Plant Archives Vol. 24, No. 2, 2024 pp. 17-23 e-ISSN:2581-6063 (online), ISSN:0972-5210

Plant Archives

Journal homepage: http://www.plantarchives.org

DOI Url : https://doi.org/10.51470/PLANTARCHIVES.2024.v24.no.2.002

AQUAPONICS: AN INNOVATIVE SYSTEM OF SYMBIOTIC AGRICULTURE AND FOOD SECURITY

P. Sudheer Kumar Reddy[1]*, K. Hari[2], R.V. Sundarrajan[3], Mohammed Jassim[3], M. Siva Prasad[4] and Suraj Luthra[5]

[1]Department of Vegetable Science, Dr. YSRHU-College of Horticulture, Anantharajupeta, Andhra Pradesh, India.

[2]Department of Horticulture, Adhiyamaan College of Agriculture and Research, Athimugam, Krishnagiri, Tamil Nadu, India.

[3]Department of Fruit Science, Horticultural College and Research Institute, TNAU, Periyakulam, Tamil Nadu, India.

[4]Department of Vegetable Science, Dr. YS Parmar University of Horticulture and Forestry, Nauni, Solan, India.

[5]Department of Vegetable Science, ANDUA&T, Kumarganj, Ayodhya, Uttar Pradesh, India.

*Corresponding author E-mail : sudheer332.123@gmail.com

(Date of Receiving-18-11-2023; Date of Acceptance-17-05-2024)

ABSTRACT

Aquaponics is a symbiotic ecosystem that includes aquaculture, hydroponic vegetables, flowers and beneficial microbes. It creates a symbiotic link between aquatic creatures and plants within a system. A productive, inventive, and sustainable fish and vegetable production method, aquaponics is transforming agriculture in the face of drought, soil nutrient losses, and climate change. Recent breakthroughs by academics from all around the world have transformed aquaponics into a viable option for environmentally friendly food production. This aquaponics invention adheres to the notion of sustainability while also providing the opportunity to boost economic efficiency through increased productivity. Some of the benefits observed in the utilization of aquaponics systems for food production include water saving, improved performance, food security, less pollution and low energy use. This review discovered that by combining aquaculture and hydroponics, we obtain aquaponics, a new innovation that respects sustainable agriculture principles (waste water biofiltration by plants) and allows us to increase economic efficiency with an increased supply (organic vegetables) to produce nutrient-rich food.

Key words : Symbiotic, Tilapia, Nitrification, Climate change, Sustainable agriculture.

Introduction

One of the most critical matters confronting the globe is how to meet the nutritional needs of a growing human population, which is expected to reach 10 billion by 2050. To fulfil the additional food demands imposed by the approximately 30% rise in population, global food production must increase by up to 50% (FAO, 2017). Climate change, pollution, and the destruction of fertile lands will all pose challenges to food production (Goddek *et al*., 2019a). According to Bajzelj *et al*. (2014), current food production trends will not fulfil anticipated global food demand by 2050, despite the introduction of high-yielding crop varieties and improved food production methods. Aquaponics is the combination of recirculating aquaculture and soilless hydroponics systems for fish and crop production. It is simply the combination of fish and plant cultivation in a recirculating system. Recirculatory aquaculture systems, in general, are intended to produce high numbers of fish in relatively small amounts of water by cleaning the water to remove harmful waste products and reusing it for fish culture (Timmons *et al*., 2010; Verdegem, 2013). Although, nitrifying bacteria convert harmful ammonia and nitrite into less toxic nitrate in specialised filters known as biofilters, if the biofilter is disrupted or ammonia production exceeds the capacity of the biofilter, it is gaining popularity as a bio-integrated concept for sustainable food production (Rakocy *et al*., 2006; Diver, 2006). Throughout the late 1970s and early 1980s, researchers from North Carolina State University's New Alchemy Institute used this technology. Later in 1980, the University of the Virgin Islands (UVI) adopted this technique. An aquaponics system not only removes nitrate from the system, but it also converts otherwise hazardous nitrogenous waste into forms consumable by plants, which are then sold to generate additional cash for the farmer (Pantanella *et al.*, 2010). As a result, less water may be used, which can be a limited resource in some locations. Furthermore, the aquaponics system's hydroponic component is filled with appropriate bacteria over time, which aids in biofiltration. As a result, this improves water filtration efficiency beyond what a single biofilter in conventional recirculating systems might achieve (Rakocy and Hargreaves, 1993).

