INTEGRATING FISH FARMING WITH VEGETABLE PRODUCTION: A STRATEGY TO ENHANCE FOOD PRODUCTION, PROFITABILITY AND INCOME DIVERSIFICATION

M.Sc. THESIS

BY

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INTEGRATING FISH FARMING WITH VEGETABLE PRODUCTION: A STRATEGY TO ENHANCE FOOD PRODUCTION, PROFITABILITY AND INCOME DIVERSIFICATION

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ADVISORS’ APPROVAL SHEET

(Submission Sheet-1)

This is to certify that the thesis entitled “INTEGRATING FISH FARMING WITH VEGETABLE PRODUCTION: A STRATEGY TO ENHANCE FOOD PRODUCTION, PROFITABILITY AND INCOME DIVERSIFICATION” Submitted in partial fulfillment of the requirements for the degree of **Master's** with specialization in **Aquaculture and Fisheries Management,** the Graduate Program of the **Department of Aquatic Sciences Fisheries and Aquaculture (ASFA),** and has been carried out by KOKOBE TEFEREDEGN ERGEGTA, ID. No GpFiAqR/0005/14 under my supervision. Therefore, I recommend that the student has fulfilled the requirements and hence hereby can submit the thesis to the department.

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We, the undersigned, members of the board of examiners of the final open defense by Kokobe Teferedgn Eregeta have read and evaluated her thesis entitled “INTEGRATING FISH FARMING WITH VEGETABLE PRODUCTION: A STRATEGY TO ENHANCE FOOD PRODUCTION, PROFITABILITY AND INCOME DIVERSIFICATION”, and examined the candidate. This is, therefore, to certify that the thesis has been accepted in partial fulfillment of the requirements for the degree of Master of Sciences in ‘‘Fisheries and Aquaculture’’.

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DECLARATION

I hereby declare that this thesis entitled ‘‘Integrating Fish Farming with Vegetable Production: A Strategy to Enhance Food Production, Profitability, and Income Diversification’’ submitted to the Aquatic Sciences, Fisheries and Aquaculture Department, College of Natural and Computational Sciences, Hawassa University. It is being submitted in partial fulfillment of the requirements for the qualification of Master of Science in Aquaculture and Fisheries Management.

I confirm that this is my independent work and has not been previously submitted for any degree or examination at any other higher education institution. I further acknowledge that all sources of materials used for this thesis have been duly acknowledged and referenced.

Name: Kokobe Teferedegn Eregeta

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List of Acronyms and Abbreviations

AAS	Atomic Absorption Spectrometry
BOD	Biological Oxygen Demand
BSF	Black Soldier Fly
BSFFF	Black Soldier Fly larvae Frass Fertilizer
CARDI	Caribbean Agricultural Research and Development Institute
CARE	Centre for Aquaculture Research and Education
ETB	Ethiopian Birr
GLVs	Green Leafy Vegetables
IAA	Integrated Aquaculture and Agriculture
K	Condition Factor
LA	Leaf Area
LL	Leaf Length
LN	Leaves Number
LSD	Least Significant Differences
PLH	Plant Height
RCBD	Randomized Complete Block Design
SAS	Statistical Analysis System
USAD-NRCS	United States Department of Agriculture Natural Resource Conservation System

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Abstract

The growth of human population requires an additional food-producing sector to meet the demand for animal protein sources. Regarding this, integrated fish farming can be considered as an additional option to enhance yield diversification with minimal investment costs. Thus, the present study was conducted to evaluate the integration of a fish farming system with vegetables as a strategy to enhance food production, profitability, and income diversification. The study encompassed both the survey component and the experimental work conducted in this study. The survey component employed visual observations, interviews, and questionnaires to assess the status of fish farming, including productivity, profitability, and constraints, in five districts of Sidama Regional State. The field experiment was conducted at Hawassa University's Centre for Aquaculture Research and Education from February 2023 to May 2023. The experiment involved stocking 150 fingerlings of Oreochromis niloticus with an average weight of 9.8 ± 0.42 g in $80m^2$ *pond, and Swiss chard production used 15 plots measuring 2m x 2m in a randomized complete block design. Swiss chard was grown with five treatments: compost, chemical fertilizer, BSFFF, control, and pond water. Data on fish and vegetable growth parameters, yield, and pre and post-soil properties were collected. Phytoplankton composition in the fish pond and stomachs of experimental O. niloticus was analyzed. The experimental and survey data were analyzed with SAS software Pro13 and SPSS software, respectively at 95% confidence interval. As for the survey results, it was found that 77% of fish farmers harvest fish for both consumption and commercial purposes, contributing to food security and income. However, constraints limit the adoption of integrated fish farming in the surveyed districts. Still, both IAA and non-IAA farmers exhibit a positive attitude toward fish farming. The Field experiments demonstrate O. niloticus achieved a final body weight of 98.6±4.9g. Swiss chard treated with fish pond water showed significant growth improvement in leaf length, leaf width, and leaf number* ($P<0.05$) *compared to all treatments except BSFFF. Marketable yields from plots treated with pond water were comparable to other treatments but significantly higher than the control* ($P<0.05$)*. Post-harvest soil analysis revealed that the application of fish pond water treatments improved the physicochemical parameters of the experimental soil. Among the identified phytoplankton groups, Bacillariophyceae and Chlorophyceae were found to be dominant in the stomach of O. niloticus, with varying abundance in genera. Cost-benefit analysis of the system revealed that Swiss chard treated with pond water showed higher profitability compared to other treatments. Based on the obtained results, it is recommended to promote the practice of integrated fish farming systems to enhance diversified yield, income generation, and sustainable agriculture.*

