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PRELIMINARY RESEARCH ON THE INTRODUCTION OF VERTICAL AQUAPONIC SYSTEMS IN AQUACULTURE IN ROMANIA

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Abstract: Vertical farms differ mainly in the technological methods used for indoor cultivation of edible plants. Vertical farming produces crops indoors under conditions of artificial lighting and controlled temperature in order to increase productivity. Vertical farming could thus contribute to reducing efforts on measures to combat climate change, reducing the waste of resources improving people's health and productivity, allowing a more positive outlook on the future of cities than the usual one. Sustainable food production needs to be strengthened, so that it is also beneficial in terms of concern about water and land degradation.Vertical aquaponics is the ability to grow a large amount of food on a very small surface that involves the use of vertical space that is not usually used in production. With this method, many plants can be grown, whether they need support or not. Practicing a high–performance aquaponics requires paying increased attention to sustainability, consumer requirements, food safety and economic efficiency, through the continuous development of new technologies. In today's conditions, aquaculture is becoming an increasingly important source of global protein production, while reducing pressure on overfished oceans. This study aims to identify the best criteria to introduce vertical aquaponic systems in aquaculture in Romania.
Keywords: aquaculture, aquaponics, preliminary research, sustainability, vertical aquaponics

INTRODUCTION

Food production currently faces significant challenges associated with limited available water and nutrient resources (especially fertilizers such as phosphorus), climate change such as extreme weather, changes in pest distribution and the growth of high–density urban populations. Vertical farms are a type of controlled environment agriculture (CEA). They have traditionally taken the form of greenhouses, which have contributed greatly to the global food supply in recent decades. The concept of "vertical farming" was introduced by de Despommier (2010) in his book: „The Vertical Farm: Feeding the World in the 21st Century". In this book, he proposes solutions to improve food safety and security for an expanding urban population. Vertical farms differ from greenhouses in terms of their height (*Despomier, 2013*).

The taller the vertical farm, the more products it produces, with the same footprint. Vertical farms differ mainly in the technological methods used for indoor cultivation of edible plants. Vertical farming produces crops indoors under conditions of artificial lighting and controlled temperature in order to increase productivity. The methods used are hydroponics, aquaponics and aeroponics. Vertical farming could thus contribute to reducing efforts on measures to combat climate change, reducing the waste of resources improving people's health and productivity, allowing a more positive outlook on the future of cities than the usual one.

Currently, in the United States of America operates the most vertical farms in the world. In Asia, the main countries that have vertical farms are Japan, China, Singapore, South Korea, Taiwan and Thailand. Vertical farms operate across Europe, including Germany, France, the United Kingdom and the Netherlands. Also, in Kuwait and the United Arab Emirates and in the countries of the Middle East, such types of farm are found.

In today's conditions, aquaculture is becoming an increasingly important source of global protein production, while reducing pressure on overfished oceans. However, traditional techniques used in aquaculture release nutrient–rich wastewater into the environment, causing eutrophication and hypoxia in water bodies. Integrated aquaculture systems such as aquaponics can address and reduce the environmental pressure caused by traditional food production techniques. Somerville et al. (2014) defines aquaculture as the rearing in captivity and under controlled conditions for the production of fish and other species of aquatic animals and plants.

Ginkel et al., (2017) defines aquaponics as the fusion of two profitable and well–established food production technologies – aquaculture and hydroponics. It integrates and synergistically combines aquaculture and hydroponic

techniques into a single system (*Wongkiew et al., 2017*). Most aquaponics systems use horizontal tanks or grow beds, competing with traditional land–based systems to produce vegetables (*GoGreenAquaponics, 2021*). According to Khandaker and Kotzen (2018), growing more plants vertically makes systems more productive. Vertical systems present an optimal space–saving solution, making them very suitable for urban areas, either for decoration or for local food production, but for this, artificial lighting above the grow bed is necessary. In research by Dos Santos (2016), Junge et. al. (2017), Rizal et al. al. (2018) it is shown that aquaponics could represent a new integrated agricultural system from producers to consumers in an integrated manner due to short supply chains and fresh organic food. This technological method has the potential for higher product and protein yields with less labor, less land, less chemicals and a fraction of water use (*FAO, 2016*). According to Brooke, N. (2019), vertical aquaponics is a space–saving system by making maximum use of the vertical space above fish tanks.

