ESI Preprints

Not Peer-reviewed

Bibliographic Review of Aquatric Systems and their Relevance to the Ivory Coast, a Sub-Saharan African Country

Nobah Céline Sidonie Koco
Maître de Conférences; Ecole Normale Supérieure d'Abidjan; Département des Sciences et Technologie; Section Science de la Vie et de la Terre; Côte d'Ivoire
Koffi Kouakou Barthélemy
Maître-Assistant; Ecole Normale Supérieure d'Abidjan; Département des Sciences et Technologie; Section Science de la Vie et de la Terre; Côte d'Ivoire
Kouakou Affoué Constantine
Doctorante Université Félix Houphouët-Boigny; UFR Biosciences ; Laboratoire d'hydrobiologie et d'écotechnologie des eaux, Côte d'Ivoire

Doi: 10.19044/esipreprint.1.2024.p117

Approved: 09 January 2024
Posted: 10 January 2024

Cite As:
Koco N.C.S., Barthélemy K.K. & Constantine K.A. (2024). *Bibliographic Review of Aquatric Systems and their Relevance to the Ivory Coast, a Sub-Saharan African Country*. ESI Preprints. https://doi.org/10.19044/esipreprint.1.2024.p117

Abstract

Through a review of aquaponic techniques, the present work highlights the interest aroused by this practice in the world as well as different modes of exploitation. Aquaponics is defined as a coupling between a recirculated aquaculture compartment and an aboveground crop compartment. Since two decades, it has been the subject of a significant economic activity in Canada, the USA, Australia and induces numerous research activities. This system is subdivided into three (3) major techniques which are the culture techniques on bed of inert substrates, on nutritive film and that of rafts. Aquaponics is the subject of profitable industrial economic activity on both large and small scale in the USA and Canada. Given the benefits of low water consumption, the non-use of fertilizers and pesticides, aquaponics is unquestionably according to researchers and users, the system capable of revolutionizing livestock farming and agriculture around the world. Côte d'Ivoire is suffering not only from the consequences of climate change but also from rapid urbanization, with the consequent change in water resources. Aquaponics deserves to be mastered then popularized in this country, to help produce fish and plants of better quality while avoiding the waste of water caused by traditional livestock systems.

Keywords: Aquaponics, agriculture, above-ground fish farming, techniques

Introduction

According to FAO (2014), by 2030, more than 60% of the population of developing countries will live in megacities. These countries will therefore have to face the dual challenge of famine and the rapid growth in the number of people suffering from food-related illnesses. Urban agriculture could be one way of overcoming famine.

The integrated fish-farming system is a traditional Chinese practice, consisting of fish or shrimp farming combined with domestic animal husbandry or agricultural practices such as market gardening. It is practised in Europe, Africa and some Latin American countries and plays an important role in increasing farm productivity (Pillay, 1990). However, the rate of adoption of this technology is low, resulting in socio-economic barriers to its diffusion. Some people, mostly Americans and Canadians and some Europeans, have adopted a sustainable integrated fish-farming system. This revolutionary practice is called aquaponics. Aquaponics can be defined as a coupling between a recirculating aquaculture compartment and a soilless plant culture compartment. After more than thirty years of dotted-line studies, the concept of aquaponics is increasingly appearing as an opening for the agricultural world in these countries, concerned with the preservation of water resources from a quantitative and qualitative point of view. According to the European Parliament, aquaponics is one of the "ten technologies capable of changing the world" (Woensel and Archer, 2015) because of its reduced environmental impact and improved sustainability. This integrated system is productive. It requires little water and little soil. The waste products from aquaculture are a source of nutrients that can be easily assimilated by plant roots. Today, aquaponics is the subject of significant economic activity in Canada, the USA and Australia, and has led to numerous initiatives by private individuals initiated by numerous media on the Internet and by scientific publications. With the exception of a few industrial operators, this technology is currently used on a garden scale, while research in this field has been intensifying for several years.
Côte d'Ivoire is characterised by a rich and diversified hydrographic network. However, the country is suffering from the harmful effects of industrial and anthropic pollution. In Côte d'Ivoire, fish farming is

booming, but the techniques are rudimentary. Very often, this activity is abandoned in favour of agriculture due to certain uncontrolled parameters. Aquaculture is not able to satisfy the needs of the population in the sense that the demand is very high (Bamba, 2002). The practice of aquaponics in the Ivorian environment is rare, as are research programmes on this topic. What are the advantages of practising and popularising aquaponics in Côte d'Ivoire? The present work, which is a bibliographical review, after a brief history, presents on the one hand the state of the art of aquaponics in the world, and on the other hand the different types of aquaponics as well as the advantages and disadvantages linked to this activity. In addition, the need to operate such a system in Côte d'Ivoire in order to make a real contribution to food security by controlling fish feed and focusing on quality is analysed.

Methodology

This work consists of a bibliographical research on the aquaponics method.

Results

I. Background

Aquaponics is as old as agriculture. It is an ancestral method whose origins date back to the Aztecs in Central America, two millennia before Christ (Foucard *et al.*, 2015). This people cultivated 'floating' gardens in a lake environment, the *chinampas*, structures covered on the surface by mud from the lake bottom, rich in nutrients from organic debris and decomposition. These rafts were irrigated by water enriched with nutrients from fish droppings that naturally accumulated on the lake bottom.