Keywords*: Food production, integrated aquaculture, Oreochromis niloticus, profitability, Swiss chard*

1. INTRODUCTION

1.1. Background of the study

The current 8 billion global population is estimated to reach 8.5 billion in 2030, 9.7 billion in 2050, and 11.2 billion in 2100 (UNDESA, 2022). Simultaneously, the global food demand is also expected to increase by 50-60% in 2050 (Falcon *et al.,* 2022). Considering these factors, countries all over the world are prioritizing the aquaculture sector as an additional means of food production to address the growing gap between demand and supply (Hasimuna *et al.,* 2023). Fish are widely recognized as a crucial source of micronutrients such as calcium, iron, zinc, vitamin A, and vitamin B12, as well as essential fatty acids and protein for human beings (Nolle *et al.,* 2020). Asia, particularly China, has shown significant attention to future global aquaculture production and its potential (Garlock *et al.,* 2020). However, less attention has been given to aquaculture in Africa. For instance, Africa's contribution to global aquaculture production in 2018 was estimated to be 2,196 million tons, representing an insignificant 2.7% of the global output, with a primary focus on freshwater finfish (Halwart, 2020).

Even though Ethiopia has abundant freshwater and fish resources, favorable climatic conditions, huge labor, and unsatisfied local demand for fish, the development of fish production in the country is relatively slower compared to other agricultural activities (Lemma Abera & Zenebe Tadesse, 2009). Meanwhile, the demand for fish has increased dramatically, while the supply from capture fisheries has persistently lagged behind the demand growth. To address this rising market demand for fish in Ethiopia, it becomes imperative to supplement the traditional capture fishery with the development of fish farming (Berihun Tefera & Goraw Goshu, 2010).

Despite aquaculture being one of the rapidly growing sectors in developing food security, it is facing some problems such as environmental degradation, organic pollution, eutrophication, a buildup of excess nutrients (primarily nitrogen and phosphorus), and other contaminants discharged to the ecosystem from point and nonpoint source (Akinrotimi *et al.,* 2011). To overcome the impact of adverse human activity, several technologies were identified. Among them, the practice of the integrated aquaculture system is a preferable technology (Ahmad *et al.,* 2022).

The concept of Integrated Aquaculture and Agriculture (IAA) can be applied in various ways to enhance food production, generate employment opportunities, and increase household incomes (Singh *et al.,* 2021). One approach involves the combination of fish alongside livestock and crops within the same production system. This integrated system allows for the mutual utilization of waste products, where the waste from each component is utilized by the others. As a result, this symbiotic relationship provides a source of affordable, high-quality food. In the context of fish-vegetable farming, fish pond water is utilized for irrigating vegetables like onions, tomatoes, and cabbage. This practice offers the advantage of reducing the reliance on chemical fertilizers, as the water from the fish pond provides natural nutrients for the crops (Luu, 2021). In return, vegetable waste can be utilized as a food source for fish, eliminating the need for small-scale farmers to purchase expensive, specially formulated diets.

To some extent, the system resembles the way of natural ecosystems function. In that regard, IAA also satisfies environmental aims and functions to improve people’s livelihoods and their welfare, rather than being solely concerned with production objectives (Hendrickson *et al.,* 2008). One of the main issues with traditional fish farming is the lack of nutrients, which can be solved with integrated practices. Due to animal manure fertilization, which speeds up fish growth and productivity, the average amount of fish produced with integrated fish farming is higher than the average amount of fish produced through traditional aquaculture (Lemma Abera, 2017).

Integration of aquaculture and agriculture has been practiced for several years in Southeast Asia, especially in Vietnam, India, and China (Ahmed *et al.*, 2014). In Africa, integrated fish farming is still in its infancy, and only a small number of effective outcomes have been documented in a few African nations. The integrated aquaculture-agriculture systems in Malawi and Nigeria have produced encouraging outcomes in terms of reducing poverty and malnutrition (Solomon Melaku & Natarajan, 2019).

The integration of small-scale fish-poultry and vegetable production is somewhat practiced, including in Ethiopia, across various types of integrated fish farming systems (Daba Tugie *et al.*, 2017). Diversifying agricultural activities through the implementation of integrated aquaculture, particularly for farmers with small land that have good water sources around their gardens, is considered the optimal solution (Mekonen Debara *et al.* 2021).

In Ethiopia, some studies have been conducted on integrating fish farming, particularly Nile tilapia, *Oreochromis niloticus* (Linnaeus, 1758) with various crop species. However, the development of the integrated fish farming production system is still limited. Therefore, further evaluation of integrated fish farming practices for diversified yield and cost minimization is needed. The present study aimed to assess the current status of fish farming practices (integrated and non-integrated) in five districts of Sidama Regional State and evaluated the productivity and profitability of fish-vegetable integration through designed experiments.

1.2. Statement of the problem

In Ethiopia, the agricultural sector plays a vital role as the mainstay, providing food, employment, and income generation (Adanech Bahiru *et al.*, 2023). However, the sector faces multiple challenges such as urbanization, drought, and population growth, which collectively threaten its ability to maintain a balance between supply and demand (Sibilo Gashure & Desalegn Wana, 2023). Moreover, the declining soil fertility in the country poses additional obstacles to food production (Chaka Gameda *et al.*, 2022). To address these challenges, aquaculture has emerged as a viable additional sector for sustainable food production (Kassaye Balkew & Bereket Haji, 2022).

