Fast-deployable co-cultivation systems in aquaculture

L Yu Lagutkina¹, E M Evgrafova¹,², E G Kuzmina¹ and A N Gundareva¹
¹ Astrakhan State Technical University, 16, Tatishev st., Astrakhan, 414056, Russian Federation
² LLC AKVABIOTEH, 24, Bugrovaya st., Starokucherganovka, Astrakhan region, 416101, Russian Federation

E-mail: lagutkina_lina@mail.ru

Abstract. The article is devoted to the creation of a combined recirculating fish farming and intensive crop production (aquaponics) on the basis of a mobile modular facility, which corresponds to the direction "Transition to highly productive and environmentally friendly agro-development and implementation of systems for the rational use of chemical and biological protection of agricultural plants and animals, storage and efficient processing of agricultural products, creation of safe and high-quality, including functional, food products" of the Strategy of scientific and Technological Development of the Russian Federation, as well as the Forecast of scientific and technological development of the agro-industrial complex of the Russian Federation for the period up to 2030 in terms of the development of specific research areas "Urbanized agriculture: combined technology of recirculating fish farming and intensive crop production".

1. Introduction
In the twenty-first century, cities’ urbanization will become a determining factor in territorial development and one of the main drivers of global economic growth.

Thus, it can be concluded that it is in growing cities that the food problem will become particularly acute: the availability of food for the growing population of cities in quantitative and, especially, qualitative terms will decrease, and the "risks" to the food security of cities will significantly increase.

Moreover, the existing traditional food supply system for cities will not be able to meet their long-term needs and needs to be supplemented.

This "supplement" will take the form of food production in the cities themselves, which will minimize logistics costs, waste generation.

According to experts, in the coming years, we should expect an "explosive" development of urbanized agricultural production – food production in cities, and technologies for self-sufficiency of cities with food will become a new "big thing", comparable in its development potential to the technology of the "Internet 20 years ago".

In recent years, technologies for food production have become more accessible. "Industry 4.0" is "democratizing" food production. It ceases to be "sacred" knowledge, depending on decades of observation and practical experience. This knowledge is becoming more accessible with the development of information communications, and the means of production are becoming less expensive, more efficient and manageable, in particular, with the development of automation and robotization.
And this makes the return of food production to the cities a matter of time. It is the "return" - as the bridging of the gap between the city and agriculture production, which was most evident in the era of industrialization and the development of urban farming [1].

The aim of the research is to solve scientific and technical problems related to the development of natural resource-saving and waste-free technologies of urbanized agricultural production (city farming) to increase the level of food security of the urban environment and the development of local communities of producers of environmentally friendly, fresh food products [2-5].

Systems of combined recirculating fish farming and intensive crop production (aquaponics) on the basis of a small-sized modular installation ("Eurocube") are being developed with the aim of creating on their basis fast-deployable aquaponic city farms for climate-independent, year-round production of fresh food (fish and vegetables) in cities and suburbs.

The target groups of users of city farms based on the use of aquaponics are: residents of cities and suburbs who want to grow fresh vegetables and fish in their own homes, apartments (B2C segment), as well as cafes, restaurants, owners of non-residential closed premises (warehouses, etc.), schools, universities, religious institutions (farmsteads, monasteries, settlements) (B2B segment).

The practical results are aimed at meeting the potential demand of the following consumer groups:

- Population-consumers of locally produced (local) fresh food products, as well as producers of such products for their own consumption using special equipment (mobile city farms). The most popular mobile city farms based on aquaponics may be in areas with poor soil or water quality (or lack thereof). Such users include pensioners who do not have the health opportunities to engage in agriculture; young parents who do not have their land, but want to provide their children with exceptionally high quality and environmentally friendly; the working class who have no "desire and energy" after work to spend time going to the store, when at home in a small area, you can arrange a full farm, the inhabitants of the northern regions, which do not have the ability year-round to have fresh produce, citizens, residents of the suburbs who want to get fresh, organic food year-round ("garden variety on the table");
- Companies interested in development of small- and medium-sized year-round, climate-independent the production of fresh food cafes and restaurants, supermarkets, educational organizations to support the learning process (training, retraining), as well as those for whom it is important to be able to teach advanced agrocommercial and/or to attach to positive employment. Such organizations include, among others, entrepreneurs of single-industry towns (medium and small businesses) and participants of the Far Eastern Hectare program (up to 500,000 people); 5,000 military units of the Ministry of Defense; 30,000 parishes and communities of the Russian Orthodox Church for which it is important to provide themselves with food on their own and / or increase the productivity of the economy; 40,000 Russian schools.