Modern aquaponics is slightly more economically efficient and uses an environmentally friendly approach to food production. Fish are frequently housed in big tanks and the plants are grown hydroponic systems; that is, without soil. Plants are generally grown in gravel or clay beds, with their roots dangling into the water. The water is cycled through the system, collecting waste from the fish and recirculating it back to the plant beds, where it's naturally filtered by the plants before being returned to the fish tanks unlike traditional agricultural methods, no chemical fertilisers are required for the plants in this cultural movement because they all come from fish faeces. It is also usually organic, as the use of pesticides would be harmful to the fish.

Principals of Aquaponics

The basic principles of aquaponics are as follows: a) Waste products from one biological system can be used as a nutrient for another biological process; b) Water can be re-used through biological filtration and recirculation processes; c) Assimilation of fish and plant culture can lead to the production of multiple products at the same time; and d) Local food production system provides access to healthy foods while also boosting the local economy (Diver, 2006).

How aquaponics works

Aquaponics is a mixture of aquaculture (raising aquatic species and other creatures) and hydroponics (growing plants without soil). Aquaponics combines the two in a symbiotic relationship in which plants have nourished the discharge or waste of aquatic animals. In exchange, the vegetables clean the water that returns to the fish. Microbes, like fish and their excrement, contribute significantly to plant nutrition. These beneficial bacteria congregate in the gaps between the plant's roots and transform fish feces and sediments into nutrients that the plants may use to develop.

The result is a perfect collaboration between aquaculture and gardening. Aquaponics is a big hope for sustainable organic crop production, aquaculture and

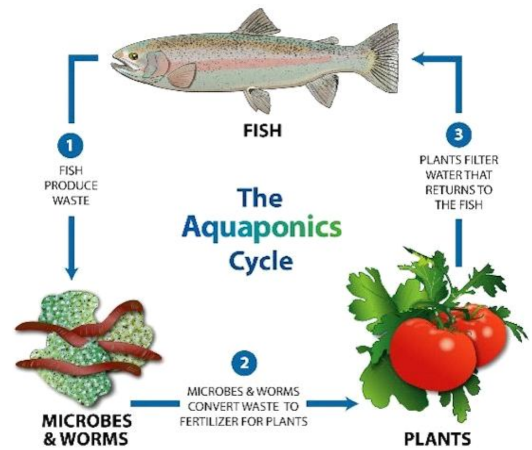

Fig. 1 : Symbiotic relationship between plants and animals in the aquaponic cycle.

