Aquaculture-Integrated Agriculture Systems

Subjects: Water Resources
Contributor: Lubna A. Ibrahim, Mohamed Abu-Hashim, Hiba Shaghaleh, Elsayed Elsadek, Amar Ali Adam Hamad, Yousef Alhaj Hamoud

Multiple uses of water aquaculture-integrated agriculture systems (AIAS) are inevitable to produce more food per drop of water to address water shortage, food insecurity, and climate change. Pond-based AIA could aid in increasing productivity, income for food producers and soil fertility, ecosystem maintenance, and adaptation to environmental change. AIAS helps adapt to and mitigate climate change by reducing waste and greenhouse gas emissions, reducing pressure on water resources, and recycling nutrients.

Keywords: climate change ; multiple-use water ; pond-based AIA

1. Introduction

The current world population is anticipated to reach 8.5, 9.7, and 10.9 billion in 2030 (10%), 2050 (26%), and 2100 (42%), respectively [1]. These future projections imply the imperative of sustainable, high-yield food production systems that maximize water and nutrient reuse while minimizing environmental impact. It is realized that the shift toward a more sustainable food framework is the second goal of the “Sustainable Development Goals (SDG) Zero Hunger” to achieve food sovereignty, enhance nutrition and advance feasible agriculture” [1].

Agriculture is essential for achieving food security in the face of population growth worldwide. Globally, agriculture consumes roughly 69–70% of yearly water withdrawals, while in a few dry countries, it consumes 90% [2]. The intergovernmental and legislative assemblies advocate for sustainable agriculture because agriculture is the major cause and victim of water pollution [2]. Any solution to save water must start by reinforcing water use for irrigation by implementing the “more crops per drop” intensification approach to increase yield, particularly in regions with limited water resources.

Similar to agriculture, aquaculture production pollutes water resources [3]. Fish waste, including excretions and unconsumed fish feed, accumulates, leading to water pollution. Aquaculture is a consumer of water, and its integration with agriculture is logical and coherent, transforming it into a non-consumptive production sector that does not contend with agriculture, which improves the benefits of sustainable farming [4]. Therefore, the multiple usages of water in aquaculture-integrated agriculture systems (AIAS) are effective in enhancing farm and water productivity, improving fish pond water quality, and reducing the environmental impact of nutrient-rich water discharge, cost of water, and amount of chemical fertilizer needed for crops. A potential strategy to increase “crops per drop” is aquaculture-integrated agriculture (AIA), which is sometimes referred to as “more crop per drop” [4].

Aquaculture-integrated agriculture systems (AIAS)-based soil is a sort of sustainable intensification that produces more food from the same land area and water use without ecological impacts [5]. AIA incorporates the joining of fish, fruits, vegetables, and livestock. In AIA, wastes are recycled from one system as inputs to another, and thus, pollution is reduced [6]. AIA has increased sustainability, productivity, profitability, efficiency, and maximally benefits from water, land, and labor [6][7]. AIA has benefits for increasing food production and reducing dangers related to water deficiency [6]. One of the main kinds of AIA systems is pond-based AIA, where fish mature as an essential crop for production and income. Pond-based AIA is environmentally feasible and gives a strategy for water reusing and nutrient recycling [8].

2. Multiple-Use Water

With critical challenges in managing water resources facing the developing world, the need to progress in multiple-use water in AIAS to reinforce both water and crop productivity has acquired critical impact. Multiple-use water could be tracked down in blue water (surface and groundwater) and green water (rain), which entails largely untapped chances to enhance the efficacy and productivity of water use. The distinction between blue and green water utilization in crop production is unclear [9]. Finally, blue water cannot be segregated from green water in aquaculture-integrated agriculture, as the two types of water are closely interrelated and complementary [10].

Various yields for a similar amount of water are obtained through the water use in fish pond aquaculture and reutilizing this water in the irrigation of crops. The water efficacy can also be essentially expanded through (1) the utilization of fertilizers by advancing the growth of fish and plants and yields per unit of water [11]; (2) relying on natural feeds in pond water, which can also increase blue water efficiency [12]; (3) the diversification and intensification of cropping patterns; (4) micro-irrigation for the production of crops in combination with pond-dike cropping [13]; and (5) small ponds or reservoirs that can potentially conserve or storage rainwater for AIAS.