Russian consumers are increasingly demanding about the environmental friendliness of goods (VCIOM), 56% of Russians agree to overpay for environmentally friendly products and are ready for increased spending when buying fresh, non-frozen, unprocessed products (51%) and products without GMOs (46%) (ROMIR) [6].

Functions modular system - combined recirculating fish farming and intensive crop production (aquaponics) based on a compact modular unit ("Eurocube") are the creation and maintenance of conditions of functioning of artificial environmentally friendly and virtually waste-free ecosystem (aquatic organisms - colony of nitrifying bacteria, the higher plants) for climate-independent, year-round production of fresh food (fish and vegetables).

2. Materials and methods
To create a system, the following components and materials are required: (included in the product (goods) being developed or used in the process of its manufacture and operation):
Electrical components (pump, water pump, film heaters, water heaters, generator, phytolamps, aerator compressor);

A set of reagents for measuring the parameters of the system environment (dissolved oxygen, ammonium, nitrites, nitrates, pH);

Standard reusable cubic container (polythene plastic container of cubic shape – "Intermediate Bulk Container");

Collectors-polyethylene and / or polypropylene pipes and fittings, composite fittings;

Fish planting material (carp, crustaceans [7-9]);

Seedlings, seeds, mixed feed for fish [6; 10], cups for seedlings, nets, automatic feeder for swimming pools, siphons for cleaning the bottom;

Bio-loading of biofilters and hydroponic modules, cassettes for seedlings, substrate for plants;

Culture of nitrifying bacteria to start the biofilter;

Raw materials for animal feed of animal and vegetable origin.

3. Results

The system is assembled fairly quickly: the water supply and heating systems are installed in the sawn "Eurocube" within 4-6 hours of operation, and a siphon for water circulation is installed (figure 1).

![Figure 1. Diagram of a stationary modular small-sized combined system - A, B – experimental sample.](image)

The upper hydroponic module is filled with a substrate-clean washed expanded clay in the amount of 200-230 liters per hydroponic module.

After connecting to the power grid (energy generator), the system is filled with water, the introduction of nitrifying bacteria to start the biofilter (up to 3 weeks), loading of planting material-young fish or crustaceans (shrimp, crayfish), planting material of crop production (greens and / or vegetables), preparation of feed for aquaculture facilities.

A necessary element of the system is a siphon, which ensures the drainage of the substrate and, consequently, the supply of oxygen to the plants. The siphon consists of an external perforated PP or PE pipe (since the use of PVC materials is prohibited in the production of organic products), which prevents the leakage of the substrate. Inside it is a drain riser enclosed in a larger diameter pipe with an air injector. The pipe covering the drain riser is tightly closed from above. The mechanism of action of this siphon is to periodically create an air plug at the inlet of the drain riser. Its disadvantages include...
contamination of the injector tube, which leads to deterioration of the siphon, so the substrate must be thoroughly washed before loading and after harvesting.

After creating fast-deployable compact combined system recirculating aquaculture and intensive crop production, created on the basis of standard design "Eurocube" - IBC (Intermediate Bulk Container — a container of average capacity), with a volume of 1000 l, the fish part of the system to 0.5 - 0.7 m$^3$ with hydroponic module (250 l), located at the front of 1m$^2$ were selected objects crop for the joint cultivation (figure 2).