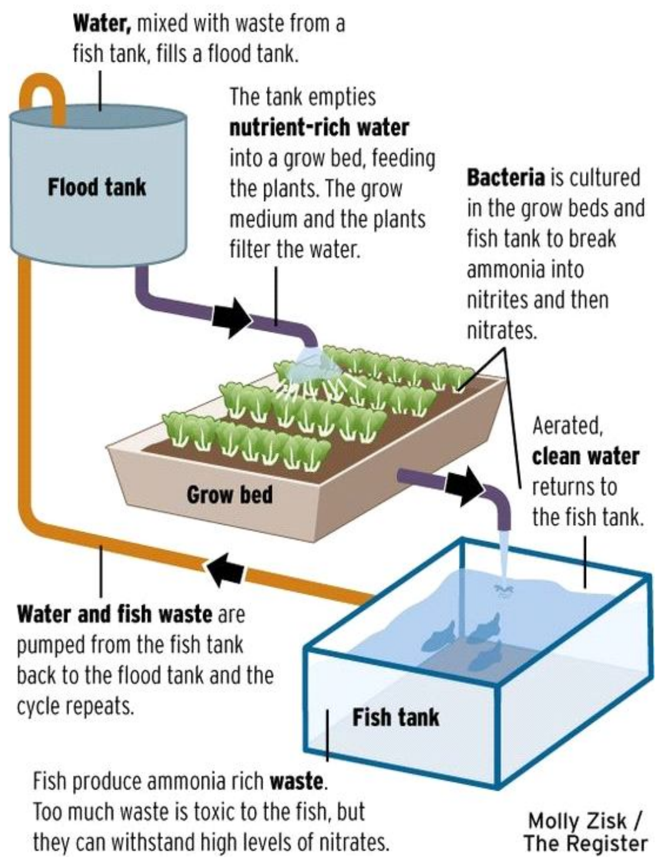

Fig. 2 : Basic design of aquaponic system.

water consumption. The fish waste is recycled and used for plant growth instead of throwing it in the ocean. The water is recirculated in a closed system lowering the consumption of this resource. If your curiosity is on fire now because you like to grow fish and vegetables and you can combine them to have a fully functional garden, we recommend you check our great and easy DIY Aquaponic Garden. You can experiment with the aquaponic system in the beginning and see how it turns out for you.

Aquaponics system designs

The designs are based on hydroponic systems, the distinction being that the water source for the aquaculture system comes from the fish tank and is returned back to its point of origin.

Media based aquaponic system

The media-based technique, also known as Flood and Drain, is widespread in small scale aquaponics systems. It is also popular among do-it-yourself aquaponics home gardeners because to its ease of usage. The media-based system design is simple and efficient with space, with a cheap starting cost appropriate for aquaponics beginners (Fig. 3).

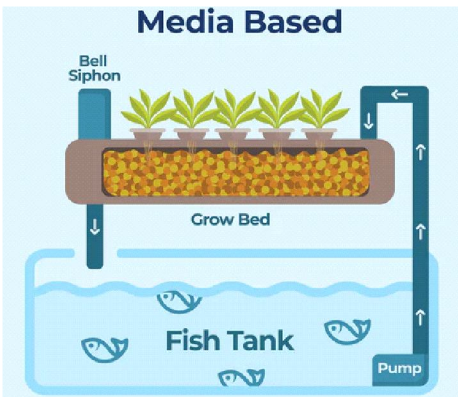

Fig. 3 : Media based aquaponic system.

Nutrient Film Technique

The Nutrient Film Technique (NFT) is a plant growing technology that has been converted to aquaponics due to its simple yet economical design that works well in particular situations. This technology employs horizontal PVC pipes with shallow flows of nutrient-rich water flowing across them. The NFT is well-known for commercial aquaponics and is especially useful in urban areas where space and food production are limited (Fig. 4).

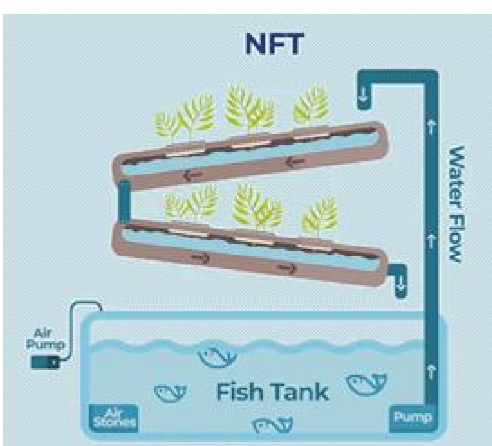

Fig. 4 : Nutrient film technique type of aquaponic design.

Raft System

The raft system of aquaponics, also known as the Deep Water Culture (DWC), is one of the most economical aquaponics system designs. Because of its mass production potential, this technique is frequently employed in huge or commercial aquaponics systems (Fig. 5).

