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Vertical Aquaculture: Maximizing Efficiency and Sustainability in Food Production

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ABSTRACT

Vertical aquaculture is an innovative technology that addresses the growing demand for animal protein by maximizing resource utilization and achieving high production levels. In the current era of increasing human needs, new methods are essential to provide sufficient animal protein. Vertical aquaculture is a technique that supports enterprise growth through significant capital investment. This system enables the efficient use of land and water resources while simultaneously producing crops, cultured fish, and livestock. By employing circulatory or resource reuse systems, vertical aquaculture promotes the sustainable use of resources.

Keywords: Vertical Farming, Sustainability, Integration, Production

1. Introduction

Asia, responsible for 80% of global aquatic production, is crucial for enhancing global food security and reducing poverty, as aquaculture stands out as the fastest-growing food production sector worldwide (Subasinghe et al., 2009). The aquaculture sector boosts rural employment and improves the nutrition and income of rural populations (Kutty & Pillay, 2005). By providing nutritious aquatic products, aquaculture helps combat hunger and malnutrition (Subasinghe et al., 2009). With the growing populations in regions such as Asia, Africa, and South America, the demand for fish is rising, necessitating the development of new techniques to meet this demand (Tidwell & Allan, 2015). Today, aquaculture holds significant importance in fishery management and private industries (Pillai, 1990), with vertical aquaculture being one of the innovative methods employed.

Vertical farming is the type of aquaculture where aquatic organisms are raised in vertically stacked layers in a controlled environment. In this system, water is continuously circulated throughout the system, allowing for the maximum use of space and optimum growing conditions (Subasinghe et al., 2009). This type of farming is becoming increasingly popular as it offers many advantages over traditional farming methods.

2. Why Vertical Farming?

Vertical farming could able to production of food in an efficient and sustainable manner, saving water and energy, enhancing the economy, reducing pollution, restoring ecosystems, and providing access to healthy food. In a controlled environment, crops produce a higher yield using less floor area (Touliatos et al., 2016). World population continues to grow and its necessary to feed growing population. Vertical farming is the best way to produce food while optimum use of land and water resources. It has potential to rise food production, maintain high quality and safety standards, and contribute to sustainable urban farming. (Kalantari et al., 2018). Because of the rapid urbanization agriculture and aquaculture land resources have been decreasing, that is directly affected to the traditional growing systems. Vertical farming provides an alternative source for sustainable food production (kyaw & Ng, 2017). One of the primary benefits of vertical fish farming is that it utilizes minimum land and water resources. Vertical fish farming helps increase the economic efficiency and sustainability of indoor fish farming (Blidariu, F., & Grozea, A. 2011). It is the controlled environment with the potential to substantially increase resource use efficiencies. In vertical farming, the environment is mostly controlled, and continually recirculated water to prevent the diseases (Huh, 2017). The logic of vertical farming is simple: produce more food on less land, allowing for stacking homes and offices in limited and expensive areas. Vertical farming offers advantages over "horizontal" urban farming, as it frees up land for incorporating additional urban activities (Al-Kodmany, 2018).

3. TYPES OF VERTICAL AQUACULTURE

3.1 Aquaponics

Aquaponics is a system where aquatic organisms and plants grow symbiotically. In this system, animal waste undergoes microbial transformation to provide nutrients for plant growth, while the plants absorb these nutrients, purifying the water for the aquatic organisms (Yep & Zheng, 2019). The three main components of an aquaponic system are fish, plants, and bacteria, and it combines hydroponic and aquaculture systems. This combination creates a natural nutrient solution for plants and eliminates waste that would otherwise be disposed of as wastewater (Connolly & Trebic, 2010). Aquaponics uses resources more efficiently than traditional aquaculture by recycling both nutrients and water (Cohen et al., 2018). Aquaponics enhances economic efficiency by reducing costs associated with nutrients, water, and land (Blidariu & Grozea, 2011). This chemical-free growing method supports the cultivation of vegetables, herbs, fruits, and fish species, providing fresh fish as a safe and healthy protein source. Its popularity stems not only from higher yields but also from efficient land and water use (Kyaw & Ng, 2017). As a sustainable technology, aquaponics offers year-round production of high-quality fish and healthy vegetables, conserving water resources in the process. Freshwater fish are primarily used because plant roots can be damaged by salinity (Wongkiew et al., 2017).

