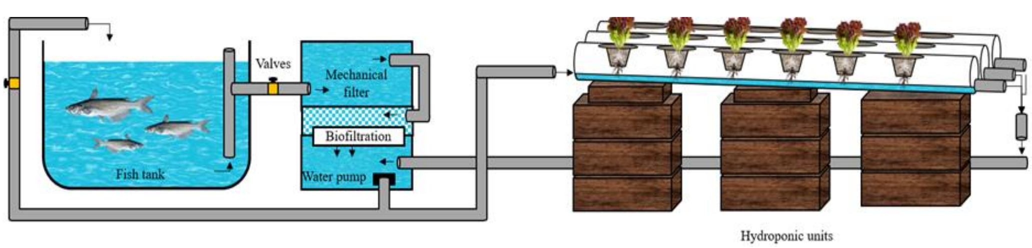

Figure 5. Nutrient film technique

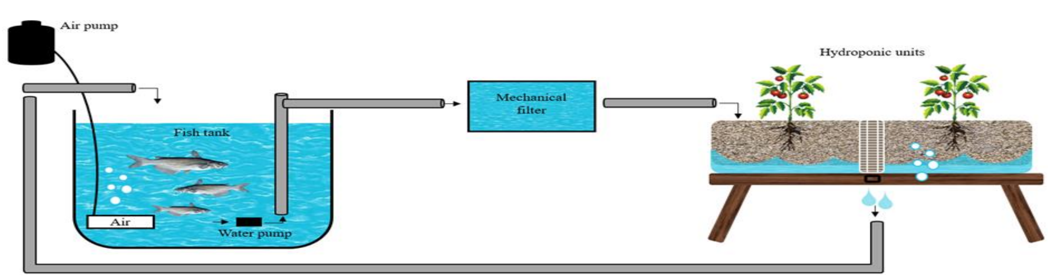

Figure 6. Media bed technique

Deep water culture techniques (Figure 7) are used for small and large aquaponic systems (Thorarinsdottir, 2015). The idea for this type of production is taken from Aztecs, who grew their crops in the same way. Deep water culture techniques are based on growing plants on floating or hanging supports (raft, plates, or boards) in troughs or containers filled with water with nutrient solution at a depth of 10 - 30 cm. Water containers are equipped with various floating material that serves to keep the plants above water, while the root of the plant itself is constantly submerged in water (Maucieri et al., 2019). The water flow dynamics in deep water culture techniques are almost identical to those through a nutrient film method.

The main difference between the nutrient film method and the deep water culture techniques is that in these systems, water is not drained from the container, namely, a large amount of water is constantly present, allowing the plants to use significant amounts of nutrients (Somerville et al., 2014).

