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COMPLEX TECHNOLOGIES FOR THE SIMULTANEOUS CULTIVATION OF PLANT PRODUCTS AND AQUACULTURE PRODUCTS

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INTRODUCTION

The modern provision of food security in Ukraine depends on many factors related to the economic structure of the country, the development of agriculture, and the level of natural resources, against the background of instability in which the technology of food production in artificially controlled conditions is becoming increasingly important. Aquaponics – refers to complex technologies for the simultaneous cultivation of plant products and aquaculture products, but due to the systematized process and modern automation of production, it has the status of ecological and economic sustainable development due to obtaining the maximum amount of products from a unit of area and volume, reducing CO_2 emissions, obtaining ecological production, the transformation of waste products as fertilizers for growing organic products.

Currently, the largest sources of emissions in agriculture are carbon dioxide, which is more than 5.3 billion tons in the world, for intestinal fermentation of animals – 40%, manure that remains on pastures – 16%, synthetic mineral fertilizers – 13%, raw rice – 10%, storage and use of manure – 7%. That is, almost two-thirds of the total emissions are for animal fermentation, fertilizers (decomposition of organic and mineral substances), and soil cultivation. Therefore, the creation of innovative systems capable of reducing the accumulation of carbon dioxide is the prerogative of the development of all components of agriculture. The unique combination of crop production and aquaculture is an innovative direction of development in Ukraine.

The construction of innovative aquaponics modular blocks for the simultaneous cultivation of valuable species of fish and plant products allows reducing emissions of nitrous oxide and methane from agricultural processes, adapts technological processes in unsuitable and poorly suitable territories, and enables instant response to climate changes, increases the level of use of renewable energy sources and minimal use of fossil fuels for technological processes, transformed them to power from solar batteries. The use of aquaponics farms will reduce water requirements for fish farming from 250,000 to 1.5 m^3/year, nitrogen release from 38,000 to 250 kg/year, energy requirements from 2,400 kW to 300 kW, and carbon dioxide emissions to less than 5 mg/l.

1. The problem's prerequisites emergence and the problem's formulation

In our century of new technologies and scientific achievements, people began to build new types of factories, and residential buildings, carry out large-scale urbanization and reduce the area of fields and forests. Because of this, large-scale environmental problems have arisen: the reduction of the area of fields causes a decrease in the yield of ecologically clean products, automobile and industrial gases affect plants and oil spills destroy entire fish populations. With the emergence of such problems, scientists began to think about how to rationally use every square meter of uncontaminated soil.

Currently, the largest sources of emissions in agriculture are carbon dioxide, which is more than 5.3 billion tons in the world, for intestinal fermentation of animals – 40%, manure that remains on pastures – 16%, synthetic mineral fertilizers – 13%, raw rice – 10%, storage and use of manure – 7%. That is, almost two-thirds of the total emissions are for animal fermentation, fertilizers (decomposition of organic and mineral substances), and soil cultivation. Therefore, the creation of innovative systems capable of reducing the accumulation of carbon dioxide is the prerogative of the development of all components of agriculture. Thanks to scientists, hydroponic, aeroponic and aquaponic systems began to appear, in which plants are grown in a soilless environment and organic, natural means of nutrition, fertilizer and pest and disease control are used.

The unique combination of crop production and aquaculture is an innovative direction of development in Ukraine. Aquaponics is a high-tech method of farming that combines aquaculture – raising aquatic animals and hydroponics – growing plants without soil. Aquaponics is an artificial ecosystem in which three types of living organisms are key: fish, plants and bacteria. This is the only artificial system for the simultaneous cultivation of fish and plants, which minimizes energy costs, increasing the effect of waste-free, ecologically clean production.

World practice proves the prospects of using this technology, which achieves the maximum growth rate of plants and fish with minimal energy and feed costs. The main advantage is the independence of production from the conditions of the external environment, and the possibility of an automated, controlled mode of growing conditions for almost any type of hydrobionts and agricultural plants[1, 2, 3, 4, 5, 6, 7, 8, 9].

Among the cultivated aquaculture facilities in closed water supply facilities, economically feasible, valuable species of fish, among which the Nile tilapia (*Oreochromis niloticus*) has recently begun to be used for its high growth rate, undemanding to the hydrochemical regime, feed quality, high resistance to stress and high dietary properties. Leaf lettuce is the

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most valuable vegetable crop with great demand for unpretentiousness to growing conditions.

The development of technology for the operation and productivity of aquaponic modular units with the simultaneous maintenance of valuable species of fish and the cultivation of plant products, which allows reducing of emissions of nitrous oxide and methane from agricultural processes, adapts technological processes in unsuitable and poorly suitable territories, enables instant response to climate changes, increases the level use of renewable energy sources. The results of the work will make it possible to simultaneously grow and obtain products of valuable species of fish and plant products, reduce emissions of nitrous oxide and methane from agricultural processes, adapt technological processes in unsuitable and poorly suitable territories, increase the level of use of renewable energy sources and minimize the use of fossil fuels for technological processes.