In scientific terms, aquaponics is thought of and developed by aquaculture research with an initial focus on phytopurification and sustainable food production. The first research work on aquaponics was carried out by the New Alchemy Institute in North Carolina. They found that pond aquaculture water was an attractive source of nutrients for hydroponic plant production. Subsequently, Mark Mc Murtry at the University of North Carolina continued this work by developing a system of vegetable cultivation combined with tilapia farming in the 1980s. At the same time, he introduced the issues of water conservation, intensive fish production and reduced operating costs. Inspired by these successes, Dr James Rakocy's experiments at the University of the Virgin Islands (UVI) on a floating raft system called "rafts" are a reference for commercial aquaponics systems worldwide (Rakocy et al., 2006). This system is best known for providing important sizing data, transferring a reproducible model, and producing over 60 different species in aquaponics.

II. Different types and techniques of aquaponics

1. Geographical distribution

Aquaponics is the subject of significant economic activity in Canada, the USA (especially Hawaii) and Australia, and is the subject of numerous research activities.

According to Love *et al.* 2014, a survey of 809 aquaponic farmers around the world indicates that 80% of aquaponics producers are in the USA, making it the leading country in the field. This is followed by 8% in Australia and only 2% in Canada.

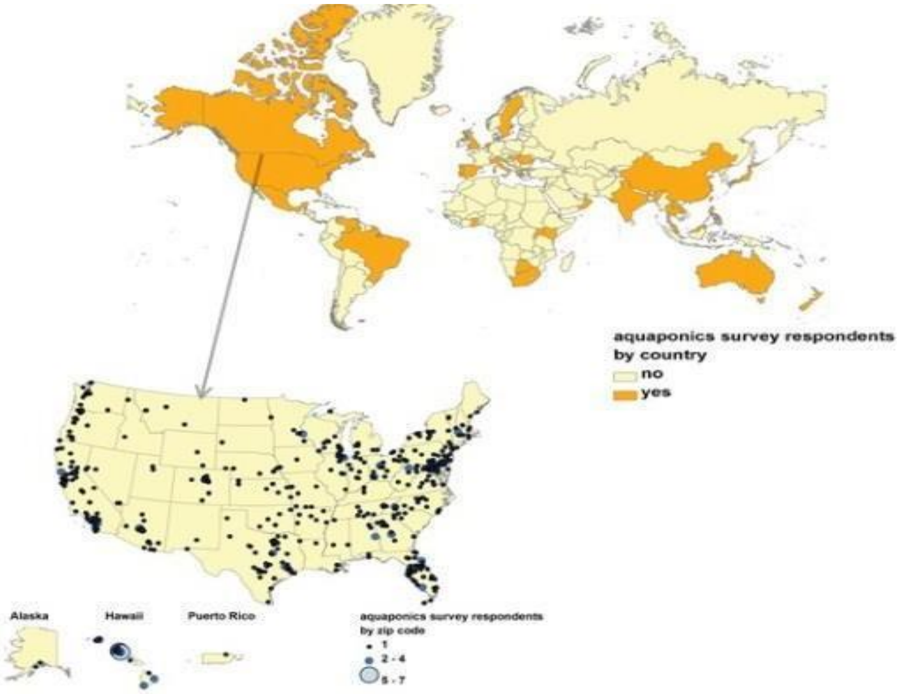

Fig 1. Distribution of aquaponics activities in the world.

2. Types of aquaponics

2.1. Domestic aquaponics

It covers vegetable ponds, vegetable aquariums and family micro-greenhouses for the garden, terrace or kitchen, building roofs and local authority land in built-up areas, gardens, parks, schools and roofs.

2.2. Commercial aquaponics

This is a small-scale activity. The farmer lives from his production but also from other activities such as training, site visits and ecotourism, which take place on the same sites as those mentioned above.

2.3. Industrial aquaponics

It is a very sophisticated system incorporating several culture basins, filtration systems (mechanical and biological), aeration and alarms, installed in urban or peri-urban environments on industrial wastelands, or on sites already identified for aquaculture and on which it is possible to couple plant cultures, or on market garden production sites on which it is possible to install recirculating aquaculture circuits.

3. Aquaponics techniques

3.1. Coupled aquaponics systems

Coupled" systems are those designed in the early days of aquaponics, such as at the New Alchemy Institute, North Carolina State University and the University of the Virgin Islands (UVI). The disadvantage of this coupling strategy is the total dependence between the two aquaculture and hydroponic compartments. These systems involve a constant dependency between the aquaculture and plant compartments. The water leaves the fish tanks and goes directly into the plant system through a biofilter and mechanical filtration before returning to the fish. In the event of a health problem with fish or plants, solutions are limited (Foucard *et al*., 2015).