To diversify aquaculture technologies, integrated fish farming, which incorporates organic nutrient sources, emerges as a promising model for sustainable food production (Solomon Melaku and Natarajan, 2019). This integrated approach not only enhances productivity and profitability but also contributes to sustainable resource utilization, offering a practical solution to the pressing concerns of waste management and environmental pollution. Some studies on integrated aquaculture systems have been conducted by various authors. For example, Belay Adugna *et al.* (2016) studied the integration of fish production with vegetables such as tomato and onion. Daba Tugie *et al.* (2017) explored the integration of fish with onion, while Teklay Gebru (2022) focused on integrating fish with beetroot and carrot.

Additionally, Dinku Getu *et al.* (2017) and Lemma Abera (2017) investigated the integration of fish with chicken and vegetables. However, these studies primarily focused on the positive effect of fish pond water on vegetable growth and did not explore how this farming system added value to the existing fish farming in terms of soil fertility, profitability, and income diversification.

Furthermore, the previous studies did not compare the performance of fish pond water with the application of other fertilizers. To improve the development of this system there is a need to increase research and development efforts in integrated fish farming and the value that has a vital role in increasing food production, profitability, and income diversification within an integrated system. In this regard, the current study was conducted to evaluate integrating the *O. niloticus* farming system with vegetables Swiss chard, (*Beta vulgaris L. var. cicla*) a strategy to enhance food production, profitability, and income diversification.

1.3. Objectives

1.3.1. General objective

The general objective of this study was to evaluate integrating a fish farming system with vegetable as a strategy to enhance food production, profitability, and income diversification.

1.3.2. Specific objectives

The specific objectives of this study were:

- To assess the contribution of fish farming practice (integrated and non-integrated) to food production, and income diversification in five districts of Sidama Regional State.
- To measure the growth parameters and survival rate of *O. niloticus* reared in a fertilized pond with a supplementary diet made from locally available ingredients.
- To evaluate the growth performance, yield, and soil properties of Swiss chard irrigated with fish pond water and fertilized with chemical fertilizer, compost, and black soldier fly larvae frass fertilizer.
- To identify and quantify the phytoplankton composition in the pond water and the stomach contents of *O. niloticus*.

- To conduct a cost-benefit analysis of the integrated fish-vegetable system using chicken manure as pond fertilizer.

1.4. Research questions

The following research questions were formulated to address the above prime objectives of the research.

- How does fish farming practice contribute to food production and income diversification?
- What is the growth performance of *O. niloticus* reared in a fertilized pond with a supplementary diet made from locally available ingredients?
- What is the effect of using fish pond water on vegetable growth performance, yield, and soil fertility compared to chemical fertilizer, compost, and black soldier fly larvae frass fertilizer?
- What is the abundance of phytoplankton in the fish pond and which specific phytoplankton groups are preferred and consumed by the fish?
- What is the productivity and profitability of integrating fish farming with vegetable production?

1.5. Significance of the study

The survey component of this thesis has significant importance as it aims to provide information on the current state of fish farming practices, both integrated and non-integrated, within the surveyed districts. Additionally, it offers valuable insights and guidance for further development of these systems. It also gives information about the challenges faced by fish farmers to relevant governmental offices and research center like CARE, to improve fish farming practices by addressing these issues. Field experiments were conducted alongside the survey to provide local, real examples of how vegetable production and fish farming could be effectively integrated, and how much this integration would affect the production efficiency of the systems. By combining field experiments with farmers' surveys, this research aims to guide the design of future integrated fish farming systems, demonstrating their feasibility in terms of yield potential, economic profitability, and soil fertility.

1.6. Scope of the study

This study encompassed both a survey and a field experiment. The survey aimed to assess the status of fish farming, including productivity, profitability, and constraints in five districts of Sidama Regional State. The field experiment focused on comparing the effects of pond water with chemical fertilizer, compost, and black soldier larvae fly frass fertilizer, on soil fertility, growth performance, and yield of vegetables. Additionally, it aimed to determine the growth performance of *O. niloticus* when reared in a fertilized pond with a supplementary diet. Phytoplankton are microscopic algae that live in the water and produce oxygen through photosynthesis. They are also a source of food for many fish species, especially herbivorous and omnivorous ones like *O. niloticus*. The abundance and composition of phytoplankton in the fish pond can affect the growth and health of the fish, as well as the water quality parameters such as pH, dissolved oxygen, and transparency. Therefore, the study also aimed to analyze the phytoplankton in the pond water and the fish stomach to understand the role of phytoplankton in the integrated fish farming system. Furthermore, the study covered the productivity and profitability of integrating fish farming with vegetable production.

1.7. Limitation of the study

The study did not include analysis of all soil parameters that could affect vegetable growth and yield. The soil analysis specifically focused on key nutrients associated with soil fertility, such as nitrogen, phosphorus, potassium, soil organic carbon, organic matter, exchangeable cations, electrical conductivity, and soil pH. However, certain parameters, including soil texture, cation exchange capacity, and microbial biomass, were not included in the analysis. Furthermore, the study did not analyze the nutrient content and chlorophyll levels in the fish pond water. This aspect is of significant importance as it allows for the measurement of the nutrient load applied to the soil through irrigation and serves as an essential indicator of algal biomass, especially phytoplankton. These limitations were primarily attributed to the unavailability of necessary laboratory equipment and budget constraints, which prevented the inclusion of all desired analyses in the study. Additionally, the analysis of water quality parameters was also limited to pH, temperature, transparency, and dissolved oxygen.