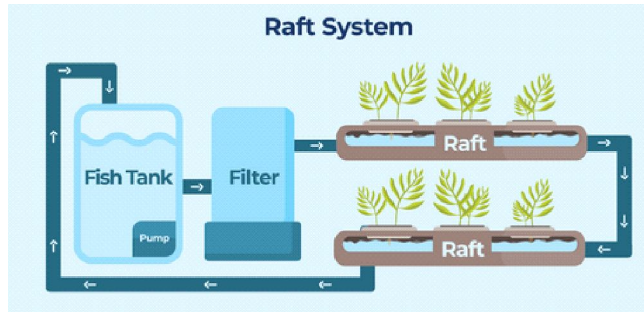

Fig. 5 : Raft system of aquaponic design.

Vertical Aquaponics system

A vertical aquaponics design is one aquaponics technology that grows plants in stakes just above fish tank without soil (Fig. 6).

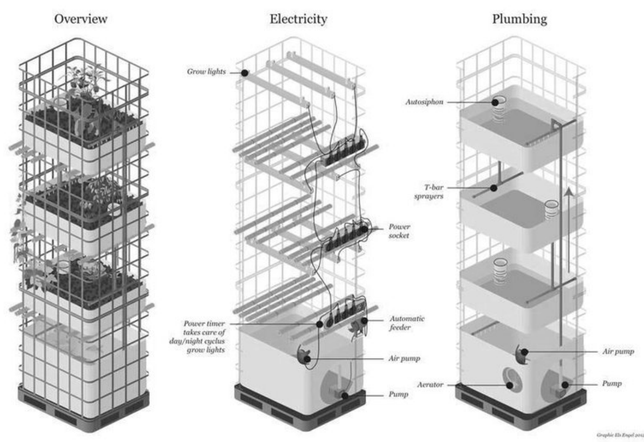

Fig. 6 : Vertical system of aquaponic design.

Plants for aquaponics

Plants are cultivated in the same way that they are in hydroponic systems, with their roots submerged in nutrient-rich effluent water. This allows them to sieve out ammonia, which is hazardous to aquatic species, as well as its metabolites. After passing through the hydroponic subsystems, the water is cleaned and oxygenated before being returned to the aquaculture vessels. This cycle is ongoing. The system cannot work correctly without plants. Planting in soil is simple, but it takes up valuable space due to moisture and spacing considerations. Lettuce, beans, peppers, squash, zucchini, cucumbers, broccoli, peas, spinach and other vegetables. Herbs such as basil, thyme, lemongrass, cilantro, sage, wheat grass, oregano and parsley, among others. Strawberries are an example of fruit.

Animals for aquaculture

Aquariums necessitate the use of filtering systems, which must be cleaned or updated on a regular basis. The aquaponics system's grow beds serve as this filter without the need for cleaning or replacement. Plants, of course, must be present in the grow beds. Almost any freshwater fish can be reared in the system, while some species, such as trout, may be prohibited due to the operating temperature. The most popular aquatic animal cultivated in aquaponics is freshwater fish. Aquaponic fish such as Tilapia, Trout, Yellow Perch, Catfish, Bass, Bluegill, Koi, Carp, Goldfish and freshwater Prawns are advised for rearing (Fig. 7).

Fig. 7 : Different types of fishes in aquaponic system.

Management of fish health

When stocking fish from other establishments into one's own system, they must be adequately disinfected. Their health should be checked for several days so that they can be treated if necessary. Always use good hygiene and biosecurity prevention, selective access, avoidance and common sense. The fish's natural immune system provides the best defence. There should always be a low-stress atmosphere for fish to sustain their health.

Role of bacteria in aquaponics system

Nitrification, or the aerobic conversion of ammonia to nitrates, is one of the most significant activities in an aquaponics system since it reduces the toxicity of the water for fish and allows the produced nitrate compounds to be taken by the plants for sustenance (Rakocy, 2006). Ammonia is continually discharged into the water as a by product of fish metabolism through their excreta and gills, but it must be filtered out because larger concentrations are harmful to fish. Although plants may absorb ammonia from water to some extent, nitrates are more easily digested, lowering water toxicity for fish (Rakocy, 2006). Ammonia can be converted into other nitrogenous compounds through, Nitrosomonas bacteria that convert ammonia into nitrites and Nitrobacter bacteria that convert nitrites into nitrates.