3.1.1. Deep Water Culture (DWC) or rafting technique or "Deep Water Culture" (DWC)

It is a recirculating aquaponics system consisting of tanks and raft, adapted to the tropics, called "Rakocy system" because it was developed by Dr. Rakocy, Professor Emeritus of the University of the Virgin Islands (Rakocy *et al*., 2006). It is the most studied and used technique especially in large-scale aquaponics, as it allows for an easy crop rotation and production plan. Plants are grown on rafts, which are floating plates (mostly made of high-density polystyrene, extruded type, with a thickness of 30 to 50 mm) placed directly on the water (15 to 30 cm deep) (Lennard and Leonard, 2006). The plants produced are supported by an inert substrate in growing pots fixed through the pre-drilled rafts. This technique works in continuous flow, and the roots of the plants are continuously irrigated with well oxygenated water. Once developed, the plant roots literally "soak" in the water. The two compartments of fish and plants must be separated and the water returning from the plants to the fish must pass through mechanical and biological filtration structures to remove as many solid particles and toxic dissolved forms of nitrogen as possible (Gravel *et al*., 2014). The surface underneath the rafts and the space between the plant roots are potential habitats for nitrifying bacteria, but they are by no means sufficient, and a precisely sized biological filtration compartment is required. The raft system is suitable for producing lettuce and herbs (Tyson *et al*., 2004). The design and management of this system allows for optimal harvesting of plants and fish.

3.1.2. Nutrient film culture or "Nutrient Film Technic"(NFT)

In NFT soilless systems, nutrient-rich water is pumped into small closed pipes or gutters (Adler *et al*., 2000; Lennard and Leonard, 2006). The water flows in a steady stream through the system, first through filtration components and then over very gently sloping gutters where plants (in pots, in inert substrate) collect nutrients for growth, before returning to the aquaculture compartment. The very thin film of water flows down each channel of the gutters, which have a slope of about 1%. A flow rate of 1 litre/minute is recommended (Savidov and Rakocy, 2007). Oxygenation of the nutrient solution is largely achieved by its movement through the gutters and by the large surface area of exchange between water and air (Foucard *et al*., 2015).

3.1.3. Cultivation technique on a bed of inert substrates

This is a flooding and drainage system. In grow bed units, the substrate used to support the plant roots also acts as a filtration medium. This technique, is most often used in small-scale, hobby aquaponics, and where maximising production space is not an objective (Lennard and Leonard, 2006; Mc Murtry et al., 1997; Tyson *et al*., 2012, Gravel *et al*., 2014). It has a relatively low cost and is suitable for beginners because of its very simple design. It allows the cultivation of a wide range of plants and simply requires a container filled with a neutral and inert substrate such as gravel or clay balls etc. These media are regularly irrigated with the nutrient solution from the aquaculture compartment, which provides the mineral salts essential for plant growth directly to the roots, either continuously or discontinuously. This system can be used in two different ways. On the one hand, with a continuous circulating flow of water as in rafting or NFT; on the other hand, by successive flooding and draining of the culture medium also called "ebb & flow", a technique for which an automatic siphon or "bell siphon" is often used for water drainage. Dissolved organic and solid waste from fish farming is usually directly decomposed within this substrate (FAO, 2008). To remove salt accumulations, regular thorough washing of the rooting bed and growing medium is often necessary (Foucard *et al*., 2015).

3.2. Decoupled systems

In this system, the aquaculture and hydroponic compartments are no longer "dependent" on each other. This technique has the advantage of coupling or decoupling each compartment as needed. In this configuration, the fish farms are built in a classic recirculating aquaculture system (RAS) with biological and mechanical treatments and a pumping system for water recirculation. A buffer tank or "return tank" stores the output water from the aquaculture system and sends it to the plants. Decoupled systems are more flexible in their operation and more secure for commercial production. In case of problems related to prophylactic or pest control treatments, mechanical, electrical or filtration problems, it is possible to make the two compartments independent in order to feed the plants with mineral inputs as in conventional hydroponics while quarantining the fish. Decoupled systems are particularly interesting for hydroponic growers who already own all the hydroponic equipment, and who can therefore analyse the water composition precisely and adjust it with mineral nutrient solution if necessary.

III. Operation and monitoring of the aquaponics system

1. Principle

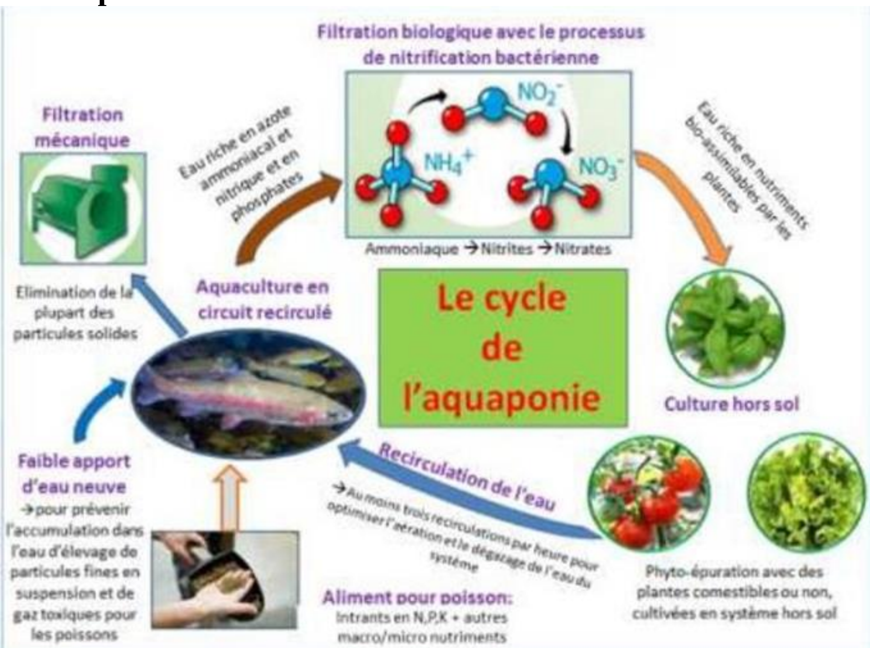

Figure 3. Principle of an aquaponics system (Foucard *et al.*, 2015)