2. LITERATURE REVIEW

2.1. Fish production and their contribution to food security

Fish supply the general community as well as the households of fishermen with food and protein. For over a billion people worldwide, fish is their primary source of animal protein, and their dependence on fish is typically higher in coastal regions. Since the majority of inland fish production is used for local or subsistence consumption, inland fisheries are especially crucial for the food security of poor people (Funge-Smith & Bennett, 2019). Fish is an important source of food for people, contributing about 17% of animal protein intake and 7% of all protein consumed by the world's population (FAO, 2014). More than 10% of the global population depends on fisheries and aquaculture for their livelihoods. Fish consumption is increasing significantly, having risen from 86 million tons in 1998 to 152.9 million tons in 2018 (Marwaha *et al.,* 2020).

The increased fish consumption is related to the growing human population in many countries such as Africa, Asia, and Latin America, which implies the importance of a consistent supply to meet the nutritional and financial demands of a large portion of the world's population. However, in recent years, capture fisheries have been unable to keep up with the rising demand for fish, and many fisheries are currently in a stagnant or even declining stage (Ye & Gutierrez, 2017). Additional means of producing fish must be developed to maintain a sufficient supply of food for an ever-growing population. Aquaculture provides one way to supplement the production of wild capture fisheries and it will continue to increase in importance as demand increases in the future (Costa-Pierce *et al.,* 2021).

Aquaculture is not a new practice, even though the global community has only recently recognized it as a potential answer to the problem of depleting water bodies. From 25.7%

in 2000, aquaculture's contribution to the world's fish production increased to 46% in 2018. Regionally, the contribution of aquaculture to total fish production was about 17.9% in Africa, 17.0% in Europe, 15.7% in the Americas, and 12.7% in Oceania. The highest aquaculture contribution to fish production in 2018 was reported from Asia (Excluding China), reaching 42%, rising from 19% in 2000 (FAO, 2020).

In general, the global aquaculture sector is considerable and provides significant contributions to poverty alleviation and food security primarily through nutritional benefits from the consumption of fish, income to those employed in the sector, and the generation of revenues from exports, taxation, license fees, and from payment for access to resources by foreign investment in aquaculture (Allison, 2011).

2.2. The concept of integrated aquaculture

Integration occurs when outputs (usually by-products) of one production sub-system are used as inputs by another, within the farm unit. Recycling animal wastes (faeces and urine) to serve as fertilizers and sometimes as food for fish in fish ponds is the aim of integrated agro-aquaculture (Farrant *et al.,* 2021). Promoting the integration of aquaculture into existing farming systems has been used as a sustainable alternative to food production, improving food security, and preserving the environment. IAA may be able to help increase food security and reduction of poverty through a source of income for poor farmers, and increase the availability of cheap animal protein for poor consumers (Prein & Ahmed, 2000).

The essential component of integrated fish farming is on-farm waste recycling, which is extremely beneficial to farmers because it boosts production efficiency and reduces the negative environmental impact of farming. Integrated fish farming can serve as a model for sustainable food production by ensuring certain principles. These include utilizing waste products from one biological system as nutrients for a second biological system, adopting mixed farming of fish and plants to achieve polyculture and increase yields of multiple products, implementing water reuse through recirculation, and promoting local food production to enhance access to healthy foods and enhances the local economy (Zajdband, 2011).

In IAA systems, aquaculture typically involves the cultivation of fish species that feed at lower trophic levels, such as herbivores or omnivorous species like tilapia, carp, and catfish. The local environment and prevalent factors, such as the availability of fish feed and seeds, facilities, and management practices, often influence the choice of cultivated species (Bostock *et al.*, 2010). Particularly, tilapia is one of the fish that may be produced in IAA systems without the need for sophisticated technology, even in remote regions.

2.3. Status of integrated aquaculture in the world

Today's economy is mostly based on the fields of agriculture and information technology software development. The availability of water for agricultural productivity is drastically declining as water demand from households and industries increases. For this reason, increasing the productivity of water through varied farming systems has been suggested (Tipraqsa *et al.*, 2007). The potential for integrating aquaculture with agriculture (IAA) can increase the efficiency of input utilization, diversify output and economic opportunities, and provide smallholder producers with the tools to sustain and improve their livelihoods. The goal of an integrated farming system is to link the various farming system components together to create synergies that allow one farming system's output to be used as input by another farming system, thereby efficiently using both water and land (CARDI, 2010).

Integrated aquaculture production system is implemented in different parts of the world and it has a very long history with the aim of enhancing fish production, minimizing fish production costs, protecting the environment from pollution and waste management, increasing income, and generating fish feed from waste materials (Prein, 2002). China is a leading country in advanced integrated fish farming technology, followed by Hungary, Germany, and Malaysia (Sorathiya *et al.,* 2014). In Southeast Asian countries, integrated agro-aquaculture production systems have been largely developed as a vital source of plant and animal protein (Lin *et al.,* 2001).