Maintenance of aquaponic system

Water quality

To sustain ideal growth environment and fish health, good water quality must be maintained at all times in a circulating fish tank. Water quality testing should be done on a regular basis and can be done with water quality testing kits bought from aquaculture supply businesses.

Maintenance of poor water quality

- Aeration to enhance the concentration of dissolved oxygen.
- Degassing reduces overall gas pressure while also removing carbon dioxide and hydrogen sulphide.
- Temperature control using water heaters or combining water of varying temperatures.
- Iron removal through sedimentation and filtration, as well as calcium addition to
- low- hardness water.

Crop selection

Aquaponic systems may support the growth of a wide variety of plants. It was once assumed that only green leafy vegetables and herb crops could be cultivated, however, it has now been demonstrated that a broad variety of fruit crops, beans and flowers may be successfully grown.

Fish harvesting

In a fish tank, stocking density is measured in units of fish biomass per volume of water; in our case, kilos per metre cubed. For numerous reasons, stocking density is a significant factor in fish growth. Water quality declines proportionally when stocking densities rise, partly due to increased waste production, which raises levels of potentially harmful chemicals like ammonia and nitrite. Another reason why fish health suffers when stocking densities are raised is that higher stocking densities consume more oxygen, and a lack of oxygen results in stunted growth and poor fish health. Under stocking the system, on the other hand, will result in a lower ratio of feed conversion and reduced system efficiency.

Table 1: Symbiotic association between plants and fishes.

Fish species	Growing crops	Crop yield	Fish biomass	References
Nile tilapia	Chives, Lettuce, Basil	2.6 t/year (Chives) 7.5 t/year (Lettuce) 3.2 t/year (Basil)	5–7.6 tons/year	Van der Heijden *et al.* (2013)
Nile tilapia and African catfish	Spinach, Eggplant and Tomatoes	3 kg/year	27.9 kg/year	Benjamin *et al.* (2020)
Nile tilapia	Maize	2.3 t/ha	-	Frimpong *et al.* (2017)
Nile tilapia	Amaranthus, Cucurbita and Artemisia	1.1 kg/m^2 (Amaranthus), 1.3 kg/m^2 (Cucurbita), 1.6 kg/m^2 (Artemisia)	-	Gichana *et al.* (2018)
Catfish	Pumpkin	160 kg/m^3	43 kg/4 months	Oladimeji *et al.* (2020)

Table 2 : Previous findings of aquaponic system by using different types of fishes and crops.

Fishes used	Crops used	Findings	References
Oncorhynchus mykiss	*Coriandrum sativum* L., *Petroselinum crispum*, *Lactuca sativa* and *Plantago coronopus*	A comparison of stand establishment, estimated harvest biomass, and harvest time for various pisciponic crops	Buzby *et al.* (2016)
Clarias gariepinus	Pumpkin-*Telfairia occidentalis*	Comparative study favours aquaponics production of catfish and pumpkin over conventional farming methods	Oladimeji *et al.* (2020)
Lemon fin barb hybrid (*Hypsibarbus wetmorei* ♂ × *Barbonymus gonionotus* ♀)	Peppermint (Mentha × piperita)	Additional night lighting favours the production characteristics of peppermints	Ogah *et al.* (2020)
Huso × *Acipenser ruthenus*	*Lactuca sativa*	Optimization of the pisciponics system for selected fish and plant species	Dediu *et al.* (2012)
Osphronemus goramy	*Lactuca sativa* L. var. *longifolia*	Gouramy waste could be processed by phytoremediation for growing romaine lettuce in a pisciponic system.	Purwandari *et al.* (2017)

Crop harvest

Harvest Greater plant densities frequently result in poorer output per plant while yielding a larger yield per area. Both spinach and tomatoes will be planted at a density of 12 plants/m^2 based on previous experience. The 6 m^2 growing area will be divided evenly between the two plant species, with 3 m^2 dedicated to growing 36 spinach plants and the remaining 3 m^2 dedicated to growing 36 tomato plants. According to hydroponic and aquaponic studies, spinach can be harvested 12 times per year and tomatoes 6 times per year.