In aquaponics, much of the plant nutrients can come from organic sources such as fish excrement, waste from food scraps, or the breakdown of algae and other microorganisms growing in the water. The idea is simple, but the implementation is complex. In their pond, fish release ammonia and phosphorus. Instead of being discharged into the environment as is the case with conventional aquaculture, this water is filtered mechanically and then biologically. In this case in a tank containing bacteria fixed on plastic supports. First Nitrosomas sp. which transforms ammonia nitrogen and urea into nitrite, then Nitrobacter sp. which transforms nitrite into plantassimilable nitrate (Fujiwara *et al*., 2013). Indeed, a large part of the nitrogen released by fish is in the ammonia form, which is toxic for them and not very valuable for plants.

Nitrification of ammonia to obtain nitrate and mineralisation of faeces to provide phosphorus and other nutrients are essential processes that take place in the system, following the installation of a biofilter on the one hand and sometimes a mineralisation tank on the other. In addition, the removal of particulate matter through adequate mechanical filtration is essential (Tyson *et al*., 2004, 2008). It is necessary to have a daily fresh water supply to replace part of the water in the system, either to compensate for evaporation and evapotranspiration losses or those generated by routine aquaculture practices such as fishing, maintenance, pond cleaning in order to avoid the accumulation of fine particles (<50 µm), gases, or certain minerals that can be harmful to fish such as iron and other heavy metals in particular, but also potassium to a lesser extent and depending on the species and plants (mainly sodium, supplied by the feed). This input of new water corresponds to an "opening rate" of 0.5 to 5% depending on the species of fish, the rearing volumes, the biomass in stock and the quantity of feed distributed.

Aquaponics is therefore an ecosystem in which three radically different types of organisms - fish, plants and bacteria - must coexist. The main challenge is to find the right balance between the fish population, the food supply, the bacterial population and the vegetation. This balance is essential to achieve high productivity and good recycling of the water, which circulates in a closed and continuous cycle.

2. Setting up the aquaponics system and monitoring

2.1. Building materials

The material requirements differ depending on the technique and the quantities you hope to produce. For example, with a floor area of 10 m2 , a single 1000 litre fish breeding tank and three culture tanks can be considered. The tanks can be made from 1 m containers3 or recycled material. Theoretically this size of installation can produce 60 kg of fish and 300 kg of vegetables per year. In temperate regions, a greenhouse is needed to get through the winter and avoid overheating the water. Pipes, elbows, taps and a pump are needed. Growing trays should be filled with clay balls to plant lettuce, tomato and spinach seeds. A pump is needed to pump water from a 300 litre basin. PVC pipes with adjustable fill levels allow the distribution of water through the system.

2.2. Species raised in aquaponics

In aquaponics, tomatoes, lettuce, peppers, leafy plants and herbs such as basil, mint, chives and lettuce have already been tested. Many other field crops such as honeydew melons, watermelons, cucumbers and fruit trees have also been successfully tested.

With regard to fish, tests were carried out with species such as freshwater tilapia (Oreochromis niloticus); red tilapia; skipper (Lates calcarifer); trout; silver perch (Bidyanus bidyanus); freshwater shrimp (Macrobrachium rosenbergii); marine shrimp (Penaeus sp.).

IV. Advantages and disadvantages of aquaponics

1. Benefits of aquaponics

Aquaponics has many advantages. It is an economically profitable system, especially with high value- added species on a large scale (Foucard *et al*., 2019). The fish waste becomes valuable nutrients for soil- less production of plants of economic interest such as ornamental plants, aromatic or medicinal herbs, and vegetables with high added value. This allows not only the valorisation of aquaculture effluents, but also the recirculation of healthy farm water for the fish, after a joint process of mechanical and biological filtration. For soilless farmers, aquaponics could provide a nutrient-rich solution ready to be used for plant cultivation. It allows water to be purified through phytodepuration and then reused in the aquaculture compartment of the system, with a theoretically even lower water turnover rate than in recirculating aquaculture (Rakocy *et al*., 2006). In contrast to open or recirculated aquaculture systems, this production system has the advantage that the dissolved compound-laden effluent from aquaculture production can be used as a nutrient for hydroponic plant production (Rakocy *et al*., 2006; Diver, 2006; Klinger, 2012). For this to happen, a situation of balance between the different productions must be achieved. The fish production must be able to grow without being disturbed by its own waste, which must allow for optimised growth of the plants. Recalling that hydroponics is a soilless agricultural system requiring the constant or intermittent addition of mineral inputs to the growing water to meet the requirements of the plants, some studies show that aquaponics can be more efficient than hydroponics, when all parameters are controlled and the bacterial community is fully mature (Nichols and Lennard, 2011). Indeed, an aquaponics system aims to be free from the need for nutrient solutions, while eliminating the need for regular emptying practiced by hydroponic systems. Aquaponics could have the potential to be labelled as "organic" if soil-less cultivation were not a limitation to this labelling, unlike in the USA where plants from aquaponics systems are labelled as organic. However, an eco-label could soon be defined for fish raised in aquaponics.