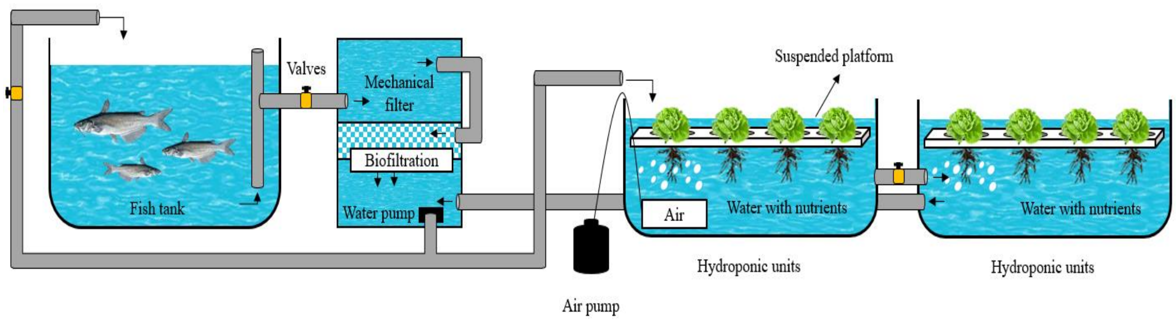

Figure 7. Deep water culture technique

Table 3
Strength and weaknesses of aquaponic systems

Strength	Weaknesses
– Organic food production (Acquacoltura Italia srl, 2016), – The possibility of applying cultivation in locations with infertile soil or without soil (Benko and Fabek, 2011), – Two agricultural products (fish and vegetables) are produced from one nitrogen source (fish food) (Somerville et al., 2014), – A wide range of cultivated aquatic animal and plant species (Acquacoltura Italia srl, 2016), – Higher yields and qualitative production (Somerville et al., 2014) , – Does not use fertilizers or chemical pesticides (Somerville et al., 2014), – There are no daily tasks, like as harvesting and planting are labor-saving (Somerville et al., 2014), – Rational water consumption (Somerville et al., 2014), – A small amount of waste is generated (Somerville et al., 2014), – Higher control on production leading to lower losses (Somerville et al., 2014), – Can be built in many ways according to the materials available (Somerville et al., 2014), – An integral part of sustainable cities (providing a better climate in institutions, landscaping, etc.) (Rizal et al., 2018), – Can be integrated into the local water cycle (use of rainwater, instead of freshwater) (Rizal et al., 2018), – Education (as an educational tool in schools) (Rizal et al., 2018), – Possibility of application of culture cultivation in space (mars) (Acquacoltura Italia srl, 2016), – Save time (hoeing, watering ...) (Rakocy et al., 2006), – Building materials and databases are widely available (Somerville et al., 2014),	– Expensive initial startup costs compared with soil production or hydroponics (Somerville et al., 2014), – Knowledge of fish, bacteria, and plant production is needed for each farmer to be successful (Somerville et al., 2014), – Fish and plant requirements do not always match perfectly (Somerville et al., 2014), – Limited types of the crop (El-Essawy et al., 2019), – Required techniques and knowledge to manage the use of equipment (Munoz, 2010), – Energy demanding (Somerville et al., 2014), – Requires reliable access to electricity, fish fingerlings, and plant the seed, especially for large aquaponics systems (El-Essawy et al., 2019),

The disadvantage of these systems is the provision of a stable and clean system due to the deposition of organic matter at the bottom of water containers, as sludge can accumulate on plant roots, so the plant can use a small amount of oxygen and nutrients from water (Palm et al., 2019). This type of hydroponic system is suitable for perennial crops, such as tomatoes, peppers, eggplant, cucumbers, zucchini, beans, etc. (FAO, 2013). In addition to the above, new methods are being developed for growing crops, such as aeroponic. The aeroponic technique is mainly aimed at smaller horticultural species and has not yet been widely used due to the high investment and management costs. Plants are supported by plastic panels or by polystyrene, arranged horizontally, or on inclined tops of growing boxes. These panels are supported by a structure made with inert materials, to form closed boxes where the suspended root system can develop. The nutrient solution is directly sprayed on the roots. The spray duration is from 30 to 60 s, whilst the frequency varies depending on the cultivation period, the growth stage of the plants, the species, and the time of day (Maucieri et al., 2019).

Although aquaponics offers many advantages compared to traditional agricultural systems, there are certain disadvantages, i.e. limitations in the spread of aquaponic cultivation techniques. Table 3 presents the strength and weaknesses of aquaponic systems.

There are currently no specific regulations or policies for the application of the aquaponics system in the European Union or most of its Member States. One of the reasons is that this area belongs to different ministries that are responsible for them (industrial aquaculture, wastewater recycling, hydroponics, and urban aquaculture), where producers are subject to potentially various and conflicting regulations (Reinhardt et al., 2019).

5. Application of aquaponics systems in the world

5.1. The first aquaponics farm - Brussels, Belgium

The Brussels star-up BIGH (Building Integrated Green Houses), which has the task of building a network of sustainable Aquaponic urban farms in larger cities, has opened its first large farm in Brussels. The farm combines a 2,000 m^2 greenhouse and a 2,000 m^2 outdoor garden, located on the roof of the Foodmet market hall (Figure 8). The company has developed an aquaponics system where fish, fruits, vegetables, and herbs are grown in a closed and zero waste loop. This farm applies the latest sustainable technology and takes into account the energy losses in buildings, as well as the use and recycling of rainwater and the use of renewable solar energy (https://bigh.farm). In one year, the fish farm can produce 35 tons of high quality striped bass fish per year.