Aquaculture practiced in Romania is largely based on traditional techniques (extensive, semi–intensive system). Aquaponics is the system of integrated cultivation of plants and fish that offers an alternative to traditional agriculture. According to the studies carried out by Blidariu F, Grozea A, (2011) aquaponics can be considered a sustainable agricultural production alternative because, through the combined production of plants and animals, it integrates the flow of nutrients through the natural biological cycles of nitrification, it is carried out without exhausting the available resources and without destroying the environment, so without compromising the possibilities of meeting the needs of future generations. This method of agricultural production is growing globally and has multiple advantages over conventional methods of growing plants and animals. In this sense, aquaponics can be considered an innovative alternative to traditional farming and aquaculture practices. Aquaponics appears as a safe alternative in the conditions of climate change – global warming, drought, reduction of water resources. The aquaponic system does not depend on the environment and climate, being located in spaces with controlled temperature and independent of the soil. The risks that occur in aquaponics are determined by the costs related to energy consumption during the cold period of the year and/or accidental power shutdowns for long periods of time. Eliminating the risk of accidental power shutdowns is done by installing a power generator or solar panels. This study aims to identify the best criteria to introduce vertical aquaponic systems in aquaculture in Romania.

MATERIALS AND METHODS

The preparation of this study was based on works and specialized studies from the country and abroad identified by consulting several databases: Google Scholar, JSTOR, Science Direct, ISI Web of Science, Springer Link, Academic Search Elite and AGRICOLA (*AGRICultural Online Access*).

To identify the development potential and adaptability of vertical aquaponic systems in Romania, the main characteristics of aquaponics and vertical aquaponics were highlighted and argued. Also, the social and economic impact, the cost–benefit analysis were highlighted and argued and several international case studies in the field of vertical aquaponics were presented.

RESULTS

Aquaponics is an integrated method of growing plants and raising fish that combines aquaculture and hydroponics. Given that Romania has a rich water resource and land suitable for agriculture, this system can be efficient and sustainable in the country.

Arguments for aquaponics as a sustainable option in Romania:

- Nutrient recycling. Water with metabolic waste from the fish in the aquaponic system can be used for plant growth. The nutrients from the fish waste are taken up by the plants for growth and the clean water is returned to the fish tank. Chemical fertilizers and pesticides are not used in the cultivation system, which contributes to a more ecological and safer agriculture for the environment.
- Efficient use of resources. Aquaponics allows for the efficient use of water, which is recycled and not constantly removed, as is the case in traditional aquaculture. This method uses about 90% less water than conventional farming.
- Diversification of production. Aquaponics offers the opportunity to grow a diverse range of plants and fish species in the same system. This can contribute to the diversification of agricultural production, reducing dependence on a single type of crop and supporting food security.

— Achieving ecological and healthy production. Aquaponics is an organic method of production, as it does not use chemicals and pesticides. Plants and fish grow in a controlled environment without artificial fertilizers and toxic substances, resulting in healthy and environmentally friendly products.
— Reduced energy costs. Aquaponics requires less energy than other methods of agricultural production, such as soil–based irrigation or growing in greenhouses. The system can also be powered by renewable energy such as solar or wind power to further reduce environmental impact.
— Efficient use of space. Aquaponics can be implemented in many locations, including urban spaces such as abandoned commercial buildings, industrial halls or even inside homes. This allows land to be used efficiently and can promote urban and local agriculture.
— Arguments supporting the choice of vertical aquaponics
— Make efficient use of space. Vertical aquaponics allows to grow plants and to culture fish in a vertical layer system, thus maximizing the use of space.
— Water savings compared to traditional methods. Vertical aquaponics uses a water recirculation system, where the water used to culture the fish is filtered and then fed back into the plant growth system. This is a very efficient water conservation process as the amount of water required is much less than in traditional cultivation methods.
— It is energy efficient. Thanks to water recirculation and the use of energy efficient artificial lighting systems, vertical aquaponics can be more energy efficient than other traditional growing methods.
— Ensures water quality control. In vertical aquaponics, the interaction between plant and fish helps maintain water quality. Plants absorb nutrients from water contaminated with fish waste, thus maintaining good water quality for fish.
— It ensures organic production. Vertical aquaponics can be effectively used for cultivation without the use of pesticides and harmful chemicals, making it an attractive option for people interested in organic production.
— Shows high production potential in small space. Vertical aquaponics systems allow high production of plants and fish in a small space. This can be particularly useful in urban areas with limited space or in countries where agricultural land is limited.
— It shows sustainability. Vertical aquaponics is an environmentally friendly technology that can help reduce reliance on traditional farming systems. By using resources efficiently and reducing the effects of water and soil pollution, vertical aquaponics can contribute to the development of sustainable and ecological agricultural systems.
— Contributes to education and knowledge. Vertical aquaponics can be a great way to educate and raise awareness about the importance of growing food sustainably and protecting the environment. The model can be used in schools, institutions and communities to teach about natural cycles and the importance of resource conservation.