Advantages of aquaponics

Less labour intensive

Aquaponics might be claimed to need less labour because weeding is no longer be required for the crops. As a result, after the initial high cost of labour to set up the system, it works on its own and requires around thirty minutes of monitoring or human interaction to keep the system running (Liang and Chien, 2013). The majority of this intervention is focused on feeding the fish and monitoring water quality metrics. Some factors, such as monitoring the plants for insect pest and disease, require relatively infrequent attention (Rakocy *et al*., 2006a).

Water conservation

Large-scale food fish production is frequently done in small or limited settings for a variety of reasons ranging from simplicity of management to making the most use of limited resources for maximum output. These living conditions, however, have consequences, one of which is cleansing the water of ammonia, which is excreted and highly harmful to the fish (Ogah *et al.*, 2020). There is no doubt that aquaponics food production is a more sustainable endeavour and an efficient water conservation technique that can be applied in both developed and poor countries around the world. The integration of fish and hydroponics plants in a stable aquatic environment enables the principle of recycling and water reuse with great efficiency (Oladimeji *et al*., 2020).

Food security

Aquaponics is presented as a reliable method of food production since, with the exception of system failures, it almost always has a guaranteed success rate in food production (Rakocy, 2012). This success could be attributed to the ability to adjust the growing circumstances (light, water parameters and flow rates), ensuring that the fish and plants aren't ever exposed to excessive frost, heat, rain, or other adverse weather conditions. This makes aquaponics a feasible option for countries/areas afflicted by harsh weather conditions (*i.e*., countries with extreme temperatures and drought).

Pollution reduction

Another advantage of aquaponics farming over old conventional food systems is that it is more environmentally friendly. This is due to the fact that no heavy earth-moving devices or equipment are required to till the soil; thus, the degradation of soil structure and the associated pollution is avoided in one fell swoop when the aquaponics system is used (Oladimeji *et al*., 2020). Skygreen farms have patented "the world's first low carbon hydraulically commercial agricultural technology." This is a vertical method of farming that rotates the plant beds around different angles for optimal sunlight, and it is driven by a water hydraulic system rather than a fossil fuel burning system (Nandy, 2020).

Improved yield

There is currently an increased responsibility to improve traditional farming operations in order to fulfil the geometric demands of an ever-increasing human population. As a result, pressure is being applied to obtain additional agricultural inputs such as chemical fertilizers, herbicides, insecticides, and fungicides (Love *et al*., 2014). Without these high-cost farm inputs, conventional farming production and profitability suffer as soil fertility declines. Unlike traditional farming, the aquaponics production technique is based on long-term nitrogen cycling and constant irrigation of the plants with nutrient-rich effluent (*i.e*., nitrate produced by fish and consumed by plants). As a result, plants and fish grow quicker with little input or outside influence (Love, 2015)

Challenges

Start-up capital

A significant hurdle is obtaining start-up finance. According to Love (2015), a minimum of 1000 m^2 is required for farmers to break even in the commercial use of the aquaponic system in the first year. Respondents in this poll admitted to having invested between 5 and 10 lakhs in the start-up, while the median amount of fish and plants gathered every year ranged between 23 and 45 kg and 45-226 kg, respectively.

Need maximum power for operation system

Another factor limiting aquaponics productivity and profitability is power (for water pumps, aeration, sensors and lightning among others). Aquaponics is promoted as a means of decreasing poverty and malnutrition while also offering an additional source of income (Tyson *et al*., 2011).