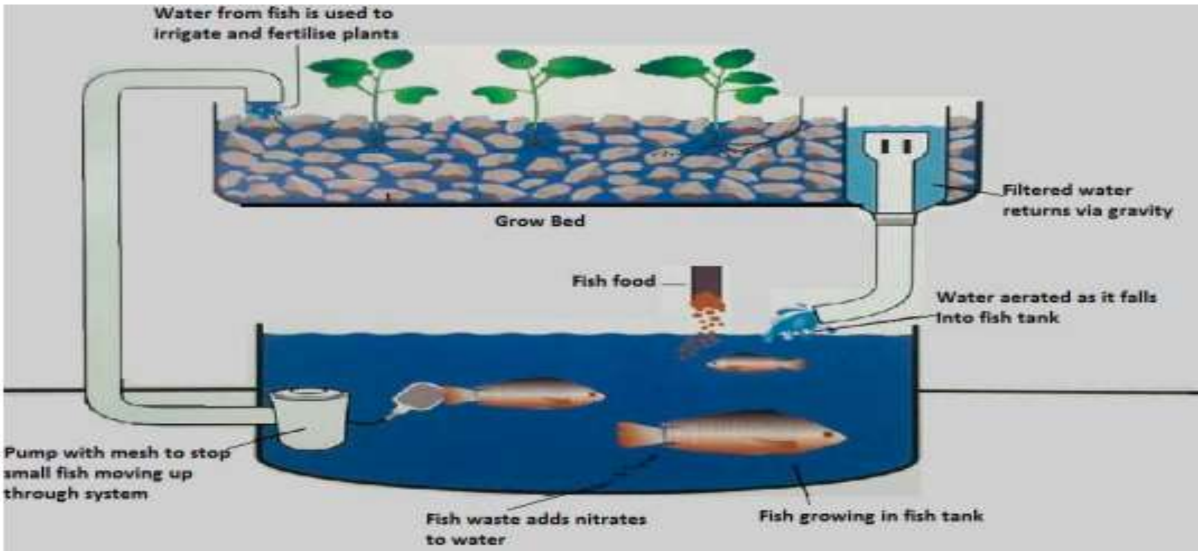

Fig: 1 Aquaponic System (Shafeena, 2016)

3.1.1 Principles of Aquaponics

This combination highlights the fact that excess nutrients do not need to be removed through the periodic exchange of enriched fish water with fresh water, as practiced in aquaculture systems. The aquaponics system results in a symbiotic relationship between fish, microorganisms, and plants, and promotes the sustainable use and recycling of water and nutrients. Within this synergistic interaction, the respective ecological weaknesses of aquaculture and hydroponics are converted into strengths (Goddek et al., 2015).

Aquaponics is one of the closed-loop systems where two crops, fish and plants, are cultivated using only one body of water (Connolly & Trebic, 2010). These is the bacteria-based biofiltration compartments. Nitrifying bacteria are converting harmful ammonia-based fish waste to harmless nitrates to feed plants. Nitrogen is an essential element for all living organisms because it is a component of proteins, deoxyribonucleic acid (DNA), ribonucleic acid (RNA), amino acids, and other cell components (Wongkiew et al., 2017). Fish feed is the main source of nitrogen input in an aquaponics system, which is extracted by fish in the form of ammonia (Zou et al., 2016). The fish extract ammonia, which contains 90% nitrogen, serving as a nitrogen source for plant growth. As the aquaculture effluent flows into the hydroponic component, nutrients undergo biological nitrification, transforming them (Nitrosomonas, Nitrobacter) and denitrification (heterotrophic bacteria), and absorption by plants in the form of nitrate (NO_3^-) and ammonium (NH_4^+) (Graber and Junge, 2009; Zou et al., 2016).

3.2 Integrated Multi-Trophic Aquaculture (IMTA)

Integrated multi-trophic aquaculture (IMTA) one of the sustainable ways to produce food from sea. The concept of IMTA was coined (Neori et al., 2004) and refers to the **trophic positions or nutritional levels** corporation of species from different in the same system. In integrated multi-trophic aquaculture, farmers combine the cultivation of fed species such as finfish or shrimp with organic extractive species including shellfish & herbivorous fish and inorganic extractive species mostly marine plant that recapture organic and inorganic particulate nutrients for their growth (Knowler et al., 2020). Many countries such as Australia, Israel and South Africa, already practiced IMTA and result have been positive (Ridler et al., 2007).

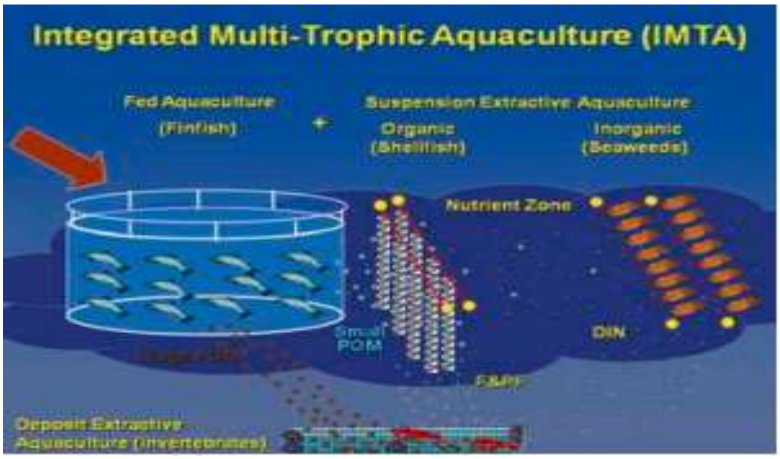

Fig: 2 Integrated Multi-Trophic Aquaculture system (Chopin et al., 2012)

This system similar to the aquatic polyculture, which is act as a co-culture of the aquatic species, but in IMTA system cultured organism share same biological or chemical nutrients with synergistic benefits. Main aim of this system transfer the energy by water current to one to another culture species (Barrington et al., 2009).