The benefits of vertical aquaponics systems include:
— saving water (the system recirculates water),
— reducing energy consumption,
— efficient use of resources,
— reducing pollution and sustainable land use.

These systems can ensure fresh and healthy food production, reducing dependence on food imports.

THE POTENTIAL FOR DEVELOPMENT AND ADAPTABILITY IN ROMANIA

Vertical aquaponics can be implemented in various environments and spaces, such as courtyards, balconies, greenhouses or even multi–story buildings. Vertical aquaponic systems can increase the number of plants that can be grown per unit area compared to horizontal systems and can lead to increased yields. This aspect may be relevant for Romania, where arable land is limited and the importance of urban agriculture or the establishment of vertical farms is increasing.

Social and economic impact

The introduction of vertical aquaponics systems could have a positive impact on local communities up to the national level by creating new jobs in the agricultural sector; they can promote healthy and sustainable food and contribute to the development of urban agriculture and the agri–food sector as a whole.

Arguments for the introduction of vertical aquaponic systems in Romanian aquaculture

A vertical aquaponic system is energy efficient. This type of system uses less water and energy than other farming methods because the water

is continuously recirculated and used both to irrigate the plants and feed the fish.

A vertical aquaponic system is suitable for urban farming because it takes up less space compared to traditional farming systems and can be installed in buildings or small spaces.

A vertical aquaponic system has little impact on the environment because the growing environment is controlled, plant growth is favored without being affected by pests and the use of pesticides and other chemicals is reduced.

A vertical aquaponic system allows plants to be grown in any season regardless of external weather conditions, thus achieving high yields throughout the year.

A vertical aquaponic system offers the possibility of obtaining fresh, nutrient–rich, quality products without the use of pesticides or other chemicals.

The introduction of vertical aquaponics in Romania can create new economic opportunities (businesses and jobs) in the field of urban agriculture and ecological technologies.

A vertical aquaponic system can be used as a model in schools, universities and education centers to provide opportunities for learning and awareness about the importance of conserving environmental resources and healthy foods.

The introduction of vertical aquaponics can contribute to the increase of food production in Romania and implicitly to the reduction of dependence on imports.

The introduction of vertical aquaponics in aquaculture in Romania can contribute to sustainable development by reducing the impact on the environment and improving the quality of life for future generations. The implementation of vertical aquaponics in Romania can be considered a way of sustainable development for aquaculture. Aquaponics is a symbiotic system where plants and fish are raised in one unit, mutually benefiting from the nutrients and waste produced.

Education and awareness: Vertical aquaponics can be a great way to educate and raise awareness about the importance of growing food sustainably and protecting the environment. It can be used in schools, institutions and communities to teach about natural cycles and the importance of conserving resources.

The benefits of vertical aquaponics systems include: saving water (the system recirculates water), reducing energy consumption, efficient use of resources, reducing pollution and sustainable land use. These systems can ensure fresh and healthy food production, reducing dependence on food imports.

The advantages of vertical aquaponics compared to the traditional methods practiced in Romania

- Shows efficiency in the use of resources. The aquaponic system uses less water than conventional methods, because the water is continuously recirculated. The nutrients from the water with fish waste are used by the plants, thus reducing the additional input of fertilizers. Also, this type of system can be developed and adapted for smaller spaces.
- Contributes to reducing the impact of pollution on the environment. The waste produced by fish (nitrogen and phosphorus) is used by plants as nutrients reducing the level of soil and water pollution and thus protecting natural ecosystems. The impact on water quality is reduced, a very important aspect in the conditions where the problems related to water pollution are increasingly urgent.
- Ensure sustainable food production. Vertical aquaponics can contribute to sustainable development by producing organic food without putting pressure on resources. Fish can be raised and vegetables can be grown providing a variety of food products. The use of pesticides and chemicals can be reduced to a minimum, resulting in healthier products.
- Economic and social. Implementation of vertical aquaponics can bring economic and social benefits to local communities. For example, investments in aquaponic systems can create jobs and stimulate the development of rural areas. Local products obtained through aquaponics can also contribute to promoting sustainable development and reducing dependence on imports.