In aquaponics, water consumption is much lower than in conventional soil-based agriculture, in the order of 90% less water consumption (FAO, 2014). Furthermore, since this system is based on water saving and reuse, aquaponics could allow the production of fresh plants and fish in regions with poor soil and limited access to water resources, or even in arid and semi-arid areas (Diver, 2006; FAO, 2014). Aquaponics is also interesting in terms of optimising certain production costs. The costs of infrastructure, production structures, use of space, soil and aquatic resources are shared thanks to polyculture. Aquaponics eliminates input costs, it induces a double valuation of the aquaculture feed which indirectly serves as fertiliser for the plants (Rakocy *et al*., 2006). An aquaponic greenhouse can be set up anywhere, particularly in urban and peri-urban areas, close to the places of consumption, which favours the development of a local economy of short circuits and direct sales, thereby limiting the costs and CO_2 emissions linked to transport and which can create a social aspect around this new activity (vegetable gardens, green sports, etc.) (Diver, 2006). The system is autonomous and requires little monitoring, productivity is very good despite slight occasional deficiencies which tend to correct themselves, and the supply of 'new' water is limited to compensating for the evapotranspiration of the plants. It is important to note that the use of phytosanitary products and antibiotics is not recommended (Rakocy *et al*., 2006). Antibiotics could have an inhibiting effect on the biofiltration process carried out by nitrifying bacteria, which is essential for the proper functioning of the recirculating system (Rakocy *et al*., 2006; Diver, 2006; Klinger, 2012).

2. Disadvantage

However, aquaponics has some disadvantages. This integrated farming system has emerged through the ideology of sustainable food production and not through market demand. The capital investment is usually high to design these systems and the long learning process often specific to each system is also to be taken into account. Indeed, merging two production systems doubles the possibility of problems arising. There is a tendency for the PVC pipes to become clogged, which means that they have to be emptied at least once every two months. So there is no "zero waste". This technique involves many areas of technical expertise, namely, recirculating aquaculture, horticulture, water chemistry. It requires a skilled and trained workforce to deal with the various problems that can arise. In addition, the water quality of the resource, the climate, the fish species, its stage of development, the plant species and its phenological stage, the applied feed ration, the composition of the feed, the thermal and energy aspects. Among other things, water movement, filtration, plant lighting, thermoregulation of livestock and crops are all parameters that can influence the performance of animal and plant production.

The fact that pesticides cannot be used leads to the use of purely biological control, the real effectiveness of which in technical and economic terms must be demonstrated. Some disadvantages may be related to the specificity of each system. The major drawbacks of NFT are the risk of depletion of the nutrient solution at the end of the circuit and the risk of clogging of fine hydraulic circuits. In the case of inert substrate culture, the risk of accumulation of phosphorus and calcium elements in the culture media is very detrimental to plant nutrition.

V. Productivity and yield of the aquaponics system

Yields can vary depending on the plant and fish species used. Some aquaponics systems produce mainly plant material, in that 3-10kg of plant material is harvested for every 1kg of fish produced. However, research has shown that plant production in aquaponics is double that of intensive conventional farming, with a 20-25% increase in plant yields, and even a 2-5 fold increase in productivity (Pantanella et al., 2010; Klinger and Naylor, 2012). Soil-less techniques therefore have a higher yield than soil-based farming (Rakocy *et al*., 2006; FAO, 2014). The average fish production from aquaponic farms can reach up to (5) five tonnes.

In the current context, aquaponics is indeed only economically viable with high value-added species, but it is very relevant for supplying the market in large conurbations. Contrary to what one might think, a mature system requires relatively little time investment. In an average system, maintenance represents about 15 minutes/day, i.e. 2 hours/month.

Aquaponics is a way to reduce the production costs of plant cultivation. Indeed, the excretions from fish farming can replace the fertilisers needed for commercial hydroponic production. The fertilisers generated by an annual production of one tonne of fish can normally support the cultivation of seven tonnes of lettuce (approximate ratio). In traditional hydroponics, without fish farming, the production of 7 tons of lettuce results in annual fertilisation costs of about $300 or 178350 FCFA. The cost of fertilisers used in hydroponic production represents about 5% of production costs. There is therefore a significant financial gain. Vegetable production contributes most to the income and profitability of an aquaponic farm. Eighty-five percent (85%) of aquaponics income comes from the sale of market garden produce. In order to reduce the financial risk associated with starting an aquaponics business, it is important to size the vegetable section so that it is profitable on its own.

In aquaponics, 95% of water is saved compared to soil cultivation. The electricity consumption of an aquaponics system is about one (1) € per month or about 650 FCFA. Moreover, producing your own food can save you a few hundred euros or more than one hundred thousand (100,000) CFA francs in food purchases each month.