2.1. Aquaculture Species in Different Water Environments

As per water salinity, aquaculture can be classified as freshwater (≤0.5 g/L), brackish (0.5–30 g/L), and marine 30 g/L cultures [14].

- Freshwater (inland) culture mainly produces fish using a culture system such as ponds, flow-through systems, recirculation aquaculture systems (RAS), or other inland waterways created based on economic perspectives. Species raised in inland ponds are the “snakehead, carp, tilapia, trout, palaemonids, goldfish, gourami, the giant freshwater prawn, trout, pike, tench, salmonids, and catfish” [14].

- Brackish (coastal) culture is carried out in coastal ponds, swamps, lagoons, and tidal regimes. This type of fish is called euryhaline, since it can maintain a variety of salinity. Crab, mullet, oyster, and shrimp are common species [15].

- In marine (Mari) culture, highly valuable fish such as salmon, seabass, bream, barramundi, trout, bivalve mollusks, and seaweeds [16] are farmed in artificial facilities for fish farming, such as cages or basins that can be operated conventionally.

Hence, numerous freshwater sorts can be effectively developed in the salinity range of 0.5–30 g/L because most fish types can adapt to the conditions of the new environment.

2.2. Plant Growth under High Salinity

A series of moderate and tolerant plants and their threshold values are depicted and experimentally tested [17][18]. Halophyte plants are best suited to growing and living in high-salinity conditions or even seawater [17][18].

To deal with climate change, research will be needed to develop or promote a new strain or breed of aquaculture species and hybrid plant (crops) crops that are tolerant of water with a poorer quality index and high salinity levels. To lessen the effects of environmental change on freshwater, integrated mariculture is necessary. The low cost of feeding, ease of propagation, resistance to disease, tolerance to adverse climatic conditions, rapid growth, and high endurance should be observed for desert aquaculture management.

2.3. Legal Framework

Lately, much consideration has been paid to the role and work of legal organizations in aquaculture improvement [19]. Risk management in aquaculture is mandatory to ascertain the efficacy and safety of production. Chemical waste and pollutants are estimated by legislation in three ways: (A) banning or restricting the utilization of unsafe chemicals to the environment; (B) improving a wastewater discharge licensing system, which is generally controlled by ‘‘a water law’’; and (C) prohibiting the utilization of specific drugs, chemicals, and hormones that can, unfortunately, influence the physiological performance of fish [20].

Due to the higher risk associated with higher contaminants in ponds, various countries have ordered specific rules relating to the following. (1) First, there is ‘‘under an aquaculture-specific legislative text’’, for instance, the United States (US), Australia, etc. [19]. In the US, the US EPA (Environmental Protection Agency) has established rule production systems for aquaculture, such as lists of detected pollutants and vessel classifications for various degrees of operational discharge [21]. Then, different countries have gone with the same pattern. Farmers must develop further production techniques to meet water quality standards when regulations are authorized based on drainage standards. (2) Second, there is the ‘‘under a basic fisheries law’’, for example, Albania, Belgium, etc. [19]. (3) A third rule is ‘‘under management (law cover fisheries or water) in general’’ such as Brazil, Australia (New South Wales), etc. [19]. For example, Malaysia has guidance for using the Environmental Quality (Industrial Waste) Regulation 2009 as the primary reference. The sewage discharge standard covering three different sewage discharge standards consisting of five sub-standard grades has been implemented in China. (4) Fourth, there is the ‘‘under a water law’’; countries such as Thailand, Taiwan, etc. [19] have set water quality standards for aquaculture. These standards consist of water quality constraints and restrictions to ensure that waste cannot adversely affect water bodies. (5) Countries that do not have regulations or guidelines can follow those provided by the International Finance Corporation (IFC) or the General Authority for Awqaf (GAA) [14].