Aquaponics is a high-tech method of farming that combines aquaculture – raising aquatic animals and hydroponics – growing plants without soil. Aquaponics is an artificial ecosystem in which three types of living organisms are key: aquatic animals, plants and bacteria. This is the only artificial system for the simultaneous cultivation of fish and plants, which minimizes energy costs, increasing the effect of waste-free, ecologically clean production.

The term "aquaponics" appeared not so long ago, but people have learned to use the obvious advantages of growing plants and fish together since ancient times. For more than two millennia, there has been a practice of growing fish in rice paddies in Southeast Asia. This polyculture (cultivation of different species in one natural area, for example in a pond) farming system existed in many countries of the Far East. Such species of fish as lake pike, pike (*Misgurnus anguillicaudatus*), Asian swamp eel (*Monopterus albus*), carp (*Cyprinus carpio*), golden crucian carp (*Carassius carassius*) and viviparidae (*Viviparidae*) were grown on floodplains[10].

The Aztecs cultivated islands – chinampas – in a system called the first form of aquaponics for agricultural use, where plants were grown on anchored, sometimes floating islands in the shallows of a lake, and spent materials were drawn from chinampa, the surrounding towns were used to irrigate the plants by hand.

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The development of aquaculture and, in particular, hydroponics in the 20th century led to the scientific understanding of aquaponics. The essence of the method is the use of aquatic animal waste as a nutrient medium for plants. During this process, plants consume the waste products of aquatic animals, purifying water and enriching it with oxygen. In the process of growing, aquatic animals emit toxic waste products: nitrogen, potassium, phosphorus compounds, and carbon dioxide. The accumulation of these substances in water is the main problem of aquaculture in closed water supply installations, which is accompanied by significant capital investments in mechanical filtration, biological filtration, sterilization, enrichment of water with oxygen and waste disposal. These substances can be used for the cultivation of environmentally friendly agricultural products, because, unlike mineral fertilizers, they do not negatively affect the environment by the secondary factors of pollution with the final amount of pesticides, nitrates, and salts of heavy metals. Plants grown in this way acquire the status of ecologically clean organic agricultural products, which belong to the category of high-quality food, the demand for which is growing daily in the world. Agricultural products grown on organic fertilizers created by aquatic animals in the process of growing them will meet all the necessary standards, and can receive a special certificate and the right to use ecological manuring. The combination of these two methods makes it possible to simultaneously grow aquatic animals and ecologically clean organic agricultural products, reducing capital costs for special water filtration and the use of precious feeds, making such production highly efficient, safe and practically waste-free.

Floating aquaponics systems on multi-cultural fish ponds were installed in recent years in China when growing large amounts of rice, wheat, canna and other crops, these structures exceeded 2.5 acres (10,000 m^2) in the area[11, 12, 13]. The developed scheme of aquaponics at the University of the Virgin Islands (UVI) allows you to get 5 tons of tilapia per year.

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The elementary structure of this system is presented in the form of a tank in which fish are grown and containers in which agricultural crops are planted. In the process of intensive fish farming, they are constantly fed, and feed residues together with waste products, which are nutrients for plants, are supplied to them through the pipeline system with the help of a recirculation system. Entering the plants that absorb these substances, the water is purified and the plants have growth activity.

Fish waste products contain nutrients for plants, but are toxic to the fish themselves. Plants absorb these substances, which provides them with the necessary nutrition, and thereby cleans the water for fish (at the same time, plants and fish grow more actively). The purified water is returned to the fish then the cycle repeats. In this case, expanded clay or gravel is used as soil for plants. Since plants and expanded clay play the role of a mechanical and biological filters, the need to use expensive artificial water filtration is eliminated. Adding water is necessary only for plant uptake, evaporation into the air, or biomass removal from the system.

Fish waste is a natural fertilizer for vegetables or flowers. The yield is significantly increased and fruit ripening is accelerated. In tomatoes grown in aquaponics, the content of nitrates is usually five to ten times less than in the best ground tomatoes, and the taste and aroma are in no way inferior. This method is used abroad on an industrial scale[14, 15].

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The use of aquaponics farms allows reducing water requirements for fish farming from 250,000 to 1.5 m^3/year, nitrogen release from 38,000 to 250 kg/year, energy requirements from 2,400 kW to 300 kW, carbon dioxide emissions to less than 5 mg/dm^3. This technology is almost the only one that combines the fields of fish farming and plant breeding with the simultaneous saving of material and natural resources, as well as rational nature use and ecology. The development of this technology will make it possible to grow fish and plant products in any region in a closed cycle. The installation of aquaponics systems does not require the selection of fertile soils, special soil preparation, the presence of running water, or a reservoir[18, 19].

The development of modern aquaponics is associated with various works of the New Alchemy Institute and Dr. Mark McMurtry and others at North Carolina State University. Inspired by the successes of the New Alchemy Institute and piston aquaponics methods developed by Dr. Mark McMurtry and others. Other institutes soon followed their example. Since 1997, Dr. James Rakosii and his colleagues at the University of the Virgin Islands have researched and developed the use of deep-sea cultures in hydroponic growing layers in a large-scale aquaponics system[20].