Maintenance balance ratio of plants and fishes

Improving plant-to-fish ratios has also been a source of contention among scholars (Tyson *et al*., 2011). In their study, Lennard and Ward (2019) compared three techniques for this goal. Rakocy (1999) aimed to maximise nutrient production and utilisation by increasing the diet provided to the fish in a first way. The second approach was devised by Lennard and Ward (2019), who created a novel method for estimating aquaponic feeding rate ratios. This method produced a complicated mathematical model that was used to forecast the amount of fish feed needed to grow a fixed number of lettuce plants. Stuart *et al*. (2016) employed the nitrate determination method as their third approach.

Future perspectives

The simplicity of design and management, combined with nearly minimum energy and minimal equipment costs, makes these systems an appealing solution when land availability, flooding, productivity and environmental footprint are important concerns. Furthermore, using water weeds as a resource can undoubtedly boost livelihood chances in all affected places worldwide. Further research is needed to address the nutrient kinetics of different growing media and to optimise system design and nutritional requirements of vegetables in water bodies with limited dissolved nutrients. This integrated system has a wide range of applications and can help both smallholders and large aquaculture operations. Yet, the potential of these systems is not fully recognised and interdisciplinary collaboration and study may surely alleviate many of the unresolved difficulties.

Conclusion

Aquaponics is a combo of aquaculture and hydroponic systems in which nutrient-rich waste water from the aquaculture system is used in the hydroponic system. The new millennium's tendencies in environmental legislation are limiting the amount of water that can be consumed or disposed. Aquaponics uses filtered effluent from aquaculture that is recirculated throughout the system. Aquaponics provides an opportunity to rethink traditional fish farming in order to increase farm gate revenue.

References

Bajželj, B., Richards K.S., Allwood J.M., Smith P., Dennis J.S. and Curmi E. (2014). Importance of food-demand management for climate mitigation. *Nat. Clim. Chang*., **4**, 924–929. doi: 10.1038/nclimate2353

Benjamin, E.O., Buchenrieder G.R. and Sauer J. (2020). Economics of small-scaleaquaponics system in West Africa: a SANFU case study. *Aquacult. Econ. Manage.*, **25**, 53–69. doi: 10.1080/13657305.2020.17 93823

Buzby, K.M., Waterland N.L., Semmens K.J. and Lin L.S. (2016). Evaluating aquaponiccrops in a freshwater flow-through fish culture system. *Aquaculture*, **460**, 15–2.

Dediu, L., Cristea V. and Xiaoshuan Z. (2012). Waste production and valorization in an integrated aquaponic system with bester and lettuce. *Afr. J. Biotechnol.*, **11(9)**, 2349–2358.

Diver, S. (2006). *Aquaponics integration of hydroponics with aquaculture*. Amy Smith, Production. A Publication of ATTRA National Sustainable Agriculture Information Service.

FAO (2017). *The Future of Food and Agriculture: Trends and Challenges*. Rome: Food and Agriculture Organisation of the United Nations.

Frimpong, F., Amponsah S.K., Owusu Danquah E., Agyeman K., Oteng Darko P. and Oppong C.P. (2017). Assessment of aquaponics-based food production system effluents on theperformance of maize. *Int. J. Agric. Res. Rev.*, **5**, 615–627.

Gichana, Z., Waidbacher H., Zollitsch W., Drexler S. and Liti D. (2018). The potential ofaquaponics as food production and nutrient recovery systems in Kenya. In: *Towards Productive, Sustainable and Resilient Global Agriculture and Food Systems*. Horská, E., Kapsdorferová Z. and Hallová M. (eds.). (Proceedings International Scientific Days), 1154–1165.

Goddek, S., Joyce A., Kotzen B. and Dos-Santos M. (2019a). Aquaponics and global food challenges. In : *Aquaponics Food Production Systems*. Goddek, S., Joyce A., Kotzen B. and Burnell G.M. (eds.). (Cham: Springer), 3–18.

Lennard, W. and Ward J. (2019). A comparison of plant growth rates between an NFThydroponic system and an NFT aquaponic system. *Horticulturae*, **5(2)**, 27.