Fish cultivating is not allowed to be created on agricultural lands. The main guideline influencing land usage is Law 124/1983, which states that only fallow land (not fit for crop production) can be used for fish farming. This regulation aims to prevent the conversion of 'old' agricultural land for other purposes and usage. Yet, it poses complications to the rotation of aquaculture and agriculture, for instance, the growing of cereal crops on the bottom of fishponds during the winter season. Aquaculture is also temporarily permitted for a specified period in salty lands; once the salt is leached and the salts are removed from the land, it turns into agricultural land for the cultivation of crops [22].

3. Pond-Based AIA

Fish culture in ponds has long been practiced by rural communities in many or several countries in Asia and is a current practice in Africa. Pond culture is an extremely known aquaculture production strategy. It can be divided into two sorts depending on their water supply, namely levee ponds (1.79 m^3/kg productivity) and watershed (or depression) ponds [23]. Pond sizes fluctuate from 100 to 100,000 m^2, depending on their production scale, site, and species types. Ponds have a typical depth of 1.2–1.5 m [23]. Most fish farming families in rural communities are engaged in extensive and semi-intensive farming because of the absence of resources [24], so fish productivity is variable [25][26][27][28][29]. AIA systems typically range from extensive to intensive types of aquacultures, and they frequently rely on fertilization of some kind to produce phytoplankton and zooplankton as natural fish food [30] (Edwards et al., 2000). According to the type of structure utilized in operation, such as cage, pond, or tank farming systems, aquaculture can be further classified.

The first (1st) most applicable scenario is the entry of pond-dike (dam) crops in rural Bangladesh, Malawi [31], bamboo fish in China, and Egypt as El-Riad-Tourism-Lake [32], where the mud of the pond rich with nutrients is utilized to compost.

Vegetables and fruit trees allow some fruits to grow on pond dams, for example, bananas, lemon, coconut, guava, palm, orange, bamboo, and papaya. Pond slopes are also utilized for growing vegetables (e.g., beans, squash, and cucumber) using bamboo structures to aid their spread over the pond water [33]. Notwithstanding, a few aquatic weeds are applied as fodder (grain) for fish and livestock, such as “Azolla, duckweed, water hyacinth, and water spinach” [24][34].

3.1. Impact of Pond-Based AIA on Soil, Fish, and Plant Characteristics

Fish pond wastewater is sometimes utilized as a potential irrigation resource to grow vegetables around places that are directly or indirectly used by humans [35]. The presence of organic feeding waste, nitrogen, and phosphorus in the lower part of the pond contrasted with the surface water could directly influence water quality, increment parasite infection, nutrient accessibility, fish growth, and production due to the exchange of substances among soil and water [36][37]. Total alkalinity and ammonia nitrogen (TN) are higher at the soil–water interface when contrasted with the surface water [38]. The accumulation of nutrients in the sediment increases directly with total nutrient input in a limited-scale freshwater pond [39]. Recycling water in an AIA is not only an approach to saving water, but it can also be a source of fertilizer (organic) to soils with lower fertility to give a higher efficiency of crops. The efficiency of nutrient water aquaculture (17–340 g of protein/m^3 water) is the most noteworthy among all significant food-producing sectors, including the production of animals and vegetables [40]. Fish wastewater irrigation was good for enhancing soil physical and chemical properties, the nutrient perquisites of the soil, growth parameters, and productivity of crops such as maize, okra, and cucumbers [41][42][43].

3.2. Water Use Efficiency (WUE)

The range of average WUE is reported to be 0.56–1.59 and 0.94–1.10 kg/m^3 for maize, and wheat, respectively. For aquaculture, WUE accounts for 0.21–0.37, 0.71–2, and 0.02 kg/m^3 in well-managed ponds, super-intensive recirculating, and extensive systems, respectively [44]. The WUE in pond-based AIA systems is 2.13 kg/m^3 for fish–maize production and up to 8.46 kg/m^3 for fish–vegetable production [4]. The upshot is that the WUE in pond-based AIA is more than in the non-AIA system. Therefore, using fish pond effluent to irrigate crops in integrated systems is preferable.