The greenhouse produces herbs, tomatoes, and microgreens. The first 700 m^2 of the outdoor garden has been cultivated since 2016, and its total area of 2,000 m^2 will be developed over time.

Production capacity depends on varieties, sizes, and temperature (https://bigh.farm).

Figure 8. Greenhouse and outdoor garden (https://bigh.farm; https://agenda.brussels/en/468756/tour-of-ferme-abattoir-the-biggest-urban-farm-in-europe; https://www.construction21.org/infrastructure/be/abattoir-bigh-farm.html)

5.2. Efficient City Farm (ECF) - Germany

ECF was founded as a private limited company in 2012. Its goal was to implement aquaponic systems in farming, especially within the urban environment with close market proximity. They started building its prototype aquaponics farm in Berlin in 2014, and the farm started with production in 2015. ECF is a food producer that serves 2 distinct markets - supermarkets and HoReCa (Hotels, Restaurants, and Catering). ECF's aquaponics farm brings together in one urban location, fish farming (invites), and plant cultivation (in a greenhouse). It concentrates on one species in the respective domains - tilapia and basil (Figure 9), (Figeac, 2019).

Figure 9. ECF's aquaponics farm (http://www.ecf-farmsystems.com/en)

On this farm, they use two circles in aquaponics: the aquaculture circle for fish and the hydroponic circle for plants. This offers three decisive advantages - two different pH values can be set, optimized for the respective circuit. In hydroponics, minerals that are important for the plants can be added as substitution fertilizers without harming the fish. Each circuit can be switched off independently of the other for cleaning and maintenance purposes, which minimizes the risk of production. The water is used twice, and the fish excrements are used as fertilizer for the plants (http://www.ecf-farmsystems.com/en).

5.3. Urban Farmers - The Hague, Netherlands

The roof and sixth floor of De Schilde, a former Philips factory in The Hague, have given way to the large European aquaponics farm Urban Farmers, (Figure 10). The construction consists of a 1,200 m^2 greenhouse on the rooftop and 900 m^2 of space for fish cultivation on the floor below. Together, they form a perfect symbiotic system for fish and vegetable production within the city, in which the dirty water from the fish tanks is pumped into the planter beds to feed the plants, which in turn filter the water for the fish. Both floors also house irrigation systems, technical installations, and fish and vegetable processing rooms, (http://www.spaceandmatter.nl/urbanfarmers).

Figure 10. Aquaponic garden on the roof of a building in the Hague (http://www.spaceandmatter.nl/urbanfarmers)

5.4. Bioaqua farm - United Kingdom

Near Frome in Somerset, UK, there is a large aquaponic farm - Bioaqua farm (https://www.newfoodentrepreneurs.org.uk/index.php/training-support/61-bioaqua-farm), (Figure 11). The farm has a total area of 4,000 m^2, of which the aquaponics system covers an area of 1,700 m^2 and the orchard about 2,000 m^2. Investment costs were about € 111,000.

Figure 11. Bioaqua farm - UK (Bioaqua farm, 2016)

About 2 tons of trout and about 6 tons of various fruits and vegetables are produced annually (Bioaqua farm, 2016). The process uses about 95 % less water than is needed to grow plants by traditional methods (https://www.fresh-range.com/bristol/producer/bioaquafarm).

On this location vegetables, fruits, and fish are grown together. Also, a small part of the farm is used for experimenting with various ecological techniques to provide zero waste cultivation. The water used in the aquaponic garden is also used to irrigate the orchards. Besides, 4 rainwater collection pools contain about 2,000 oblong trout.