Over the years, changes in the sphere of state administration of Ukraine, resource management, environmental conditions, and, in recent years, climate change have led to more rational use of natural and material resources. This is what prompted the cultivation of agricultural crops and fish in Ukraine and united in a single opinion on the combination of the two technologies. Currently, the information base on the creation of aquaponics farms is small and mostly of foreign origin, there are almost no own developments.

When using an aquaponic system, the main problem is the increase in the amount of ammonia and carbon dioxide in the water. This causes a sharp slowdown in the development of plants and fish and leads to the death of living organisms. Oxygen (O_2) enters through the gills and is needed for energy production and protein breakdown, while carbon dioxide (CO_2) and ammonia (NH_3) are produced as waste. Undigested

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food is released into the water in the form of excrement, also called suspended solids and organic matter. Carbon dioxide and ammonia are released into the water through the gills. Consequently, fish consume oxygen and feed, as a result of which the water in the system is polluted with excrement, carbon dioxide and ammonia.

A mechanical filter does not remove all organic matter, the smallest particles pass through it as well as soluble substances such as phosphate or nitrogen. Phosphate is an inert substance without toxic effects, but nitrogen in the form of free ammonia (NH_3) is toxic and must be converted in a biofilter into safe nitrates and nitrites. The decomposition of organic matter and ammonia is a biological process that occurs due to special bacteria. Heterotrophic bacteria oxidize organic matter, consuming oxygen and producing carbon dioxide, ammonia, and sludge. Nitrifying bacteria will turn ammonia into nitrite, and then into nitrate.

To maintain balance in such a system, especially on an industrial scale, it is necessary to use special equipment. As a rule, solid elements of fish waste products are cleaned with the help of mechanical filtration and settling tanks. Pumps and culverts help to create a difference in flow levels in the system, which reduces energy consumption. At the same time, the neutralization of harmful impurities is carried out directly by plants, and microorganisms of the created ecosystem.

For the effective functioning of the symbiotic ecosystem of aquaponics, it is necessary to observe certain environmental conditions: temperature, acid-alkaline and oxygen balance.

A change in the optimal temperature regime for each representative of the flora can negatively affect their vital activities. Therefore, it is necessary to carefully approach the selection of inhabitants of the aquaponics system in order to create optimal conditions for their joint cultivation. Adequate water aeration is also a prerequisite for the normal functioning of the system and is important for both fish and plant life. Therefore, it is necessary to use mechanical equipment for the aeration and oxygenation of water[21].

Results of nitrification:

NH_4 (ammonium)$+1.5O_2 \rightarrow NO_2$ (nitrite)$+H_2O+2H^++2e$

NO_2 (nitrite)$+0.5O_2 \rightarrow NO_3$ (nitrate)$+e$

$NH_4 + 2\ O_2 \leftrightarrow NO_3 + H_2O+2H$

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[21] Характеристика та вирощування салату посівного: http://agroua.net/plant/catalog/cg-8/c-33/info/cag-59/

The effectiveness of biofiltration depends mainly on the following factors:

- water temperature in the system;
- pH level in the system.

To achieve an acceptable rate of nitrification, the water temperature should be in the range of 10-35°C (optimally around 30°C), and the pH level should be between 7 and 8. The water temperature most often depends on the cultivated species and, accordingly, is not set so as to ensure the most optimal rate of nitrification, and the optimal rate for fish growth. Nevertheless, it is important to adjust the pH according to the efficiency of the biofilter, since low pH levels reduce the efficiency of biofiltration. Thus, to achieve a high rate of bacterial nitrification, the pH must be kept above 7. On the other hand, a higher pH leads to an ever-increasing amount of free ammonia (NH_3), which increases the toxic effect. Therefore, a balance must be struck between these two opposing goals of pH regulation. The recommended point is between pH 7.0 and 7.5. The pH value in the water treatment system is determined by the following main factors:

- carbon dioxide (CO_2) is produced by fish due to biological activity in the biofilter;
- the acid is produced during the nitrification process;
- CO_2 is removed using water aeration, and degassing also occurs at this stage.

In the process of nitrification, acid (H^+) is formed, which lowers the pH level. Stabilization of pH requires the addition of any base. For this purpose, lime, sodium hydroxide or other base is added to the water.

Fish secrete a mixture of ammonia and ammonium (total ammonium nitrogen (TAN) = ammonium (NH_4) + ammonia (NH_3)); the main part of these secretions is ammonia. But the amount of ammonia in water depends on the pH value, which shows the balance between ammonia (NH_3) and ammonium (NH_4).