3.3. Economics, Social, and Environmental Benefits of Pond-Based AIA

Reusing wastewater from fish farming for irrigation reduces fertilizer costs [45]. The gross revenue from tilapia production (on 1 ha of land) for two production cycles in a year is US$ 960 × 20 with net revenue of US$ 384 × 20, while the gross margin is about US$ 466 × 20 per year [46]. The rate of return on investment represented by percent profit is 66.7%, which is equivalent to a 1.67 production efficiency index that shows how beneficial tilapia cultivation is, despite tilapia farmers exceeding cost by 67% [46]. In Malawi [33], AIAS was 11% more fertile than non-AIAS, and the incomes of AIAS farmers increased by 134%/ha. The median annual income of farmers in AIAS and non-AIAS was $185 and $115, respectively. Therefore, fish farming directly contributed to an increase in productivity, profitability, and income for the AIA farm.

In Kilombero [7], AIA-based farming systems, including fish and vegetables (*B. Rapa Chinensis*), resulted in a three and 2.5-fold increase in net production compared to fish and vegetable farming alone in non-integrated systems, respectively. In selected areas of Bangladesh [47], it has been observed that a large number of agricultural enterprises (crop, poultry, fisheries, cattle, etc.) and a large area of land ponds increase the income of farmers [48]. Finally, pond-based AIA produced fish, crops, and protein and increased farm productivity and farm net income per hectare (ha) by 11% and 134%, respectively, compared to pond-fish culture or non-AIA [7][32][48].

Pond-based-AIA is considered an ecologically sustainable system as it provides water/nutrients recycling ability and increases both productivity and water usage efficiency [8]. Fish waste improves soil fertility by increasing the number of organic fertilizers and renewing nitrogen and phosphorous elements. The fertilizer is dredged from the bottom (lower part) of the ponds to be used as a successful fertilizer to enhance crop production [12]. Furthermore, vegetables and herbs were grown on the pond sediments to protect the embankments (dikes or levees) from erosion by rain.

4. AIAS in Coastal Areas

In recent decades, saltwater shrimp cultivation has increased significantly in Asia's inner and coastal areas, including river deltas, with well-known environmental effects on mangroves and other biotas [49][50]. Additionally, agriculture has significant repercussions, particularly in Thailand, Bangladesh, and Vietnam [50][51]. In the inland areas of Thailand, where rice is grown extensively with irrigation that traditionally relies on free water, interference between agriculture and aquaculture is notable [51][52][53]. During the dry season, saltwater naturally enters these areas, and during the wet season, it can be retained in ponds and mixed with fresh water to provide saltwater shrimp with ideal conditions for growth. In the 1990s, the seepage and release of water from ponds caused severe pollution of irrigation water and agricultural soils [50][54]. In 1998, the Thai government responded by prohibiting shrimp aquaculture in some areas [50]. However, enforcement has not always been consistent. Shrimp are favored by economic incentives to such an extent that hypersaline water and even bagged salt are trucked in to maintain shrimp growth conditions, despite the adverse effects on nearby agriculture [50][55].

In Bangladesh, shrimp aquaculture relies on trapped seawater carried inland by tides through constructed and natural channels. The ponds allow water to escape through percolation and overflow, accumulating sediment from upstream runoff. During the growth season, water is also frequently released, and then after each annual cycle of shrimp culture, the contents of ponds are pumped onto adjacent land [50]. Soils can become unsuitable for agriculture as a result of sedimentation and the release of saltwater from ponds in this manner [50].

In the UAE [56], the desalinated water is used to irrigate a wide variety of high-value crops such as radish, cauliflower, maize, lettuce, spinach, amaranthus, carrot, tomato, mustard, asparagus, eggplant, and quinoa. On the other hand, about 150 m^3/day of brine water is utilized for aquaculture, which is followed by irrigation salinity-tolerant forage grasses and halophytes. The outcomes obtained within four months demonstrated that the weight of fish increased by 200% and the length of fish increased by 60%. Two species of fish, *Sparidentex hasta* (sobaity seabream) and *Oreochromis spilurus* (tilapia), demonstrated remarkable adaptability to the local conditions.