VI. The value of aquaponics

The estimated world population that will need to be fed by 2030 is 10 billion! According to the FAO, by 2030, more than 60% of the population of developing countries will live in megacities. These countries must therefore face a double challenge, that of famine and the rapid growth in the number of people suffering from food-related illnesses. Fisheries are no longer able to meet the demand, in either quantity or quality. In terms of quantity, the share of fisheries in total world protein production has tended to erode since the mid-1980s. Some countries, victims of intensive exploitation of the seabed off their coasts, have become unable to satisfy local populations. As regards quality, the pollution of the seabed and rivers by heavy metals and pesticides poses serious food contamination problems.

After more than thirty years of piecemeal studies, the concept of aquaponics is increasingly seen as an opening for the agricultural world in countries concerned with the preservation of water resources in terms of quantity and quality. According to the European Parliament, aquaponics is one of the "ten technologies capable of changing the world" (Woensel and Archer, 2014) because of its reduced environmental impact and improved sustainability. In Europe, the resolution adopted by the European Parliament in 2014 (Mc Intyre, 2014), states that aquaponics systems have the potential to produce food locally and sustainably and can contribute to reducing resource consumption compared to conventional systems. All of these changes are driving a large part of the population to seek quality products. Therefore, new protein potentials of aquaponically farmed fish need to be explored.

In many developed countries, large-scale aquaculture is now considered a source of environmental pollution due to the release of organic matter into the surrounding environment, especially in rivers, bays and coastal areas. This is particularly the case for trout farms in South America. In addition, the excessive use of feed leads to eutrophication of inland and coastal waters in some areas. Aquaponics is therefore becoming a sustainable, economically viable integrated fish farming system with local production potential that can contribute to reducing the consumption of water resources. Among the many types of integrated fish-farming systems, aquaponics is a revolutionary system that can meet the expectations of climate change smart agriculture. It paves the way for more sustainable farming with fewer inputs to produce a wide variety of high value, healthy food all year round. It contributes to food security by producing fish and vegetables all year round. It produces 1 kg of fish for every 4 kg of plants.

The need to deploy aquaculture expertise to produce fish and plants in symbiosis, while avoiding the accumulation of animal waste, contamination by bacteria, parasites and the proliferation of benthic species such as gastropods, is compelling.

Aquaponics is an innovation that is in line with the directions set by the agricultural world to contribute to the production of healthy and fresh food, even in environments that are hostile to conventional agriculture. Production is not dependent on fertile land or high water availability. It can therefore be grown on polluted land, on industrial wastelands, in urban areas, or in water-deficient areas, on the roofs of buildings, on balconies, etc.

In Côte d'Ivoire, the fisheries and aquaculture sector occupies a strategic place in the economy with regard to the issue of food security. This sector represents 3.1% of agricultural GDP and 0.74% of total GDP (FAO, 2009). National fish consumption is estimated at 278,463 tonnes/year for an average local production of 43,532 tonnes in 2005 (FAO, 2010). Growth forecasts for the sector are possible due to the insufficiently developed ecological assets. Indeed, Côte d'Ivoire has a dense hydrographic network with an estimated potential of 170,000 tonnes of exploitable fisheries resources per year (PDPA, 2010 - 2025). However, national fisheries production, the most productive sector of which is artisanal fishing (60%), has fallen significantly since 2000 and only covers 20% of national needs, estimated at 300,000 tonnes per year. The reasons given to explain this low productivity of water bodies are essentially the degradation of aquatic ecosystems and the overexploitation of fisheries resources (Coulibaly, 2012). Investment in industrial mining is limited, while the artisanal mining sector is booming. Although Côte d'Ivoire has experienced an oil spill, increased oil exploration in the Gulf of Guinea increases the risk of an oil spill in coastal waters. As a result, the capacity to deal with an oil spill is reduced, making the country doubly vulnerable.

Human activities combined with seasonal variations induce new constraints causing major changes, with varying frequencies and intensities. Like many countries in the tropical zone, Côte d'Ivoire is experiencing the significant effects of climate change, which, among other consequences, are significantly modifying the hydrological regime of rivers and therefore the functioning of the coastal areas that are under their influence. These processes are taking place in a context of intensified anthropic pressures, linked to the profound socio-economic and environmental changes that the country is undergoing. Thus, in addition to the increase in demographic pressure from populations concentrated in coastal areas, there is an intensification of activities linked to tourism, the exploitation of mining resources (precious stones, gold), agropastoral activities (firewood, agricultural intensification, overgrazing) and aquatic activities (fishing, aquaculture).

Côte d'Ivoire is suffering from the effects of rapid deforestation. Indeed, with nearly 16 million hectares of forest in 1960, only 3.4 million hectares remain. The conversion of forests and national parks into agricultural land, in order to feed local populations, urbanisation or land use planning and illegal logging are the main causes of deforestation in Côte d'Ivoire, which has reduced the biodiversity of national parks by half.

In the north of Côte d'Ivoire, particularly in Korhogo, the decade 2000-2010 was marked by significant climatic variability, with relatively high rainfall followed by intense drought, leading to the drying up of small basins and dams supplying drinking water to the town of Korhogo. This was followed by heavy rainfall causing flooding in the town and its surroundings. This led to severe disruptions in agricultural and aquaculture activities, resulting in famine. The problems facing Côte d'Ivoire are due to the pollution of continental and maritime waters, fishing pressure, the depletion of fisheries resources, and water shortages, accentuated by the effects of climate change. This is prompting a large part of the population to seek new methods and techniques for protein production. In order to find a solution to these problems, new sources of potential production need to be explored. Thus, aquaponics can be an alternative for maintaining or increasing aquaculture production and also for combating food insecurity, while helping to slow down the process of deforestation, depletion of water and fisheries resources and many other consequences of climate change.