Fish farming waste does not disappear even when fish are grown in Recirculating aquaculture system with constant reuse of water. Pollution and fish excrement must get somewhere even in this case. Biological processes in the system reduce the amount of organic compounds to some extent through simple biodegradation or mineralization within the system. However, a significant amount of organic sludge still requires treatment. Waste accumulates in a mechanical filter, where excrement and other organic substances are removed by entering the filter's sludge outlet. Cleaning and washing biofilters also increase the total volume of water leaving the recirculation cycle. Waste that is removed from the Recirculating aquaculture system can be cleaned in various ways. Quite often, secondary mechanical water treatment is installed, designed to concentrate the sludge in the discharge water. From there, the sludge fraction enters a sludge impoundment for sedimentation or further mechanical dewatering, after which it is discharged onto the terrain, usually as fertilizer for agricultural farms. Mechanical dewatering also facilitates sludge handling and reduces sludge volume, thereby reducing disposal costs or potential fees. The disadvantages of mechanical dehydration are a higher investment and operating costs[22, 23, 24].

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Treated wastewater leaving secondary treatment usually has high concentrations of nitrogen and phosphorus. This so-called "clarified effluent" can be released into the environment, into a river, etc., or returned to the of Recirculating aquaculture system. Nutrients contained in clarified runoff can be removed by directing the water to plant-based water treatment ponds, root zones, or soil filters where phosphorus and nitrogen compounds are removed.

Nitrogen contained in clarified effluent can also be removed by denitrification. Methanol is usually used as a carbon source in this anaerobic process. Inside of Recirculating aquaculture system denitrification is typically used to reduce nitrate levels in the production water to minimize the system's need for make-up water. Outside of Recirculating aquaculture system, denitrification is usually used to reduce the release of nitrogen into the environment. As an alternative to methanol, as a source of carbon, you can use sludge, for example, from mechanical filters. The use of sludge requires strict control of the denitrification chamber, and the backwashing and cleaning of the chamber are difficult. However, an effective denitrification chamber can reduce the nitrogen content in wastewater to a minimum. It is important to note that fish secrete metabolic products differently than other animals, such as pigs or cows. Nitrogen is mainly excreted in the form of urine through the gills, only a small part of it is excreted in the form of excrement through the anus. Phosphorus is excreted only with excrement. Thus, the main part of the nitrogen is completely dissolved in water and cannot be removed by a mechanical filter.

Removal of excrement with a mechanical filter will retain a smaller part of the nitrogen in the feces, as well as a larger amount of phosphorus. Dissolved nitrogen is transformed in the biofilter, mainly into nitrates and nitrites. In this form, nitrogen is easily assimilated by plants and can be used as a fertilizer in agriculture or can be removed in treatment ponds with plants or root zones [5, 18, 21].

Ammonia is the main product of the microbiological decomposition of fish waste, which they release into the water. In the presence of oxygen dissolved in water, aerobic bacteria oxidize ammonia and its gaseous amine derivatives with the formation of nitrites and nitrates. This reduces the toxicity of the water to the fish and allows the plants to remove the nitrate compounds that are formed, using them for nutrition. Nitrification, the aerobic conversion of ammonia into nitrates, is one of the most important functions in an aquaponics system.

Table 1

Optimum parameters of different physical and chemical parameters of water quality in Recirculating aquaculture system

Parameter	Formula	Unit of measurement	Norm	Unsatisfactory level
Temperature		°C	Depends on the species	
Oxygen	O_2	%	70-100	<40 and >250
Nitrogen	N_2	% saturation	80-100	>101
Carbon dioxide	CO_2	mg/l	10-15	>15
Ammonium	NH_4	mg/l	0-2.5 (depends on pH)	>2.5
Ammonia	NH_3	mg/l	<0.01 (depends on pH)	>0.025
Nitrite	NO_2	mg/l	0-0.5	>0.5
Nitrate	NO_3	mg/l	100-200	>300
pH		mg/l	6.5-7.5	<6.2 and >8.0
Alkalinity		mg/l	1-5	<1
Phosphorus	PO_4	mg/l	1-20	
Suspended substances	SS	mg/l	25	>100
Chemical oxygen demand		mg/l	25-100	
Biochemical need for oxygen		mg/l	5-20	>20
Humus			98-100	
Calcium	Ca^{++}	mg/l	5-50	

Table 2

Example of nitrogen release from traditional flow farms from the recirculated water system and Recirculating aquaculture system

Output from various types of farms with a capacity of 1000 t per year	Nitrogen output, kg/year	Water demand, m^3/year
Traditional flow farms	38,000	250,000
Recirculated water system	2,000	10,000
Recirculating aquaculture system	250	1.5

This process is analogous to bioremediation. Colonies of special bacteria in closed-loop aquaculture mainly inhabit the substrate of biofilters, and in aquaponics – also the root system and substrate of plants.

Thus, bacteria purify water from substances toxic to fish, and plants consume nitrates, nitrogen, phosphorus, and carbon dioxide dissolved in water and to some extent enrich the water with oxygen, which can be returned to fish [18, 25, 26].

Aquaponics does not use herbicides or pesticides, as they are harmful to fish and bacteria. For the same reason, a careful approach to the selection and dosage of nutritional supplements for plants is required.