In Brazil [57], diluted brackish aquaculture effluent is used to irrigate *Enterolobium contortisiliqum* seedlings. The outcomes revealed increased shoot growth and the total dry weight in *E. contortisiliquum*. These outcomes indicate that saline aquaculture effluent can be reutilized to irrigate tree species.

In Egypt, some projects were completed in a salty environment, such as El-Gouna Park (water salinity 15 g/L) [32] rula for land reclamation (RLR) [32]. In the RLR project, groundwater with a salinity of more than 26 g/L was utilized for European seabass (*Dicentrarchus labrax*) and gilthead seabream (*Sparus aurata*) cultivations. After that, water was used for *Sarcocornia* planting. RLR is not operational due to the high cost of electricity, which in the end represented more than 30% of the total production cost and made further use unprofitable.

Salinity is an emerging issue that results in significant yield losses in many parts of the world, particularly in arid and semiarid regions. Soil acidification, groundwater pollution, land subsidence, and other hydrological perturbations can shift away from agriculture [50][58]. However, it is challenging to mitigate soil salinization. Consequently, the long-term economic benefits of fish and shrimp culturing may not be realized. As a result, economic stimuli and localized environmental factors significantly influence the integration that makes up the precarious balance between aquaculture and agriculture [50][59].

Farmers frequently face a difficult choice: They can continue fish and shrimp cultivations, mitigate cropland salinization, or maintain agriculture.

References

1. UN. World Population Prospects, Report ST/ESA/SER.A/423 Department of Economic and Social Affairs; Population Division; United Nations (UN): New York, NY, USA, 2019; Available online: https://population.un.org/wpp/publications/files/wpp2019_highlights.pdf (accessed on 20 October 2021).
2. UN-Water. Water, Food and Energy; UN-Water: New York, NY, USA, 2018; Available online: http://www.unwater.org/water-facts/water-food-and-energy/ (accessed on 20 October 2021).
3. Ahmed, N.; Thompson, S.; Glaser, M. Global aquaculture productivity, environmental sustainability, and climate change adaptability. Environ. Manag. 2019, 63, 159–172.
4. Abdul-Rahman, S.; Saoud, I.P.; Owaied, M.K.; Holail, H.; Farajalla, N.; Haidar, M.; Ghanawi, J. Improving Water Use Efficiency in Semiarid Regions through Integrated Aquaculture/Agriculture. J. Appl. Aquacult. 2011, 23, 212–230.
5. Godfray, H.C.J.; Beddington, J.R.; Crute, I.R.; Haddad, L.; Lawrence, D.; Muir, J.F.; Pretty, J.; Robinson, S.; Thomas, S.M.; Toulmin, A.C. Food security: The challenge of feeding 9 billion people. Science 2010, 327, 812–818.
6. Ahmed, N.; Muir, J.F.; Garnett, S.T. Bangladesh needs a “bluegreen revolution” to achieve a green economy. Ambio 2012, 41, 211–215.