Liang, J.Y. and Chien Y.H. (2013). Effects of feeding frequency and photoperiod on waterquality and crop production in a tilapia-water spinach raft aquaponics system. *Int. Biodeterioration and Biodegradation*, **85**, 693–700.

Love, D.C., Fry J.P., Genello L., Hill E.S., Frederick J.A., Li X. and Semmens K. (2014). An international survey of aquaponics practitioners. *PLoS One*, **9(7)**, e102662. https://doi.org/10.1371/journ al.pone.0102662

Love, D.C., Fry J.P., Li X., Hill E.S., Genello L., Semmens K. and Thompson R.E. (2015). Commercial aquaponics production and profitability: Findings from an international survey. *Aquaculture*, **435**, 67–74. https://doi.org/10.1016/j.aquaculture.2014.09.023

Nandy, S. (2020). *Food for Urban Resilience in India*. https://cityfarmer. info/wpcontent/uploads/2020/04/Food-for-Urban-Resilience-in-India_Somdeep-Nandy_2019-04-23-rev-3.pdf

Ogah, S.I., Kamarudin M.S., Nurul-Amin S.M. and Edaroyati M.W. (2020). Nutrient recycling through aquaponics and night-lighting. *J. Environ. Biol*., **41(5)**, 1113–1125.

Oladimeji, A.S., Okomoda V.T., Olufeagba S.O., Solomon S.G., AbolMunafi A.B., Alabi K.I., Ikhwanuddin M., Martins C.O., Umaru J.A. and Hassan A. (2020). Aquaponics production of catfish and pumpkin: Comparison with conventional production systems. *Food Sci. Nutr*., **8**, 2307–2315.

Pantanella, E., Cardarelli M., Colla G., Rea E. and Marcucci A. (2010). Aquaponics vs. hydroponics: production and quality of lettuce crop. In : *XXVIII International Horticultural Congress on Science and Horticulture for People* (IHC2010): International Symposium on 927 (pp. 887–893).

Purwandari, Y., Effendi H. and Wardiatno Y. (2017). The use of gouramy (*Osphronemus goramy*) rearing wastewater for growing romaine lettuce (*Lactuca sativa* L. var. *Longifolia*) in aquaponic system. *Asian J. Microbiol., Biotechnol. Environ. Sci*., **19(2)**, 359–366.

Rakocy, J. (1999). Aquaculture engineering- the status of aquaponics, part 1. *Aquaculture Magazine*, **25(4)**, 83–88.

Rakocy, J.E. (2012). Aquaponics: Integrating fish and plant culture. *Aquacult. Prod. Sys*., **1**, 344–386.

Rakocy, J.E. and Hargreaves J.A. (1993). Integration of vegetable hydroponics with fish culture: A review. In L Wang J.-K. (ed.), *Techniques for modern aquaculture, proceedings aquacultural engineering conference* (pp. 112–136). American Society of Agricultural Engineers.

Rakocy, J.E., Masser M.P. and Losordo T.M. (2006). Recirculating aquaculture tank production systems: Aquaponics- integrating fish and plant culture. SRAC publication - Southern Regional Aquaculture Center (454):16.

Rakocy, J.E., Masser M.P. and Losordo T.M. (2006a). Recirculating aquaculture production systems: Aquaponics-integrating fish and plant culture (p. 16). SRAC Publication-Southern Regional Aquaculture Center (454).

Stuart, M.E., Wang L., Ascott M., Ward R.S., Lewis M.A. and Hart A.J. (2016). *Modellingthe groundwater nitrate legacy*. British Geological Survey, Nottingham, UK (2016)

Tyson, R.V., Treadwel D.D. and Simonne E.H. (2011). Opportunities and challenges to sustainability in aquaponic systems. *Horticult. Technol.*, **12(5)**, 22–27.

Van der Heijden, P.G.M., Farrag F. and Blom-Zandstra G. (2013). Bustan aquaponics: Egypt's first working commercial aquaponic farm. *Aquacult. Europe Mag*. **38**, 25–27.