![A-planting](image1)
![B - arugula](image2)
![C - basil](image3)
![D - self-pollinating variety of cucumbers](image4)

**Figure 2.** Objects for the hydroponic module.

Stocking of plants and aquaculture objects is carried out simultaneously after starting the system and loading the biofilter with nitrifying bacteria. The varieties are selected taking into account the closed space – self-pollinating. Operating conditions-closed rooms with an air temperature of +40 ... +10 °C with the provision of water temperature in the system +20 ... +27 °C (depending on the species of hydrobionts and plants grown).

When selecting objects of aquaculture should be guided by the temperature of the selected objects crop, so the fruit (cucumbers) and leafy (basil, arugula), you can grow objects warm-water aquaculture, such as carp and crustaceans, which have similar needs regarding key hydrochemical parameters of the water that allows you to set the conditions of their detention in containers as modular units: T – 26 °C, pH of 7.4, O2 – 6.5 mg/l, the amount of water losses and topping – up to 25%. The feeding of these objects must be carried out with specialized compound feeds that meet the nutritional needs, balanced in nutrients in accordance with the body weight (table 1).

The feed supply to the system per day is 40-50 g of feed per 1 m$^2$ of the area of growing leafy plants (arugula, basil) and 50-80 g of feed per 1 m$^2$ of the area of growing vegetables (cucumbers).

For the efficient production of the proposed objects of the tench (*Tinca tinca*) and the Australian crayfish (*Cherax quadricarinatus*) under similar conditions of living objects, developed an optimal scheme for growing small plants modular components super-efficient system – on the basis of research...
of changes of the relevant physiological and biochemical parameters and the subsequent justification of the recommended fish-biological standards (in terms of stocking density for both species) (table 2).

Table 1. Nutritional value of the diets used.

| ingredient          | per 1 kg of mixed feed | crustaceans | cyprinids |
|---------------------|------------------------|-------------|------------|
| protein             | 40-45                  | 35-40       | 40-45      | 30-35      |
| lipid               | 7-8                    | 8-9         | 7-8        | 6-7        |
| fiber               | 5                      | 4           | 5          | 5          |
| buoyancy            | negative               | positive    |            |
| pellets             | do not erode, gravitate| do not erode, do not gravitate |

Table 2. Biological norms of growing in the module.

| i/i indicators parameters                                                                 |
|-------------------------------------------------------------------------------------------|
| the content of individuals (crustaceans, cyprinids)                                        |
| 1 small-sized combined system module                                                       | up to 0,5 - 0,7 m³ |
| 2 temperature range                                                                       | 26⁰C |
| 3 level of pH                                                                              | 7,4 |
| 4 level of O₂                                                                              | 6,5 mg/l |
| 5 amount of water loss and topping up the water level:                                      |
| cyprinids                                                                                  | 65 sm |
| crustaceans                                                                                | 30 sm |
| 7 level of NO₂/NO₃                                                                        | 0,01-0,10 mg/l |
|      level of NH₄                                                                          | 0,02-0,10/0,5-4,5 mg/l |
| the norm of carp stocking density:                                                        |
| 8 or 5 g <50 g                                                                            | 150 pcs/ m² |
| > 100 g                                                                                  | 15 pcs/ m² |
| > 1 g                                                                                     | up to 1000 pcs/ m² |
| > 5 g                                                                                     | up to 500 pcs/ m² |
| > 45 g                                                                                     | up to 200 pcs/ m² |
| the rate of stocking density of crustaceans:                                               |
| 9                                                                                         | up to 1000 pcs/ m² |
| > 1 g                                                                                     | up to 500 pcs/ m² |
| > 5 g                                                                                     | up to 200 pcs/ m² |
| the diet of carp:                                                                         |
| 10 protein                                                                                | 35-45 |
| lipid                                                                                     | 7-8 |
| carbohydrates                                                                             | 5 |
| the diet of crustaceans:                                                                  |
| 11 protein                                                                                | 40-45 % |
| lipid                                                                                     | 8-9 % |
| Carbohydrates                                                                             | 4-5 % |
| feed quantity*, g/1 m² area                                                               |
| 12 carp                                                                                   | 40 | 58 |
| crustaceans                                                                              | 56 | 81 |
| the norm of compound feed from body weight, carp:                                          |
| 13 less than 50 g                                                                          | 4% | 4% |
| more than 50 g                                                                             | 1-2% | 1-2% |
| more than 100 g                                                                            | 1% | 1% |
the rate of feed of body weight, crustaceans:

| Weight (g) | 2-4% | 2-4% |
|-----------|------|------|
| more than 1 g | 2%  | 2%  |
| more than 5 g  | 1,5% | 1,5% |

15 the buoyancy of the feed

| Feed | negative | positive |
|------|----------|----------|
| deciduous | 20-25 | 4-6 |

16 the density of stocking per 1m²

Note * feed of own formulation, a, b – feeding standards for growing in combined growing systems.

Also, the experiments conducted indicate the possibility of co-cultivation of the studied species with plant products, and the compact volume of installations and the relative ease of maintenance and maintenance make these systems promising for business models of city farming within small and medium-sized businesses in cities, at the same time, not excluding the possibility of application in large-scale production due to the low risk of climatic conditions, as well as due to diseases and pests associated with concentrated growth at scale.

Table 3 shows the necessary growing conditions for some plants using metal-halogen lamps (MH) and high-pressure sodium lamps (NLHP). LED phytolamps ("plant" spectrum) are characterized by high efficiency, low energy consumption and environmental friendliness, compared with household incandescent lamps, special lamps for growing plants AST, MGD, luminescent.

| Plant | Lighting | Lamp Type | Temperature Group | pH       |
|-------|----------|-----------|-------------------|----------|
| basil | bright light | 250/400/1000 W MH | thermofil | 5,5-6,5 |
| cucumber | average illumination | 1000 W | thermofil | 5,5-6 |
| arugula | average illumination | 250/400/1000 W MH | mesoderm | 6-7 |

For the developed small-sized combined system, experimental light compositions (Blue, Red, FarRed, Full Spectrum) were used as part of the experiment and effective ratios for the grown crops were determined. We used light culture: the phytolamp acts as the main light source, and no other light fell on the plants, the lamp was located at a height of 100 cm.

When self-assembling lamps for calculating diodes, we determined the power: 100 - 250 "live" (that is, actually consumed) Watts per 1m² depending on light-demanding plants. On average, for fruit and vegetable plants, the calculation is 100-150 W/1 m², for greens and seedlings at the rate of 50-100 W/1 m².

Garden expanded clay with a particle diameter of 8-16 mm was chosen as the best substrate for the hydroponic module. When using too small expanded clay, there are difficulties with the supply of oxygen, and the use of larger particles has led to inefficient rooting of plants.

4. Discussion

The possibility of effective production of the proposed objects in the implementation of integrated cultivation of carp and crustaceans with arugula, basil and cucumber plants is established. The studied biological indicators of living objects superefficient system optimal content: T - 260°C, pH of 7.4, O₂ and 6.5, the rate of feeding of 4.5% of body weight 2 times/day, water losses and topping, at 25% normal density planting without led lighting: carp - 500 pcs/m², crustacean - up to 1000/m². An integrated base module has been developed - stationary, not automated, based on the so-called "Eurocube" - a plastic container of a cubic shape with a volume of 1000 liters. This container is placed in a rigid aluminum frame and stands on a plastic pallet. The volume of the fish-breeding part of the system is up to 0.7 m³. The upper part or the hydroponic module (250 liters) is located on a rack on top of the lower one and is designed for growing plants with a volume of 35 kg.
5. Conclusion
In conclusion, it should be noted that a module for intensive crop production has been developed, including subsystems for artificial LED lighting of the plant spectrum, phytolamps for cucumbers 1000-1500 W/m² for basil and lettuce seedlings 200/350/1000 W/m². The results obtained complement the existing ideas about the fields of aquaponics, are scientific and practical.

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