7. Limbu, S.M.; Shoko, A.P.; Lamtane, H.A.; Kishe-Machumu, M.A.; Joram, M.C.; Mbonde, A.S.; Mgana, H.F.; Mgaya, Y.D. Fish polyculture system integrated with vegetable farming improves yield and economic benefits of small-scale farmers. Aquacult. Res. 2017, 48, 3631–3644.
8. Phong, L.T.; van Dam, A.A.; Udo, H.M.J.; van Mensvoort, M.E.F.; Tri, L.Q.; Steenstra, F.A.; van der Zijpp, A.J. An agroecological evaluation of aquaculture integration into farming systems of the Mekong Delta. Agric. Ecosys. Environ. 2010, 138, 232–241.
9. Hoekstra, A.Y. Green-blue water accounting in a soil water balance. Adv. Water Resour. 2019, 129, 112–117.
10. Hansen, N.C. Blue water demand for sustainable intensification. Agronomy J. 2015, 107, 1539–1543.
11. Verdegem, M.C.J.; Bosma, R.H. Water withdrawal for brackish and inland aquaculture, and options to produce more fish in ponds with present water use. Water Policy 2009, 11, 52–68.
12. Ahmed, N.; Ward, J.D.; Saint, C.P. Can integrated aquaculture-agriculture (IAA) produce “more crop per drop”? Food Sec. 2014, 6, 767–779.
13. Dukes, M.D.; Zotarelli, L.; Morgan, K.T. Use of irrigation technologies for vegetable crops in Florida. Hort. Technol. 2010, 20, 133–142.
14. Ahmad, A.; Abdullah, S.R.S.; Abu Hasan, H.; Othman, A.R.; Ismail, N.I. Aquaculture industry: Supply and demand, best practices, effluent and its current issues and treatment technology. J. Environ. Manag. 2021, 287, 112271.
15. FAO. FAOSTAT. Database; Food and Agriculture Organization, United Nations (FAO): Rome, Italy, 2016; Available online: http://faostat3.fao.org/browse/R/RP/E (accessed on 1 November 2021).
16. Hai, A.T.N.; Speelman, S. Economic-environmental trade-offs in marine aquaculture: The case of lobster farming in Vietnam. Aquaculture 2019, 516, 734593.
17. Brown, J.J.; Glen, E.P.; Fitzsimmons, K.M.; Smith, S.E. Halophytes for the treatment of saline aquaculture effluent. Aquaculture 1999, 175, 255–268.
18. Kempenaer, J.G.; Brandenburg, W.A.; van Hoof, L.J.W. Het zout en de pap. een Verkenning Bijmarktexperts naar Langeretermijn Mogelijkheden voor Zilte Landbouw; Rapport Innovatie netwerk nr 07.2.154: Utrecht, The Netherlands, 2007; p. 93.
19. Houtte, A.V. Establishing Legal, Institutional and Regulatory Framework for Aquaculture Development and Management. In The Food and Agriculture Organization of the uns and the Network of Aquaculture Centres in Asia Pacific Present Int Con Aquacul 3rd Millennium: Central Grand Plaza Convention Centre Bangkok, Aquacul Seafood Fair; Dep Fish Thailand: Bangkok, Thailand, 2000.
20. Takoukam, P.T.; Erikstein, K. Aquaculture Regulatory Frameworks: Trends and Initiatives in National Aquaculture Legislation; FAP Legal Papers: Rome, Italy, 2013.
21. Tornero, V.; Hanke, G. Chemical contaminants entering the marine environment from sea-based sources: A review with a focus on European seas. Mar. Pollut. Bull. 2016, 112, 17–38.