5.5 Tilamur - Spain

Tilamur is a Spanish company that was founded in 2012. The implemented technology is based on a special design conceived with the aim of quick and easy installation of components that enable the production of sustainable food for humans, (Figure 12). This model of the circular economy consists of a connected aquaponics system divided into three different areas. Due to its optimized design and low power consumption, this system can operate autonomously using photovoltaic and wind technology. The model is completely scalable, and the smallest design has a total greenhouse area of 400 m^2 in which about 2,000 kg of fish (tilapia), 3,320 kg of tomatoes, and up to 137 kg of algae (Spirulina) are produced annually. This amount of production can feed 100 people in one year, following the nutritional needs dictated by the FAO, (http://tilamur.com/es/nuestras-instalaciones/).

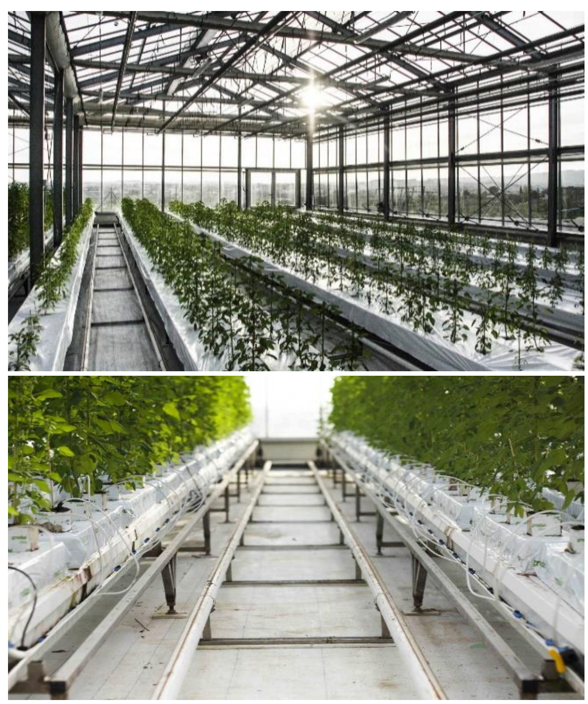

Figure 12. Aquaponics system in Tilamur (http://tilamur.com/es/nuestras-instalaciones/)

5.6. Water garden - Republic of Serbia

In the Republic of Serbia, aquaponics is still not widely represented. In the settlement of Stapar, in Sombor, in the Zapadnobački district, there is one of the few households that applies an innovative ecological method of production - aquaponics, (Figure 13).

This household is a pioneer in aquaponics farming, not only in Serbia but also in the region. On 600 m^2 of land, this household has 2 greenhouses that approximately occupy an area of about 200 m^2.

During one growing season (April-October) about 3-4 tons of tomatoes, about 500-900 kg of strawberries, and about 700 kg of carp are produced on an area of 70 m^2.

About 700 kg of carp is produced in three fish tanks (each 1 m^3) in 9 m^3 of water. The rest of the area goes to bio rectors, fish tanks, and passages (S. Radin, personal communication, 10.08.2020.). The process of production begins with feeding the fish, which introduces proteins into the system. At the end of the circular process, proteins are found in the food. From the fish tank, water is pumped into the hydroponic unit. In the hydroponic unit, water leaks through the growth medium, next to the plant roots, and after that, water is drained back into the fish tank.

Plants extract necessary nutrients for their further growth from the water and, at the same time, purify the water. From vegetable crops, in these greenhouses, tomatoes, strawberries, and Dutch lettuce are produced. The plant (tomatoes) has a rapid growth and can reach a height of about 4 m in one growing season, but due to the height of the greenhouse, the height of the plants is usually limited to 2-3 m (S. Radin, personal communication, 10.08.2020.). For this method of cultivation, there is no need for hoeing, watering, etc., so all attention is paid to the needs that plant requires.

The vertical system of aquaponic is implemented for strawberry production. About 1,000 strawberry seedlings were planted on only 3 m^2, and during the one growing season, it can produce about 500 - 900 kg of strawberries. In vertical systems, water comes to the seedlings from above, like artificial rain, provides a sufficient amount of oxygen and moisture for the plant. Dutch lettuce is also grown experimentally in the part of the greenhouse as the raft system in which plants float on styrofoam. About 15 kg of lettuce is produced within 15-20 days.