However, the implementation of vertical aquaponics in Romania must be supported by appropriate policies and the support of the authorities. They must provide financial and technical support for the adoption and development of these innovative systems in agriculture.

COST–BENEFIT ANALYSIS FOR THE IMPLEMENTATION OF THE VERTICAL AQUAPONIC SYSTEM

The cost–benefit analysis is to assess the financial viability of a vertical aquaponic system and to identify whether the investment is profitable in a

certain context. Important aspects that could be considered for analysis.

Initial costs include the cost of purchasing the equipment needed to build and implement the vertical aquaponic system, such as tanks, water circulation plant, water filtration systems, artificial lighting lamps, soil and seeds.

Maintenance costs include system operation and maintenance costs (costs for electricity, water circulation pumps and lighting), fish feed and plant nutrient costs and system monitoring costs.

Vegetable and fish production. The analysis takes into account the estimation of vegetable and fish production that the vertical aquaponic system can produce. This can be quantified in monetary terms, given the market prices of the products.

Savings generated. Cost benefit analysis can also evaluate the savings generated by vertical aquaponics. This can include energy savings by using natural light instead of artificial lighting, water savings by using a water recirculation system, and space savings by using a vertical structure.

Important cost–benefit analysis arguments supporting the introduction of vertical aquaponics

Through efficient use of space, vertical aquaponics allows growing plants and raising fish in a vertical layer system, thus maximizing the use of space.

Vertical aquaponics uses a water recirculation system, where the water used to raise the fish is filtered and pumped back to grow the plants. This type of aquaponics is very efficient in conserving water (the need for water is much reduced compared to traditional cultivation methods).

Due to water recirculation and the use of energy efficient lighting systems, vertical aquaponics can be more energy efficient than other traditional growing methods.

The interaction between the plant and the fish helps maintain water quality. The plants absorb nutrients from the water with waste from the culture ponds and a filtered feed to the fish.

Vertical aquaponics systems enable high production of plants and fish in a small space. This can be particularly useful in urban areas with limited space or in countries where agricultural land is limited.

Vertical aquaponics is an environmentally friendly technology that can help reduce reliance on traditional farming systems. By using resources efficiently and minimizing water and soil pollution, vertical aquaponics can contribute to the development of sustainable and ecological agricultural systems.

Vertical aquaponics can be a great way to educate and raise awareness about the importance of growing food sustainably and protecting the environment. It can be used in schools, institutions and communities to teach about natural cycles and the importance of conserving resources.

International case studies in vertical aquaponics

The case studies cover the sustainable food production results achieved by several countries that have implemented vertical aquaponics systems.

— In the United States of America – Green Sense Farms, one of the largest commercial vertical aquaponic farms in the United States, is located in the state of Illinois, covers an area of approximately 2,800 m^2 and produces a wide range of vegetables and plants using the vertical aquaponic system. "Green Sense Farms" uses aquaponics technology to combine plant growth with fish farming in a cyclical system. Water is constantly recirculated between the fish ponds and the plant greenhouses, creating a sustainable environment where the plants get the nutrients they need from the fish's waste, even as the water is cleaned.

This vertical aquaponic farm has achieved significant success due to the high production and superior quality of the vegetables and plants grown. The vertical system allowed to maximize the space used for growing plants vertically, which resulted in a higher production per unit area. Also, the use of aquaponics ensured better control of the growing environment by reducing consumption (water, energy). With such an innovative and efficient approach, "Green Sense Farms" managed to establish itself on the agricultural market, offering fresh, high–quality, sustainable and ecological products. This example demonstrates how vertical aquaponics can contribute to sustainable food production in an increasingly urbanized world and limit environmental impact such as limiting resource use (water and soil).