Ammonia is released into the water through the gills and excrement of fish, as a product of their metabolism, and must be removed from the water, as high concentrations of ammonia (0.5-1.0 mg/dm^3) are lethal for many species of fish. And while plants can absorb ammonia from the water, nitrates are more readily absorbed, thus effectively reducing the toxicity of the water to fish. Ammonia can be converted into other nitrogen compounds through the following populations:

- nitromonads: bacteria that convert ammonia to nitrites
- nitrobacterium: bacteria that convert nitrites to nitrates

In an aquaponic system, the bacteria responsible for this process form biofilms on all solid surfaces of the system that are in constant contact with water. Vegetable roots submerged in water have a large surface area where many bacteria can accumulate. Along with the concentration of ammonia and nitrite in the water, the surface area determines the rate at which nitrification occurs. Caring for colonies of these bacteria is important for regulating the complete assimilation of ammonia and nitrites. This is why aquaponic systems contain a section with a biofilter that helps facilitate the growth of these microorganisms. Generally, after the system stabilizes the ammonia level in the range of 0.25 to 2.0 mg/dm^3, the nitrites stabilize in the range of 0.25 to 1 mg/dm^3 and the nitrate content in the range of 2 to 150 mg/dm^3. During the start-up of the system, jumps in levels may occur for ammonia (up to 6.0 mg/dm^3) and nitrite (up to 15 mg/dm^3), with nitrates, the peak concentration occurs later in the start-up phase [17, 27]. Since the nitrification process oxidizes the water, sodium-free bases can

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be added to neutralize the pH of the water, such as potassium hydroxide or calcium hydroxide, if the natural amount present is insufficient to buffer the oxidation. In addition, selective minerals or nutrients such as iron can be added in addition to fish waste, which serve as the main source of plant nutrients. A good way to combat the accumulation of solids in aquaponic systems is the use of worms, which liquefy solid organics so that they can be used by plants or other animals in the system [17, 28].

Research on the feasibility and efficiency of growing agricultural plants in aquaponic systems was conducted in the research laboratories of the Department of Aquatic Bioresources and Aquaculture "Perspectives of Aquaculture" and Department of Agriculture.

The objects of research in the first block "agricultural plants" were lettuce (*Lactuca sativa*) of the Dragone variety, and in the second block "fish farming" – Nile tilapia (*Oreochromis niloticus*). Promising crops and fish species that can be used in aquaponic systems are strawberry, thyme, parsley, mint, tropical species of hydrobionts such as Australian red claw crab, tilapia, African clary catfish and others.

2. Research results and discussion

The main characteristic of lettuce (Lactuca sativa): is an annual herbaceous crop belonging to the Asteraceae family. The tap root, thickened in the upper part, has a large number of side branches. The leaf blade is blistered, wrinkled or almost smooth, light green, green or dark green in color, sometimes with red-brown pigmentation. A milky juice protrudes at the cut sites [21, 29].

Lettuce is a cold-resistant plant. Seeds germinate at a temperature of +5°C, optimal – +15-20°C, at +12-14°C dense heads are formed, and above +20°C – the formation of stems accelerates. The culture is light- and moisture-loving [30, 31].

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Lettuce belongs to plants of long daylight. Reducing it to 9-10 hours contributes to the growth of marketable products – leaves, hand eads, but delays the transition to generative development – stem formation and seed formation. In the winter period, when grown on a shorter day and in thickened crops, the plants are elongated and poorly form heads in the headed varieties. Plants shoot intensively when the duration of the daylight hours exceeds 12-14 hours [17, 18, 19].

Lettuce plants are quite demanding on soil moisture and moderate on relative air humidity. With a lack of moisture in the soil during sowing, the emergence of seedlings is delayed, and they, as a rule, are variegated, which significantly affects the early ripening period. A lack of moisture during the growing season slows down the growth of plants and the formation of heads. Overwetting of soil and air leads to stunting of plants and their damage by various fungal diseases. Optimal soil moisture during the growing season is 60-70% RH, and relative air humidity is 65-75% [18].

Zoological characteristics of the Nile tilapia (*Oreochromis niloticus*): belong to the cichlid family. It is best known and widely used as an object of artificial breeding in industrial conditions due to its biological features, namely rapid growth, mass accumulation and dietary properties. Cultivation of tilapia in pools is an alternative to cage and pond breeding when there is a shortage of water and land. The high density of planting in pools limits the possibility of spawning and allows females and males to be grown together to commercial size. Growing tilapia in open pools depends on the water temperature. The optimal water temperature is 25-33ºC (thresholds – 10-15 and 38-42ºC). At lower values, the growth rate of the fish slows down and its resistance to diseases decreases. At temperatures below 8ºC, fish die. Therefore, in areas with insufficient amount of heat and low temperatures in the autumn and winter period, recirculation units are used [17, 23, 24, 32, 33, 34, 35, 36].