22. Nassr-Alla, A. Egyptian Aquaculture Status, Constraints and Outlook; Centre International de Hautes Études Agronomiques Méditerranéennes: Paris, France, 2008.
23. Ngo, H.H.; Guo, W.; Tram, V.T.; Nghiem, L.D.; Hai, F.I. Aerobic treatment of effluents from the aquaculture industry. In Current Developments in Biotechnology and Bioengeering, Biological Treatment of Industrial Effluents; Elsevier: Amsterdam, The Netherlands, 2017; pp. 35–77.
24. FAO. Small Ponds Make a Big Difference: Integrating Fish with Crop and Livestock Farming; Food and Agriculture Organization of the United Nations (UN): Rome, Italy, 2000.
25. Mulokozi, D. Integrated Agriculture and Aquaculture Systems (IAA) for Enhanced Food Production and Income Diversification in Tanzania. Ph.D. Thesis, Department of Physical Geography, Stockholm University, Stockholm, Sweden, 2021.
26. Ahmed, N.; Wahab, M.A.; Thilsted, S.H. Integrated aquaculture-agriculture systems in Bangladesh: Potential for sustainable livelihoods and nutritional security of the rural poor. Aquacult. Asia 2007, 12, 15–23.
27. van Der Heijden, P.G.M. Water use at integrated aquaculture agriculture farms. Experiences with limited water resources in Egypt. Glob. Aquac. Advocate 2012, 2012, 28–31.
28. Tran, N.; Crissman, C.; Chijere, A.; Chee, H.M.; Jiau, T.S.; Valdivia, R.O. Ex-Ante Assessment of Integrated Aquaculture Agriculture Adoption and Impact in Southern Malawi; WoldFish: Penang, Malaysia, 2013.
29. Phong, L.T.; Udo, H.M.J.; van Mensvoort, M.E.F.; Tri, L.Q.; Bosma, R.H.; Nhan, D.K.; van der Zijpp, A.J. Integrated agriculture aquaculture systems in the Mekong Delta, Vietnam: An analysis of recent trends. Asian J. Agr. Dev. 2007, 4, 51–66.
30. Edwards, P.; Lin, C.K.; Yakupitiyage, A. Semi-intensive pond aquaculture. In Tilapias: Biology and Exploitation. Fish and Fisheries Series; Beveridge, M.C.M., McAndrew, B.J., Eds.; Springer: Dordrecht, The Netherlands, 2000; Volume 25.
31. Karim, M.; Little, D.C.; Kabir, M.S.; Verdegem, M.J.C.; Telfer, T.; Wahab, M.A. Enhancing benefits from polycultures including tilapia (Oreochromis niloticus) within integrated pond-dike systems: A participatory trial with households of varying socio-economic level in rural and peri-urban areas of Bangladesh. Aquaculture 2011, 314, 225–235.
32. Corner, R.; Fersoy, H.; Crespi, V. Integrated Agri-Aquaculture in Desert and Arid Lands: Learning from Case Studies from Algeria, Egypt and Oman; Fish Aquacult Circular No 1195; FAO: Cairo, Egypt, 2020.
33. Dey, M.M.; Paraguas, F.J.; Kambew, P.; Pemsl, D.E. The impact of integrated aquaculture-agriculture on small-scale farms in Southern Malawi. Agr. Econ. 2010, 41, 67–79.
34. Poot-López, G.R.; Hernandez, J.M.; Gasca-Leyva, E. Input management in integrated agriculture-aquaculture systems in Yucatan: Tree spinach leaves as a dietary supplement in tilapia culture. Agr. Sys. 2010, 103, 98–104.
35. Ojwala, R.A.; Elick, O.O.; Nzula, K.K. Effect of water quality on the parasite assemblages infecting Nile tilapia in selected fish farms in Nakuru County, Kenya. Parasitol. Res. 2018, 117, 3459–3471.
36. Hasibuan, A.; Syafriadiman, S.; Aryani, N.; Fadhli, M.; Hasibuan, M. The age and quality of pond bottom soil affect water quality and production of Pangasius hypophthalmus in the tropical environment. Aquac. Fish. 2023, 8, 296–304.
37. Saraswathy, R.; Muralidhar, M.; Sanjoy, D.; Kumararaja, P.; Suvana, S.; Lalitha, N.; Vijayan, K.K. Changes in soil and water quality at sediment–water interface of Penaeus vannamei culture pond at varying salinities. Aquac. Res. 2019, 50, 1096–1106.
38. Pouil, S.; Samsudin, R.; Slembrouck, J.; Sihabuddin, A.; Sundari, G.; Khazaidan, K.; Caruso, D. Nutrient budgets in a small-scale freshwater fish pond system in Indonesia. Aquaculture 2019, 504, 267–274.
39. Molden, D.; Oweis, T.; Steduto, P.; Bindraba, P.; Hanjra, M.A.; Kijneo, J. Improving agricultural water productivity: Between optimism and caution. Agri. Water Manag. 2010, 97, 528–535.
40. Musa, J.; Dada, P.; Adewumi, J.; Akpoebidimiyen, O.; Musa, E.; Otache, M.; Yusuf, S. Fish pond effluent effect on physicochemical properties of soils in Southern Guinea Savanna, Nigeria. OA Lib. J. 2020, 7, 1–15.
41. Ndagi, A.; Adeoye, P.A.; Usman, B.I. Effect of Fish Pond Wastewater Irrigation on Receiving Soils and Crops in Dry Season Farming. Direct Res. J. Eng. Inform. Technol. 2020, 7, 75–83.
42. Nsoanya, L.N. Response of Fish Pond Effluent on Soil Chemical Properties and Growth of Cucumber (Cucumis sativus) in Igbariam South Eastern, Nigeria. Int. J. Curr. Microbiol. App. Sci. 2019, 8, 2799–2807.
43. Ali, M.H.; Talukder, M.S.U. Increasing water productivity in crop production—A synthesis. Agric. Water Manag. 2008, 95, 1201–1213.
44. Verdegem, M.C.J.; Bosma, R.H.; Verreth, J.A.J. Reducing water use for animal production through aquaculture. Int. J. Water Resour. Dev. 2006, 22, 101–113.