— Singapore – the largest vertical aquaponics system in the world, called "Sky Greens". Sky Greens is an aquaponics system that uses vertical technology to

allow plants to be grown in buildings up to nine meters high. The system uses a rotating cylinder on which plant shelves are mounted, and next to each shelf are several fish tanks. This continuous cycle of water and nutrients between plants and fish ensures a sustainable and efficient food production system. Sky Greens has achieved positive results in terms of sustainable food production, being able to produce up to 10 times more vegetables per square meter than traditional farming methods, using less water and without using pesticides or chemical fertilizers.

— In Japan – successful vertical aquaponics is "Mirai", a project developed in a ten–story building in Tokyo. In this project, every floor of the building is dedicated to aquaponics (growing plants and fish). The Mirai project has demonstrated that vertical aquaponics can be implemented even in confined spaces such as an apartment and can produce enough food to feed the building's inhabitants. This system also allowed the local integration of production and consumption, thus reducing dependence on food imports.
— The largest aquaponic farm in Europe is located in the Hague on the roof of a building built in 1950 and which was once used by a telecommunications company. The farm has an area of 1,200 square meters cultivated with vegetables and a fish farm of 370 square meters and was built by the Swiss company UrbanFarmers AG.

The Tower Farms system is distributed by Ibiza Farm. Following the survey by Love et al. (2015) on commercial aquaponic producers, found that almost one–third of them used grow towers. Comparative data on the yields of aquaponic tower systems and conventional horizontal aquaponic systems are not presented.

ZipGrow is a vertical hydroponic technology designed for high–density vertical crop production by Bright Agrotech, which operates a vertical aquaponic system with 400 towers in Laramie, Wyoming. In Europe, the ZipGrow system is distributed by Refarmers. A standard 152 cm tower provides mechanical and biological filtration for 0.7 to 1.1 kg of mature fish. A stocking density between 12 kg and 15 kg per m^3 is recommended.

In the UK, GrowUp Urban Farms combines aquaponics with vertical growing technologies and controlled environment production (CEP) to produce year–round lettuce and herb crops. Since 2015, GrowUp has operated 'Unit 84', a commercial–scale urban aquaponic farm in an industrial warehouse in East London. The 762 m^2 growing space could produce over 20,000 kg of lettuce and herbs (enough for 200,000 bags of lettuce) and 4000 kg of fish each year.

The farm in Brno–Dolní Heršpice is the largest vertical aquaponic farm in the Czech Republic. The renovated shop and sun–heated greenhouses are adapted for year–round aquaponic cultivation of leafy vegetables, herbs and warm water fish. The products of this aquaponic farm are primarily intended for customers in Brno and the surrounding areas. The greenhouses in Brno–Heršpice are equipped with modern roofs with high insulation capacity, so it is possible to grow African catfishes with warm water all year round, with very advantageous energy costs. Solar energy is used to heat greenhouses in an environmentally friendly way.

CONCLUSIONS

Since all aquaponic systems, regardless of size or constructive solution, present the same technical advantages (high productivity, production of plants and fish without chemicals, low water consumption, etc.), it follows that the choice of the type of system and its size must be made following a cost–benefit analysis.

Vertical aquaponics is an aquaponics alternative designed for efficient production that conserves water and land use. The development of a vertical aquaponic farm can ensure more efficient food production and be widely used in urban areas with limited land capacity. The implementation of vertical aquaponics in Romania requires significant initial investments and specialized technical knowledge. Also, vertical aquaponic systems require constant monitoring and care to ensure proper functioning.

The implementation of a vertical aquaponics system in an urban farm in a densely populated city is presented. This system helped transform a limited area of land into a sustainable source of food, thereby reducing environmental impact and providing a local and affordable alternative to sourcing fresh vegetables and fish.

The implementation of a vertical aquaponics system in a school as part of an educational program for students is presented. This system allowed the children to learn about the life cycle

of plants and fish, about protecting the environment and about healthy eating. It also provided an opportunity for the school to ensure a constant source of food and to involve the community in the food production process.

These case studies demonstrate the benefits of vertical aquaponics in various contexts and show that this system can be implemented in different environments, becoming an innovative and sustainable solution for the production of fresh and nutritious food.

Vertical aquaponics can be a sustainable solution for raising fish and growing plants, but a strong commitment from farmers and authorities is needed to promote and develop this method in Romania. Farmer education and awareness is important to adopt this production technique and learn how to manage it effectively.

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