In Ukraine, tilapia is grown using waste-heated water from thermal power plants or geothermal water and in closed water supply installations. Due to the intensive cultivation of tilapia, with a high planting density, it is possible to obtain 50-100 kg from 1 m^3 of garden or pool area. Growing fish in Recirculating aquaculture system at high stocking density requires appropriate feed quality. The optimal level of protein in feed for young tilapia is 40%, and for commercial fish – 30-35%. The results of cultivation depend to a large extent also on the mode and norms of feeding. Tilapias have a small rudimentary stomach, so they should be fed several times a day. The value of the daily ratio is 3-5% of the weight of the fish, depending on the temperature of the water and the size of the fish [1, 2, 3, 4, 37, 38].

Tilapia juveniles are grown in pools in two stages: Stage I – up to a weight of 1 g at a planting density of 10-20 thousand specimens/m^3; II stage – up to a mass of 10 g at a planting density of 1.5-2.0 thousand specimens/m^3. When switching to active feeding, the larvae are able to consume the artificial feed. The optimal level of protein in feed is: at the

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1st stage of cultivation – 35-45%, as growth progresses, its content in feed can be reduced to 30 – 35%, when growing commercial fish in cages – to 28-32%, in pools – 32-38%. The duration of growing fry up to a weight of 10 g is 45-60 days, with a survival rate of 80-85%. Cultivation of commercial tilapia is carried out at a planting density of 450-500 specimens/m^3. The duration of growing to a weight of 250-300 g is 120-130 days, fish survival is 85-90%. Tilapias tolerate oxygen deficiency well (optimal content – 5-7 mg/dm^3), resistant to high oxidation of water and the acidic reaction of the environment (up to 4.5 pH). Tilapias have high ecological plasticity [39, 40, 41, 42, 43, 44].

Lettuce is one of the most popular types of greens consumed by humans. Growing lettuce in aqua-, aeroponics or hydroponics is naturally much more difficult than growing lettuce in conventional greenhouse conditions. Special problems arise because it is necessary to regulate not only the temperature and nutrient regimes but also the need and amount of light, the supply of CO_2 in the room, the shading of plants, the temperature of the nutrient solution, the cleanliness of the air in the room, etc.

Among the green crops, the most common is lettuce, which has three varieties – leafy, heady and romaine. Leaf lettuce (*var. secalina Alef.*) forms a rosette of leaves; capitate (*var. capitate L.*) – after the formation of a semi-raised rosette of leaves in the center, it forms a head of different shape and density; romaine – (*var. Lonifolia Lam.*) – forms a cone-shaped

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head of medium density in a rosette of elongated leaves. For food, the rosette of leaves is used in leaf forms, and the rosette and heads are used in head varieties. Marketable products are formed in the 30-45 days after the emergence of seedlings, depending on the variety [26, 28, 30, 31].

Commercial maturity of leaf varieties of lettuce occurs 25-35 days after the emergence of seedlings when a rosette of 7-8 leaves is formed. According to the duration of the growing season (from the appearance of seedlings to the onset of technical ripeness), lettuce varieties are divided into ultra-early (up to 30 days), early (31-40), medium-early (41-50), medium-ripe (51-60) and late-ripe (over 60 days). In early-ripening varieties, the heads are smaller (30-70 g) and loose, in late-ripening varieties – larger and denser, weighing 150-500 g. Depending on the weather conditions, the duration of the growing season can vary.

Lettuce cultivation began with the mother plant. Lettuce seeds were placed in a substrate (mineral wool) and placed in a plastic container filled with water. Conditions were created in the brooder under which air humidity was maintained within 90% and the temperature of the air and all constituent components of the brooder within 25-26°C. The growing of plants in the mother plant was carried out under conditions of limited light, therefore, in the experiments, we used supplemental lighting thanks to the use of LED lamps. The duration of additional lighting varied depending on the time of growing seedlings. The duration of lighting depends on the period of growing seedlings, but the maximum duration of lighting should not be more than 16-18 hours, since 24-hour lighting is not efficient and economically unsubstantiated. Seeds germinate in 2-4 days. When the first pair of cotyledon leaves was obtained, the seedlings were placed in the hydroponic blocks of the aquaponic system. The layout of lettuce plants was 14.1×14.1 cm, or the feeding area of one plant is 198.8 cm^2, that is, 50 plants were placed on 1 m^2. The area of the pool for growing lettuce was 3 m^2, that is, the productivity was 150 plants. With proper sanitation of the greenhouse, there is no need to use chemical plant protection products, which makes the products environmentally friendly.

For artificial lighting of plants, you need to use lamps with blue and red colors in the radiation spectrum. The light of a lamp with a predominance of the red spectrum stimulates flowering and fruiting, and a lamp with a predominance of the blue spectrum – the growth and development of the plant. Thanks to this radiation, the growth of plants is noticeably accelerated, and plants grow well even in rooms without daylight. LED phytolamps with a spectrum of red 85% and blue 15% are used for germinating lettuce. The lamps should be located so that the light spreads evenly throughout the growing area and the light intensity of which should be at least 100 μmol/m^2/s of the so-called PAR-spectrum (photosynthetically active radiation). For the cultivation of parsley, mint, basil, cilantro, thyme and other greens, it is possible to use white light LED lamps, but also taking into account the spectrum [3, 4, 7, 22, 25, 29].