While the utilization of these concepts and their practical application has traditionally been prominent in Asia, there has been a notable interest from various regions, particularly Africa. Since 1983, The World Fish Center (formerly The International Center for Living Aquatic Resources Management, ICLARM) has played a key role in the development of IAA strategies in Africa (Brummett & Jamu, 2012). In Africa, the integrated aquaculture production system is not well developed and the traditional aquaculture primarily practiced in Egypt and Kenya was the starter of the modern one (Gupta & Acosta, 2004). The implementation of integrated aquaculture-agriculture systems in Malawi and Nigeria has produced promising results in terms of reducing poverty and alleviating malnutrition (Solomon Melaku & Natarajan, 2019).

Integrated fish farming holds a significant potential method of food production that can address problems facing vulnerable farmers however its adoption and practice in Ethiopia are currently limited and a few attempts at integrating fish farming with crop cultivation have been conducted (Daba Tugie *et al.,* 2017). To increase the productivity of the entire integrated system, ongoing research is required since integrated aquaculture is not widely practiced in the countries.

2.4. The role of integrated aquaculture in food security

Food consumption, particularly the demand for protein, will rise as the world's population increases. In the face of current population growth, agricultural production which includes aquaculture and fisheries is essential for maintaining food security (Finegold, 2009). It is essential to increase food production to achieve a balance between the growing human population and food availability and to ensure global food security. In this regard, the sustenance of increased productivity must emphasize the development of strategies aimed at improving yield through rational utilization of resources and proper environmental management like integrated aquaculture (Channabasavanna *et al.,* 2010).

One of the undeniable methods for increasing food production by simultaneously maintaining an equitable use of the available land and human resources to meet human food demands in an environmentally friendly way is the integration of aquaculture with crop production and animal husbandry. This is because integrated aquaculture productivity has been shown to relatively lower production costs (Ugwumba *et al.,* 2010), thus the sustenance of increased farmer income and nutrition. To improve the food security of the human population, there is a need for farmers to engage in a result-oriented farming system that can guarantee and sustain adequate food security in an environmentally sustainable manner (Onada & Ogunola, 2016).

The diversification of integrated agriculture-aquaculture (IAA) is only effective when the amount of investment required (e.g., pond construction, feeds, and fertilizer) is low and the use of already-existing on-farm and near-farm resources can be maximized, for instance through residue recycling. These small-scale IAA agricultural techniques are seen to offer significant potential to aid the rural poor economically and nutritionally (Prein & Ahmed, 2000).

Aquaculture that is integrated can provide and maintain appropriate food security in an environmentally friendly manner. It is a diversified and coordinated way of farming with fish as the main target along with other farm products. IAA can significantly increase food availability and hence improve food security. In addition to production enhancement, integrated fish farming also gives a platform for managing environmental integrity through waste recycling and utilization (Onada & Ogunola, 2016). Overall, integrated aquaculture systems offer a sustainable and efficient approach to food production that can increase food security by diversifying production, optimizing resource utilization, increasing productivity, enabling local food production, and enhancing climate resilience.

2.5. Economic and ecological role of integrated aquaculture

The economic benefit of integrated fish farming is significant. It contributes to substantial economic empowerment for households, especially in rural areas, and makes it possible for farmers to be productive throughout the year, providing the different components of the farming system to the farmer (Crissman & Antle, 2013). In integrated systems, many crop byproducts are utilized as animal feed, while fish and animal excrement are returned to the crops. Fish can also help control insects and weeds in the rice fields surrounding the ponds. Furthermore, when the pond water is used for crop irrigation, it enhances nutrient availability for the crops. The ecological effectiveness of integrated fish farming is vital for the overall success of the agricultural operation and distinguishes it from several other agricultural production systems due to its synergistic and mutually beneficial approach (Edwards *et al.,* 2000).

All modern, large-scale food systems have observable effects on the environment and society. Even the sustainability of modern, large-scale, organic agriculture has been questioned. The sustainability of ecological parameters in any agroecosystem is very important in determining the success of the farming venture. The Brundtland Commission (Browne *et al.,* 1993) defined sustainable development as the ability to meet the needs of the present without compromising the ability of the future generation to meet their own needs.

Poorly managed integrated systems typically experience significant nutrient loading, resulting in cyanobacterial blooms (Paerl & Tucker, 1995). Conversely, well-managed systems demonstrate the opposite effect, with relatively low to zero waste output. These well-managed aquaculture systems aim to preserve and enhance the social and natural settings in which they operate, thereby promoting ecological sustainability. Practical ecological approaches are employed in the development of aquaculture production methods for various integration systems, including the utilization of local resources, efficient recycling of waste and materials that could harm natural ecosystems, appropriate job creation planning, and the implementation of marketing strategies that satisfy both economic and ecological considerations (Gabriel *et al.*, 2007).

2. 6. Integration of fish with vegetable production

Vegetables play a crucial role in human nutrition and overall well-being. They are packed with essential nutrients, vitamins, minerals, and dietary fiber that are vital for maintaining a healthy diet. Vegetables are particularly rich in vitamins such as vitamin A, vitamin C, vitamin K, and folate, which are essential for supporting various bodily functions, including immune system support, vision, and cell growth (Boeing *et al.,* 2012). Fish-vegetable farming, also known as integrated fish farming, is an innovative and sustainable agricultural practice that combines fish rearing with vegetable cultivation. In Ethiopia, this farming method holds great potential for addressing food security challenges and promoting economic growth (Mohammed Ibrahim *et al.,* 2016). Various vegetables have been identified as suitable candidates for integration with fish farms, including onions such as Baro and Red Bombay, different types of cabbage such as Chinese cabbage and round cabbage, tomatoes, potatoes, and others.