In Côte d'Ivoire, aquaponics is almost non-existent. Integrated fish-farming systems exist in rural areas and the techniques used are rudimentary and different from those used in an aquaponics system. There is rice-fish farming, fish farming integrated with pig, duck or other poultry farming. Today, aquaponics must overcome technical, economic and societal obstacles. Aquaculture in Côte d'Ivoire is very often inhibited by the high cost of setting up ponds or other infrastructure required to build a fish farm. For the past few decades, the quality of the largest lagoon in West Africa, the Ebrié Lagoon, which borders the city of Abidjan, has been heavily dependent on industrial and anthropogenic activities. These are dependent on rapid population growth and uncontrolled urbanisation, with disastrous consequences (Akpétou *et al.*, 2010; Coulibaly *et al.*, 2010). In addition, since October 1999, a sudden mass mortality of fish has been observed in sectors IV and V of the Ebrié Lagoon bordering the towns of Jacqueville and Dabou. In addition, fishing pressure and pollution induce important changes in the ichthyological population (Konan *et al.*, 2011). Aquaponics could be an alternative to counter the fish deficit linked to the above-mentioned problems and the water shortage in the semi-arid areas of northern Côte d'Ivoire.

Adapting aquaponics to the Ivorian context can meet the main challenges, which are the appropriation of natural cycles by producers, through the standardisation of breeding protocols, the reduction of investment costs, the training and retraining of traditional fish farmers, and the availability of fish in savannah areas where water resources are constantly diminishing. The start-up of such a sector requires the support of research and training structures. The development of aquaponics in Côte d'Ivoire inevitably requires the establishment of a strategic plan, then a value chain, i.e. the development of a detailed business plan supported by a market study on the most appropriate plant and aquaculture products in the context of a given region, targeting high value-added products. This is a pragmatic plan that is essential for a commercial set-up. Highly effective marketing techniques will need to be deployed with diversification into retail, tourist attraction, equipment supply, training, consultancy, while aiming at a sufficiently large scale of production.

Conclusion

In short, this study shows that aquaponics, a system of fish farming combined with soil-less agriculture, offers different techniques that can be adapted to all seasons, climates and areas, whether arid, semi-arid or desert, because it saves 80 to 100% water. It is an innovation in line with the guidelines defined by the agricultural world to contribute to the production of healthy and fresh food, even in environments hostile to conventional agriculture. Production is not dependent on fertile land or high water availability. It can therefore be grown on polluted land, on brownfields, in urban areas, or in water-deficient areas. It contributes to food security by producing fish and vegetables all year round. Given the ecological and environmental damage that Côte d'Ivoire suffers from anthropogenic and industrial pollution, aquaponics could be popularised following the example of the United States and Canada in order to solve food insecurity. However, this popularisation cannot be done without research. Indeed, research on the characterisation of the aquaculture, agricultural and bacterial compartments in order to control them must be undertaken; the organoleptic quality of the cultivated food must be conducted. In addition, the cultivation system adapted to the climatic, economic and social specificity of Côte d'Ivoire must be determined.

Conflict of Interest: The authors reported no conflict of interest.

Data Availability: All of the data are included in the content of the paper.

Funding Statement: The authors did not obtain any funding for this research.

References:

1. Adler P.R., Harper J.K., Takeda F., Wade E.D., & Summerfelt S.T. (2000). Economic evaluation of hydroponics and other treatment options for phosphorus removal in aquaculture effluent. HortScience 35:993-999.
2. Akpétou K. L., Kouassi A. M., Goula B. T. A, Assemian S. & Aka K. (2010). Nutrients induction on lead, cadmium, manganese, zinc and cobalt speciation in the sediments of Aby lagoon (Ivory Coast), International Journal of Engineering Science and Technology Vol. 2(8), 3894-3900.
3. Bamba V. (2002). "Marché et commercialisation du poisson de pisciculture en Côte d'Ivoire" Author's contract-Rome: FAO. 55 p. \
4. Coulibaly A.S., Monde S., Wognin A.V. & Aka K. (2010). Dynamics of metallic trace elements in the sediments of Abidjan bays (banco bay and harbour bay). European Journal of Scientific Research, 46: 204-215.
5. Coulibaly S. (2012). Bioaccumulation of heavy metals and induced biological effects in Sarotherodon melanotheron Rüppell, 1852 caught in Biétri Bay in the Ebrié Lagoon (Ivory Coast).
6. Diver S. (2006). Aquaponics-Integration of Hydroponics with Aquaculture. National Sustainable Agriculture Information Service. ATTRA Publication. 28pp.
7. FAO. (2008). Aquaculture Development: Technical Guidelines for Responsible Fisheries. No 5, suppl.4. Rome.
8. FAO. (2009). How to feed the world in 2050. Rome
9. FAO. (2010a). Making agriculture climate smart. Policies, practices and financing for food security, mitigation and adaptation. Rome.
10. FAO. (2014). The State of Food and Agriculture. Opening up family farming to innovation, Food and Agriculture Organization of the United Nations Rome.
11. Foucard P., Tocqueville A., Gaumé M., Labbé L., Baroiller J.F., Lejolivet C., Lepage S. & Darfeuille B. (2015). Overview of the development potential of aquaponics in France: presentation and critical look at this alternative development path for fish and horticultural productions. Innovations Agronomiques, 45: p. 125-139.
12. Foucard P., Tocqueville A., Gaumé M., Labbé L., Baroiller J.F., Lejolivet C., Lepage S. & Darfeuille B. (2019). Development potential of aquaponics in France: the APIVA programme