Round-the-clock illumination of lettuce seedlings is carried out when the illumination is lower than 1000 lux, first for 15 days, then – 14-16 hours a day during the day. The day before harvesting the salad, the plants are stopped lighting. After 45 days, the ready-made salad, which reached a mass of 140-150 g, together with the pot, was placed in a polyethylene conical bag and sent for sale. This method of harvesting and transporting the crop makes it possible to keep the product fresh for 10 days without special storage conditions.

An additional incentive for growing fish according to the aquaponic cycle is its safety. This is manifested in the fact that almost all fish in stores have bacterial or fungal damage on their bodies, which is absent in the aquaponic system.

Fish productivity of tilapia in industrial conditions, when juveniles are kept in gardens or pools, 10-20 thousand specimens weighing up to 1 g per 1 m^3 are planted. With a weight of 1 to 10 g – 2 thousand. At this density, fry gain 10 g in 1-1.5 months. Commercial tilapia is considered to be 250 g or more. The fish will gain this weight in about 6 months. And in polyculture, fish productivity can reach 5 t/ha. In monoculture, the average fish productivity of tilapia is low. However, with increased feeding, it is possible to reach 1.0-2.5 t/ha.

Tilapia meat is high in protein and low in fat. The texture of the meat is of medium density, it has a pleasant taste without a specific "fishy" smell. The taste of the cooked meat is similar to chicken, which is why the fish is sometimes called "water chicken". However, tilapia skin can give a bitter taste to the dish. Because of this, it is removed when preparing the fillet for freezing. Meat is prepared in all the ways intended for fish. The finished dish is served with different sauces. Nutritional value of tilapia meat (per 100 g): kcal – 98; fat – 2.4 g; protein – 18.5 g; calcium – 52 mg [2, 44].

The reasoning behind the feasibility of growing lettuce and tilapia at the same time lies in their relatively similar growing cycle in terms of temperature and light regime, as well as the possibility of using a variety of fish feeds, which in turn will create a nutritious environment for growing agricultural crops.

A granulated compound feed with the following quality indicators was used as feed: protein, not less than 32.0%, crude fat, not less than 1.0%, crude fiber, not more than 7.0%, phosphorus, not less than 1.0%, humidity, no more than 10.0%. Feed composition: soy, corn gluten, corn grits, ground chicken offal, dicalcium phosphate, calcium carbonate, fish meat, animal fat (preserved with mixed tocopherols), salt, choline chloride, potassium chloride, vitamin A, vitamin D_3, vitamin E, zinc sulfate, L-ascorbyl-2 polyphosphate (source of vitamin C), ferrous sulfate, niacin, calcium pantothenate, riboflavin supplement, copper sulfate, pinoxin hydrochloride, thiamine monoamirate, manganese sulfate, manganese sulfate, copper protein, calcium lodate, cobalt carbonate, folic acid, sodium selenite, biotin, vitamin B_{12}.

The amount of feed was 3% of body weight, which ensures the most effective conversion of food into meat. Feeding should be done at the same time, either early in the morning or late in the afternoon.

For normal functioning in closed plants and fish water supply facilities, constant control of water quality is necessary, which must meet sanitary and hygienic standards (Table 3).

Table 3

General requirements for the quality of water that enters reservoirs for keeping tilapia broodstock

Indicator	Normative value
Smell	absent
Transparency, m	0.75-1.0
Suspended substances, mg/dm^3	up to 25
Nitrites, mg/dm^3	up to 0.1
Nitrates, mg/dm^3	up to 2.0
Hydrogen index, (pH)	6.5-8.5
Dissolved oxygen, mg/dm^3	at least 5
Phosphates, mg/dm^3	up to 0.5
Hydrogen sulfide, mg/dm^3	absent
Ammonia dissolved, mg/dm^3	0.05

A prerequisite for the best growth of lettuce plants and fish is water saturation with oxygen, which determines the hydrobiological and sanitary state of the system. An aerator was used to increase the oxygen content in the water. During the operation of the aerator, in addition to the saturation of water with oxygen, other factors are manifested, such as a change in the thermal balance of the water environment, a redistribution of temperature between water layers, and the release of carbon dioxide. In general, aeration, improves the oxygen regime of the reservoir, increases the productivity of phytoplankton, general destruction in the water, strengthens the contact of water with bottom sediments and the atmosphere and increases the overall bio productivity, affects fish productivity [22, 26].

When growing lettuce and tilapia, the water temperature was – 25-31ºC, the reaction of the environment – 6.5-7.5, dissolved oxygen – 3-24 mg/dm^3, ammonia – 0.3 mg/dm^3, nitrites – 0.02 mg/ dm^3, nitrates – up to 60 mg/dm^3, suspended solids – up to 50 mg/dm^3. If necessary, no more than 1/3 of the volume of fresh water was added, and the photoperiod was maintained: 12 h – light, 12 h – night. The illumination of the surface where the fish were grown was about 600 lux.