In a fish-vegetable farming system, fish are reared in ponds, tanks, or cages, while vegetables are grown nearby. The nutrient-rich water from the fish pond is used to fertilize and irrigate the vegetables, creating a mutually beneficial relationship between the fish and plants (Hasimuna *et al.,* 2023). This farming technique offers several advantages to farmers. Firstly, it maximizes the use of limited land resources, making it ideal for small-scale farmers with limited space. By utilizing vertical space, farmers can grow both fish and vegetables in the same area, increasing productivity and income potential. Secondly, fish-vegetable farming provides a sustainable source of protein through fish production (Nnaji *et al.,* 2004). Ethiopia, being a landlocked country, faces challenges in accessing affordable and nutritious protein sources. By integrating fish farming, farmers can meet local protein demands and contribute to improved nutrition in their communities.

Furthermore, this farming system promotes the efficient use of water resources. The water that circulates between the fish pond and vegetables is recycled, reducing water consumption compared to traditional farming methods (Abdul-Rahman *et al.,* 2016). Fish vegetable farming also has environmental benefits. The fish waste acts as a natural fertilizer, eliminating the need for synthetic fertilizer.

In general, fish vegetable farming offers a promising solution to enhance food security, promote sustainable agriculture, and improve livelihoods in Ethiopia. By integrating fish farming with vegetable cultivation, farmers can maximize land use, conserve water resources, and provide a sustainable source of protein.

2.7. Nile tilapia (*O. niloticus*) as a candidate for aquaculture

Aquaculture plays a great role in the production of high-protein food and is a rapidly growing sector. In 2015, global tilapia production reached an impressive 5,576,800 tonnes confirming the significant contribution of tilapia to global food security (Fitzsimmons, 2016). Among the various tilapia species, *O. niloticus* has the potential to become the world's leading farmed fish species (Fitzsimmons *et al.,* 2011). Over the past three decades, there has been a consistent and remarkable expansion of this species, leading to its contribution in 87 countries globally with an estimated production of 4.2 million tonnes in 2016 (FAO, 2018).

This particular freshwater species possesses all the necessary qualities for successful and cost-effective farming on a global scale. It is known for its ease of breeding and growth, adaptability in terms of feeding, and low-tech farming requirements (Jarding *et al.*, 2000). In addition to the above-mentioned advantages, *O. niloticus* offers several benefits. It can adapt to a wide range of environmental conditions, allowing for cultivation in diverse areas. The species is known for its ease of propagation, enabling efficient and quick multiplication.

Furthermore, *O. niloticus* demonstrates tolerance to stress in handling as compared to other cichlid species. It has also an excellent food conversion ratio and readily accepts artificial feed, resulting in efficient utilization of resources (Azaza *et al.,* 2009). Its diet primarily consists of phytoplankton, representing the lower level of the food chain. The ability to utilize natural food including plankton is an important quality of *O. niloticus* and is suitable for integrated aquaculture. Since the main aim of integrated aquaculture is to minimize input costs especially, feed costs.

2.8. Physicochemical parameters of water in fish pond

Aquatic organism composition, distribution, and abundance are all influenced by the physical and chemical qualities of water. These interactions also provide insight into how species interact with their environments and can be used to assess the water quality and productivity of a water body. Physicochemical attributes of water would assist in discovering the design and function of the water environment to its living organisms because the presence of certain chemical components in water may have an impact on its biotic component (Mustapha & Omotoso, 2005).

The presence or absence of a given element in an aquatic habitat can be a determining factor in the general productivity of that water body, it could also determine the category of living organisms that might be present in the water body (Ajibade *et al.,* 2008). Fish require high-quality water throughout their whole lives because it meets their basic needs for breathing, eating, growing, and reproducing. Therefore, the appropriate equilibrium of the physical, chemical as well and biological components of a water body is a vital requirement for effective fish production.

2.8.1. Temperature

Temperature refers to the level of heat or coldness present in the body of a living organism, whether it is in water or on land. Since many biological and chemical processes are temperature-dependent, it is a crucial physical characteristic in an aquatic environment. It is one of the environmental factors influencing fish survival and growth (Hart & Reynolds, 2002). When water temperature increases, the evaporation, and volatilization of chemical substances also increase, but conversely the solubility of gases such as oxygen decreases, the respiration rate of aquatic animals increases, as well as the decomposition of organic matter that requires oxygen (Portner *et al.,* 2005).

Each fish species has a certain range of optimum temperatures where it performs best in terms of growth and survival. Since fish is a cold-blooded animal, directly affected by the rearing water temperature, which is reflected in the fish's body temperature, feed intake, feed utilization, growth performance, digestion, metabolism, and reproductive activity (Pandit & Nakamura, 2010). According to Haque *et al.* (1984), several species suffered when exposed to temperatures below 12ºC and warm-water fish species exhibited optimal survival and growth when the water temperature exceeded 18ºC. In ponds with temperatures ranging from 24 to 30°C, *O. niloticus* shows better growth performance (Santhosh & Singh, 2007).