3.2.1 Principles of IMTA

This Integrated Multi-Trophic Aquaculture (IMTA) aquaculture practice is based on a very simple principle: 'the solution to nutrification is not dilution, but extraction and conversion through diversification' (chopin et al., 2012).

Main difference between the traditional practice and aquatic polyculture is the incorporation of the species from the different level including nutritional or tropical level, but integrated in IMTA system refers to the more cultivation of different species connected by nutrient and energy transfer through water (Granada, et al., 2016).

3.2.2 Selection of species

This is the main criteria for the IMTA culture system, because of species selection directly depends on the production and environmental benefits. Choose the fed species are carnivores to feed those pellets or trash fishes. Some basic criteria such as adaptability of the environment, market demand, commercial potential (Sasikumar et al., 2015).

One of the effective IMTA system necessitates the selection of the species and place, arrangement and placement of the different species or organism, so that easily detention of the both dissolved and particulate generated by farm. Types of designs should be recapture of the waste generated by the organism (Sasikumar et al., 2015). Bivalve is the key components of the organic extractive species because of bivalve is largely distributed culture organism and ideal for the waste bifilteration (Filgueira et al., 2017).

3.3 Integrated Chicken, Plant and Fish Farming (ICPF)

Culture of fish plant and chicken together it is the zero bio-waste system. Fish culture together with the agree crop, and livestock in the same system but grown individually. Integrated chicken is one of the most effective technique to enhance the small-scale culture productivity, also one of the best environment friendly system. ICPF system increase diversity and yields of multiple products, also recirculating water system its help to conserve water resources (Hasimuna et al., 2023).

Fig: 3 Integrated Chicken Plant and Fish Farming System

Benefits of the ICPF is circulated feed culture fishes because manure from the chicken is provide the food of culture species and nitrogen rich water recirculate through the plants to nurise them. Integration with the livestock, plant and fish is proved to sustainability in the Asian country. In china, culture the fish with some leafy vegetable and livestock included ducks, chickens, etc. and increase fish production. Exchange of the manure and nutrition that is the main benefits of this system (Al Mamun et al., 2011).

In aquaculture integration with agriculture is the more developed system in the world and china has long and successful history of the integrated farming system (Edwards et al., 1988). In the present era having a big economic pressure for minimizing production cost and maximizing food production with the general concern for energy conservation had to method of integrating fish farming with plant and animal (Hirpo 2017).

ICPF is most complex and consist system, rise an animal and plant around the fish pond. Integrated chicken plant and fish farming system is practice with links together the three normally separate farming systems, where by the chicken, vegetable and fish become culture in one area of whole farming system. Integrated farming activity is a multi-purpose farming system, the key feature is the waste recycling process and fish culture as the major activity (Hirpo 2017). Natural fertilization are more effective in fish pond, biologically fertilization are stimulation of primary productivity like zoo and phytoplankton. Planktons are provides a food for the cultivable fish species and that's why Pond fertilization can double or triple fish production (Ahmed et al., 2011). Poultry manure has been considered as a complete fertilizer having a organic and inorganic compound, and help to increase a pond productivity (Njoku and Ejiogu, 1999; Njoku, 2008).

Main aim to using poultry droppings in fish pond at resolving the problems like algal blooms, oxygen depletion and stress related mortalities in pond. After adding manure gives good results in ponds with higher recovery and help to increase fish growth (Njoku, 1997). Chicken house constructed on the top of the pond, they first leave waste in fish tank and help to produce primary productivity for fish feeding (Hirpo, 2017). Protein rich chicken dropping provide a food either directly or indirectly via the primary producers like zoo and phytoplankton in the aquatic food web (Oladosu et al., 1990). Poultry has short digestive tract so chicken manure signifies 80% undigested feed stuffs (Chen, 1989). Then solid waste are transfer in to bio filter they help to transfer the Ammonia wastes in to nitrates (Hirpo, 2017).

The solid waste of fish and bird transfer into the bio filter, where ammonia waste converted into nitrates. This nitrate-rich water now passes in the hydroponics system and nourishing plants, in return roots of plants purify the water and return back into the fish tank which creates a circulatory system. This symbiotic integration ensures that **zero bio-waste** and effective utilization of farm resources (Njoku and Ejiogu, 1999).

4. Conclusion

Vertical aquaculture presents a promising solution for enhancing production efficiency while minimizing land use. This innovative approach allows for more efficient water resource management and significantly reduces waste generated by traditional aquaculture practices. By cultivating fish in a controlled environment, vertical aquaculture lowers the risk of disease transmission and decreases the reliance on antibiotics and pesticides, contributing to healthier and more sustainable food production. Looking ahead, vertical aquaculture holds great potential for providing high-quality food to meet the growing global demand. It is imperative to raise awareness among communities and stakeholders about the benefits of adopting vertical aquaculture systems to maximize their productivity and contribute to a more sustainable future.

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