Table 4

Aquatic and biological standards for growing tilapia in Recirculating aquaculture system [1, 2, 3,4]

Mass, g	Density, kg/m^3	Survival rate, %	Cultivation period, days	Water exchange, hour
2-15	2,5	75	30	1
15-60	20	95	30	1
60-100	60	96	30	1
100-140	90	97	30	1
140-180	120	97	30	1
180-220	150	97	30	1
220-250	150	93	30	1

According to scientists [1, 2, 3, 4], the annual capacity of Recirculating aquaculture system is determined not only by creating favorable conditions for growing plants, fish and providing high-quality feed but also by the applied production technology. The use of aquaponic systems makes it possible to increase the efficiency and productivity of both lettuce and fish farming several times.

According to the conducted research, a properly developed cycle of growing leafy lettuce and the selection of seedlings makes it possible to obtain a full and high yield of the specified objects within 45 days (Table 4). Cultivation of these agricultural and biological objects makes it possible to obtain a harvest of leaf lettuce in the amount of 150 pieces with an average weight of 145 g, which forms a yield at the level of 7.25 kg/m^2 or 0.66 kg from 1 m^2 of the total volume of the aquaponic system. Growing fish from fry weighing 50 g with an average daily growth of 4 g for the specified period forms the marketable weight of fish for sale – 220 g, which are 59.5 kg/m^3 of the aquaponic system.

This method is quite effective and can be adjusted depending on the object of the agricultural plant and fish farming technology. Under these conditions, the number of periods (cycles) out of 8 can range from 3 to 5.

This technology is innovative for agriculture in Ukraine.

Table 5

Productivity of the aquaponic system

Indicator	Unit of measurement	Indicator value
1	2	3
The total usable area of the aquaponic system, of which:	m^2	5.5
for growing lettuce	m^2	3.0
filter station and aerator	m^2	1.5
fish pool	m^2	1.0
the protective area around the aquaponic system (path 0.7 m)	m^2	11.06
The total amount of lettuce plants	pieces	150
The average weight of lettuce	g	145
Duration of one cycle (from the appearance of cotyledon leaves to biological maturity)	day	45
The maximum possible number of cycles for growing lettuce		8
The total yield of leaf lettuce in one cycle	kg/m^2	7.25
	t/ha	72.5
The total volume of tilapia cultivation	m^3	1
The amount of fish planting material	pieces	350
The average weight of tilapia at the beginning of cultivation	g	50
Average daily gain	g	4

Закінчення табл. 5

1	2	3
The average weight of commercial tilapia at the end of cultivation	g	220
The survival rate of tilapia	%	85-90
The duration of one cycle (from the landing of fish to commercial weight)	day	45
The maximum possible number of cycles when growing tilapia		6
Total productivity of the pool	kg/m^3	77
Productivity of increased fish biomass	kg/m^3	59.5
The total productivity of the aquaponic system per 1 m^2 of area, kg	lettuce	0.66
	tilapia	5.38

The efficiency of environmental and economic indicators:

- a significant decrease in the usable area for harvesting;
- saving natural and energy resources;
- obtaining ecologically clean products;
- increase in labor productivity per 1 m^2 of the used area;
- consistently high yields of high-quality fresh products;
- year-round functioning of the system;
- do not use poisonous chemicals;
- possibility to increase the employment of the population, etc.

CONCLUSIONS

The creation and regulated operation of the aquaponic system is capable of producing a full and high yield of leaf salad and fish products within 45 days. Cultivation of these biological objects makes it possible to obtain a harvest of leaf lettuce in the amount of 150 pieces with an average weight of 145 g, which forms a harvest at the level of 7.25 kg/m^2 or 0.66 kg from 1 m^2 of the total volume of the aquaponic system. Cultivation of fish with an initial weight of 50 g, with an average daily growth of 4 g for the specified period, forms the marketable weight of fish for sale – 220 g, which are 59.5 kg/m^3 of the aquaponic system.

During the operation of the aquaponic system, positive ecological and economic conditions are created, namely: a significant reduction of the area for harvesting; saving natural and energy resources; obtaining environmentally friendly products; increase in labor productivity per 1 m^2 of the used area; consistently high yields of high-quality fresh produce;

year-round operation of the system; absence of toxic chemicals; the possibility of increasing the employment of the population, etc.

SUMMARY

The construction of aquaponic farms will make it possible to obtain ecologically clean organic agricultural products, which belong to the category of high-quality food, the demand for which is growing daily in the world. Agricultural products grown on organic fertilizers created by aquatic animals in the process of growing them will meet all the necessary standards and can receive a special certificate and the right to use ecological manuring. The combination of these two methods makes it possible to simultaneously grow aquatic animals and ecologically clean organic agricultural products, reducing capital costs for special water filtration and the use of precious feeds, making such production highly efficient, safe, and practically waste-free.

This technology is almost the only one that combines the fields of fish farming and plant breeding with the simultaneous saving of material and natural resources, as well as rational nature use and ecology. The development of this technology will make it possible to grow fish and plant products in any region in a closed cycle. The installation of aquaponic systems does not require the allocation of fertile soil, special soil preparation, the presence of running water, or a reservoir.

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