2.8.2. Dissolved oxygen

In terms of water quality, dissolved oxygen concentration (DO) is regarded as being the most crucial factor in fish farming. It is essential to the survival (respiration) of fish, to sustain healthy fish and bacteria that decompose the waste produced by the fish, and to meet the biological oxygen demand (BOD) within the culture system. Dissolved oxygen levels can affect fish respiration, as well as ammonia and nitrite toxicity (Boyd & Hanson, 2010). The oxygen level will enhance growth rates, lower the food conversion ratio, and increase overall fish production if it is kept around saturation or even slightly supersaturation at all times (Mallya, 2007).

The dissolved oxygen concentration should be maintained around saturation for optimal physiological and general health conditions. When the levels are lower than the optimum, the growth of the fish can be highly affected by an increase in stress, tissue hypoxia, a decrease in swimming activities, and a reduction in immunity to diseases (Conte, 2004). *O. niloticus* is well-known for its ability to tolerate hypoxic and even anoxic conditions for short periods. However, for optimal growth, it is preferable to maintain a dissolved oxygen

(DO) level above 5 mg/L (Boyd & Hanson, 2010). Overall, fish growth and yields are greater in ponds with higher dissolved oxygen concentrations.

2.8.3. pH

The pH of water is a universal measure used to indicate the acidity or alkalinity of a solution. It quantifies the concentration of hydrogen ions in the water, which determines its level of acidity or alkalinity. The pH scale ranges from 0 to 14, with 7 representing a neutral state. A pH value below 7 indicates acidity, whereas a pH value above 7 indicates alkalinity. This pH measurement provides a standardized way to express the intensity of the acid or alkaline condition of a solution (Buck *et al.,* 2002). The pH of the water in fish ponds varies during the day, just as the concentration of oxygen.

It increases from dawn to mid-afternoon, as microalgae (phytoplankton) remove carbon dioxide from the water during photosynthesis. The decrease in carbon dioxide concentration throughout the day decreases the concentration of H+ ions and increases that of OH- ions, making the water more alkaline. The more phytoplankton there is in the pond, the more the pH varies throughout the day (Mustapha, 2020). The physiology of aquatic animals can be strongly influenced by the pH of the water. Aquaculture fish may be affected by stress and abnormal growth due to the water's level of acidity and basicity.

Important metabolic indices in fish, such as the concentrations of glucose, glycogen, and lactate, might change as a result of acid-base disturbances in blood and body fluids (Bolner *et al.,* 2014)**.** The ideal pH range for aquaculture water is typically 6.5 – 9.0 (Boyd *et al.,* 2016). According to Stone and Thomford (2004), the optimal pH range for the growth of *O. niloticus* is between 6.5 and 9.5. Within this range, the conditions are most favorable for the growth and development of this species. However, *O. niloticus* can tolerate a wider pH range, and the acceptable range for survival and well-being is reported to be between 5.5 and 10.

2.8.4. Water transparency

The first-order indication of water quality is water transparency (or clarity), which is typically measured as the Secchi disk depth. It is related to the light penetration and its attenuation in the underwater ecosystems which plays an important role in understanding water ecology environment variations and biogeochemical processes, such as phytoplankton photosynthesis (Bai *et al.*, 2020). Water transparency is typically measured using a tool called a Secchi disk. A Secchi disk is a circular disk, typically painted with alternating black and white quadrants, that is lowered into the water until it is no longer visible.

The depth at which the disk disappears is referred to as the Secchi depth and is used as an indicator of water transparency. Water transparency, as determined by the visibility of a Secchi disk, often exhibits a strong correlation with plankton density in various water bodies. As plankton density increases, the visibility of the Secchi disk tends to decrease. Boyd (1998) has provided insights specific to ponds, stating that if the Secchi depth is less than 20 cm, the pond is considered turbid, which can lead to issues such as low dissolved oxygen concentration. On the other hand, if the Secchi depth falls within the range of 30-45 cm, the turbidity is considered favorable for fish production.

2.9. Role of plankton in fish pond

Due to natural fisheries reaching their maximum degree of exploitation, aquaculture will be looked to for additional supplies as the market for fish, crustaceans, and other aquatic animals grows. The plankton community comprises phytoplankton and zooplankton. Phytoplankton are tiny, free-floating aquatic plants that form the base of the aquatic food chain and act as primary producers in any aquatic ecosystem (Boyd, 2016). Phytoplankton communities play a vital role as a fundamental component in the majority of pond aquaculture systems. Primary production by phytoplankton is the base of the food chain in pond cultures that depend upon natural foods to support fish production (Lindsey *et al.,* 2010).

Algae and bacteria activities control the water's oxygen concentration in the majority of aquaculture ponds. During the day, algae produce oxygen and bacteria are frequently the primary cause of respiration. In extensive, semi-intensive, and some intensive aquaculture systems, bacteria also contribute significantly to the food web. They may be eaten directly by the cultured species (e.g., tilapia or mullet) or by small animals on which the cultured species feed (e.g., in the culture of penaeid prawns) (Moriarty, 1986).

Manures or chemical fertilizers can be intentionally added to ponds to enhance the growth of phytoplankton. In tropical semi-intensive aquaculture, organic fertilizers have been traditionally used. When introduced to ponds, these fertilizers can ultimately increase fish yields through soluble and particulate pathways. For instance, they release soluble nitrogen (N) and phosphorus (P) that stimulate algal production. The resulting algae can be directly consumed by fish or serve as a food source after being processed by zooplankton or microbes (detritus formation) (Colman & Edwards, 1987). While the application of manure enhances plankton productivity, it is important to note that exceeding a certain limit can lead to water quality deterioration, and the presence of algal toxins can pose problems in both vertebrates (fish) and invertebrates (Das & Jana, 2003).