"Aquaponics Plant Innovation and Aquaculture". Innovations Agronomiques, 71: p. 385-400.
13. Fujiwara H., Kawai S., Murata K. (2013). Significance of sulfiredoxin / peroxiredoxin and mitochondrial respiratory chain in response to and protection from 100% O2 in Saccharomyces cerevisiae. Mitochondrion, 13 (1):52-8
14. Gravel V., Dorais M., Vandenberg G. (2014). Fish effluents promote root growth and suppress fungal diseases in tomato transplants. Canadian Journal of Plant Science, dot: 10.4141/CJPS-2014-315.
15. Klinger D., Naylor R. (2012). Searching solution for aquaculture: charting a sustanable course. Annual Review of Environment and Resources. 37, 247-276.
16. Lennard W.A. & Leonard B.V. (2006). A comparison of three different hydroponic sub-systems (gravel bed, floating and nutrient film technique) in an Aquaponic test system. Aquaculture International 14, 539-550.
17. Love D.C., Fry J.P., Genello, L., Hill, E.S., Frederick, J.A., Li, X., Semmens, K. (2014). An international urvey of aquaponics practitioners. PLoS One, 9 (7): 102662 https://doi.org/10.1371/journal.pone.0102662.
18. Konan K.J., Sylla S., Diaha N.C., Joanny T.G., Atse B.C. (2011). Stock assessment of Brachydeuterus Auritus and Pseudotolithus sp. by size frequency analysis methods. F.Tech. & Doc. Vulg. : 38-42.
19. Mc Intyre A. (2014). Report on technology solutions for sustainable agriculture in the European Union https://www.europarl.europa.eu/meps/fr/111011/ANTHEA_MCINTYRE/history/8 (Accessed 1 October 2020).
20. McMurtry M.R., Sanders D.C., Cure J.D., Hodson R.G. (1997a). Effects of biofilter/culture tank volume ratios on productivity of a recirculating fish/vegetable co-culture system. J. Appl. Aquacult. Seven: 33-51.
21. McMurtry M.R., Sanders D.C., Cure J.D., Hodson R.G., Haning B.C., St Amand E.C. (1997b). Efficiency of water use of an integrated fish/vegetable co-culture system. J. World Aquacult. Soc. 28:420-8.
22. Nichols M.A. & Lennard W.A. (2011). Aquaponics: a nutrient and water efficient production system. Acta Hortic. 947:129-32
23. Nichols M., Lennard W. (2010). Aquaponics in New Zealand. Pract. Hydroponics Greenh. 115, 46-51.
24. Pantanella E., Cardarelli, M. Colla G., Rea E., Marcucci A. (2010). Aquaponics vs. hydroponics: production and quality of lettuce crop. Acta Hortic. 927, 887-893

DOI:10.17660/ActaHortic.2012.927.109; https://doi.org/10.17660/ActaHortic.2012.927.109.

25. Pillay, T.V.R. (1990). Aquaculture: principles and techniques. Fishing New Books. Blackwell Scientific Publications Ltd. 575 pp.

26. Rakocy J.E., Masser M.P., Losordo T.M. (2006). Recirculating Aquaculture Tank Production Systems: Aquaponics-Integrating Fish and Plant Culture; Southern Regional Aquaculture Center: Stoneville, MS, USA, pp. 1-16.
27. Savidov N.A., Hutchings E., Rakocy, J.E. (2007). Fish and plant production in a recirculating aquaponic system: a new approach to sustainable agriculture in CANADA. Acta Hortic. 742, 209-221. DOI: 10.17660/ActaHortic.2007.742.28
28. Tyson, R.V., Simonne, E.H., White, J.M., & Lamb, E.M. (2004). Reconciling Water Quality Parameters Impacting Nitrification in Aquaponics: The pH Levels. Proc. Fla. State Hort. Soc. 117, 79-83.
29. Tyson R.V., Danyluk D.M., Simonne E.H., Treadwell D.D. (2012). Aquaponics-Sustainable Vegetable and Fish Co-Production. Proc. Fla. State Hort. Soc. Natural Resources Section. 125 :381-385.
30. Van Woensel, L., Vrščaj D., Oh Y. (2014). Ten technologies, which could change our lives: potential impacts and policy implications (forthcoming). Science and Public Policy. ISBN: 978-92-823-6474-1 DOI: 10.2861/367909 CAT: QA-02-15-029-EN-N
31. Van Woensel, L., & Archer G. (2015). Ten technologies that could change our lives: potential impacts and policy implications. Report European Parliament Research Service, Scientific Foresight Unit, 38p.