45. Eid, A.R.; Hoballah, E.M.; Mosa, S.E.A. Sustainable management of drainage water of fish farms in agriculture as a new source for irrigation and bio-source for fertilizing. Int. J. Sci. Res. Agric. Sci. 2014, 1, 67–79–79.

46. Bannor, R.K.; Bentil, J.K. Comparing the profitability of tilapia farming to maize farming on a hectare of land in the Agona West municipality of Ghana. J. Bus. Manag. Soc. Sci. Res. 2015, 4, 382–392.

47. Sharmin, S.; Islam, M.S.; Hasan, M.K. Socioeconomic Analysis of Alternative Farming Systems in Improving Livelihood Security of Small Farmers in Selected Areas of Bangladesh. Agriculturists 2012, 10, 51–63.

48. Shoko, A.P.; Limbu, S.M.; Lamtane, H.A.; Kishe-Machumu, M.A.; Sekadende, B.; Ulotu, E.E.; Mgaya, Y.D. The role of fish-poultry integration on fish growth performance, yields and economic benefits among smallholder farmers in sub-Saharan Africa, Tanzania. Afr. J. Aquat. Sci. 2019, 44, 15–24.

49. Truong, T.D.; Do, L.H. Mangrove forests and aquaculture in the Mekong River Delta. Land Use Policy 2018, 73, 20–28.

50. Pueppke, S.G.; Nurtazin, S.; Ou, W. Water and Land as Shared Resources for Agriculture and Aquaculture: Insights from Asia. Water 2020, 12, 2787.

51. Ahmed, M.; Lorica, M.H. Improving developing country food security through aquaculture development—Lessons from Asia. Food Policy 2002, 27, 125–141.

52. Braaten, R.O.; Flaherty, M. Hydrology of inland brackishwater shrimp ponds in Chachoengsao, Thailand. Aquacult. Eng. 2000, 23, 295–313.

53. Poapongsakorn, N.; Ruhs, M.; Tangjitwisuth, S. Problems and outlook of agriculture in Thailand. Tdri. Quart. Rev. 1998, 13, 3–14.

54. Vandergeest, P.; Flaherty, M.; Miller, P. A political ecology of shrimp aquaculture in Thailand. Rural Soc. 2009, 64, 573–596.

55. Flaherty, M.; Vandergeest, P.; Miller, P. Rice paddy or shrimp pond: Tough decisions in rural Thailand. World Devel. 1999, 27, 2045–2060.

56. Ismail, D.; Lyra, S. Integrated Aqua-Agriculture for Enhanced Food and Water Security; International Center for Biosaline Agriculture (ICBA) & International Water Management Institute (IWMI) Project, Arabian Peninsula: Dubai, United Arab Emirates, 2015.

57. de Sousa Leite, T.; de Freitas, R.M.O.; Nogueira, N.W.; de Sousa Leite, M.; De Souza Pinto, J.R. The use of saline aquaculture effluent for production of Enterolobium contortisiliquum seedlings. Environ. Sci. Pollut. Res. 2017, 24, 19306–19312.

58. Kruse, J.; Koch, M.; Khoi, C.M.; Braun, G.; Sebesvari, Z.; Amelung, W. Land use change from permanent rice to alternating rice-shrimp or permanent shrimp in the coastal Mekong Delta, Vietnam: Changes in the nutrient status and binding forms. Sci. Total Environ. 2020, 703, 134758.

59. Lázár, A.N.; Clarke, D.; Adams, H.; Akanda, A.R.; Szabo, S.; Nicholls, R.J.; Matthews, Z.; Begum, D.; Saleh, A.F.M.; Abedin, A.; et al. Agricultural livelihoods in coastal Bangladesh under climate and environmental change—A model framework. Environ. Sci. Process. Impacts 2015, 17, 1018–1031.