The growth and development of the plant are up to 6 times faster, and the yield is up to 3 times higher (Radin, 2020.). The whole system represents one ecological chain which results in much faster development of plants precisely because of that organic matter that is presented in the water. In such systems, the fish disease has not yet been investigated. Over 90 % of plant diseases are eliminated (because plant diseases are transmitted through the soil), and the remaining 10 % are treated preventively, with agents based on essential oils. Also, plants need to be protected from pests, insects, etc.

The material used to make this system is from the domestic market and is completely safe for food production. Different plumbing materials are most often used, while some of them have been remodeled and adapted to this method of cultivation. The average investment per 1 m^2 is about 130 €, without a solid base and greenhouse. About 3 million dinars were invested in this production, and the system consumes very small resources during production, such as the purchase of seedlings, juvenile fish, fish food, and electricity and water costs. On average, the sale of fish provides free crop production (S. Radin, personal communication, 10.08.2020.).

Premium final products are currently being produced and made - tomato juice, smoked fish steak, and strawberry jam.

Figure 13. Tomato production in small aquaponic farm in the Republic of Serbia (S. Radin, personal communication, 10.08.2020.)

6. Conclusions

Aquaponics is a modern, young, and sustainable new agricultural industry, which depends less on primary energy and material inputs, than conventional production systems. Also, aquaponic systems with their circular process fit perfectly into the principles of the circular economy and provide for a reduced impact of the agri-food sector in the environment. Thus, this technique involves the cultivation of vegetables without the use of land, and with a decrease in water consumption of up to 90 %. There are various types of aquaponic systems, and their advantages are enormous, in particular, because they contribute to the concept of the circular economy.

Even though the expansion of aquaponic, is significant, in practice, the use rates of aquaponics technologies are still low. Aquaponics businesses operate in a vague policy environment that falls under both aquaculture and agriculture. Thus, neither the EU nor the Republic of Serbia have the regulation for aquaponic.

Our literature review demonstrates that many countries and cities use aquaponic systems for the cultivation of different plant and fish species. The leading aquaponic firms include BIGH Farm in Anderlecht, ECF Farmsystems in Berlin, Urban Farmers in Hague, Bioaqua Farm in Blackford, United Kingdom, and Tilamur in Spain. They are among a growing number of aquaponic pioneers. In the Republic of Serbia, the pioneer is a small aquaponics farm in Stapar, in Sombor.

This small aquaponic farm on only 3 m^2, during the one growing season, produces about 500-900 kg of strawberries. The Republic of Serbia has the potential to develop more aquaponics systems and should use this potential to get closer to other countries that successfully use these systems.

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Analiza primene akvaponskog sistema kao modela cirkularne ekonomije – pregled

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I Z V O D

U vremenu ograničenih vodenih resursa, klimatskih promena i značajnog smanjenja broja vrsta riba i biljaka, akvaponski sistemi mogu igrati važnu ulogu za budućnost ekološki i socio-ekonomski održivih pametnih gradova. Cilj ovog rad je da istraži dostupnu literaturu koja se bavi temom akvaponskih sistema i da ispita trenutnu situaciju u vezi sa ovim sitemima – njihovu primenu, rezultat rada, perspektivu i nedostatak ovog modela cirkularne ekonomije. Istraživačka metoda uključuje pregled literature i analizu intervjua sa pionirima u akvaponiji u Republici Srbiji. Glavni kriterijum prilikom pregleda literature je bio pronalaženje uspešnih primera akvaponije u svetu i Republici Srbiji. Rezultat istraživanja je pokazao da se akvaponski sistemi, zbog kružnog toka proizvodnje, mogu posmatrati kao model cirkularne ekonomije. Među sve većim brojem pionira u akvaponiji, kao primeri sa uspešnom primenom cirkularne ekonomije, nalaze se BIGH Farm, ECF Farm Systems, Urban Farmers, Bioaqua Farm, Tilamur i Vodena bašta. Ova preduzeća proizvode hranu bez stvaranja otpada, potrošnja energije je smanjena na minimum i imaju pozitivan uticaj na životnu sredinu, što predstavlja osnovne ciljeve kružne ekonomije.