2.10. Swiss chard (*Beta vulgaris cicla*)

The awareness of the health benefits arising from vegetable consumption, together with increased incomes, creates a rise in market demand for fruits and vegetables as consumers seek to diversify their diets. Green leafy vegetables (GLVs) are low in energy but comparatively high in micronutrients and currently advised for consumption in the daily diet. Experimental studies show that increased consumption of green vegetables can prevent coronary heart disease by preventing the growth of atherosclerosis (Sener *et al.*, 2002). Swiss chard (*Beta vulgaris cicla*), an edible plant of the Chenopodiaceae family, is considered one of the GLVs. The plant has broad, fan-shaped green leaves and a thick, crunchy stalk that can be white or colored. The leaves can be eaten raw in a salad or cooked with stems in a similar way as spinach (Gamba *et al.*, 2021).

Swiss chard plays a crucial role in food security and holds significant socioeconomic value. It is a nutritional powerhouse, offering substantial amounts of magnesium, potassium, iron, and dietary fiber. Additionally, it serves as a rich source of vitamins K, A, and C. Consuming Swiss chard has been associated with a reduced risk of age-related macular degeneration, glaucoma, and cataracts (Kubala *et al.*, 2022). Vitamin A is essential for the appropriate development and maintenance of organs such as the heart, lungs, and kidneys. Swiss chard provides three times the daily required amount of vitamin K and 44% of the daily recommended amount of vitamin A (Laura, 2022).

Swiss chard has been found to have various health benefits, including the reduction of blood pressure, potential cancer-fighting properties, and improvements in sports performance. It contains flavonoids called syringic acid, which are known to support healthy liver function, prevent liver degeneration, and lower liver enzymes in the blood (Julie, 2011). Due to the above-mentioned importance, the present study also chose this vegetable to integrate with *O. niloticus*.

2.11. Pond water and black soldier fly larvae frass fertilizer as organic fertilizer

Traditionally, the water used in aquaculture (fish farming) was disposed of, but this practice has changed. Recent research on plant development using fish pond water has revealed potential advantages. Aquaculture relies on a continuous supply of fresh water from rivers and other water sources. However, discharging fish pond waste into these sources can negatively impact water quality and the fish reared in the aquaculture system (Amankwaah *et al.,* 2014).

The discharge of fish pond water and sediments into natural systems poses a threat to the ecosystem, leading to increased nutrient load, contamination, and pollution. However, it is important to note that these discharges also represent wastes of valuable nutrients (Muendo *et al.,* 2014). In land-based fish production, significant amounts of expensive water exchange and subsequent recirculation of treated water may be employed to regulate water quality (Bregnballe, 2022). Integrated fish farming offers a promising approach to mitigate nutrient discharge and enhance profitability. The focus is on achieving optimal waste or byproduct utilization, where waste from one subsystem serves as an input for another subsystem (Lemma Abera, 2017).

The application of fish pond water often provides benefits to plants in terms of irrigation and fertilization (Valencia *et al.,* 2001). Maia *et al*. (2008) found that the application of fish pond water increased the development of lettuce plants by meeting their nutritional and water needs. Fish pond water contains abundant nitrogen and other elements that are essential for plant health and growth. However, if the water is not regularly removed and replaced with fresh water, the nutrient-rich water can become harmful to fish. Utilizing fish pond water that is enriched with manure can enhance production and yield. This nitrogen, phosphorus, potassium, calcium, and magnesium-rich water efficiently promotes high growth and productivity in plants (Payebo & Ogidi, 2020).

Boyd *et al.* (2002) also reported that fish pond sediment, which accumulates during fish culture, is rich in organic matter, nitrogen, and phosphorus. However, the accumulation of organic waste is undesirable as it can lead to the release of harmful substances such as hydrogen sulfides and nitrites, which can have detrimental effects on fish growth. High deposition of organic matter in fish ponds can also result in increased oxygen demand and oxygen depletion, both of which can impact fish yields. Recycling, as a strategy for minimizing waste, offers several benefits. Firstly, it decreases the demand for new resources. Secondly, it reduces the costs associated with transportation and the production of energy. Lastly, it allows for the utilization of waste that would otherwise be released into rivers and streams as contaminants (Tam, 2008).

The black soldier fly (BSF) (*Hermetia illucens, L*) is an effective recycler of organic waste into nutrient-rich organic fertilizer for crop production and soil health management (Beesigamukama *et al.,* 2020). According to Commission Regulation (EU) 2021/1925, frass is a mixture of excrements originating from farmed insects, the feeding substrate, pieces of farmed insects, and dead eggs, with a maximum content of 5% in volume and 3% in weight of dead farmed insects (Elissen *et al.,* 2023). The composition of the produced frass varies depending on the substrates used. It contains organic materials, chitin (from the skins of the larvae), and significant amounts of nitrogen (N), phosphorus (P), and potassium (K). Frass can be utilized directly or composted as fertilizer or soil conditioner (Hol *et al.,* 2022). Similar to vermicompost (produced by earthworms digesting organic substrates), frass can impact soil fertility by influencing soil enzymes and bacterial growth.

3. MATERIALS AND METHODS

3.1. Description of the study area

The study was conducted at the Centre for Aquaculture Research and Education (CARE), situated at the experimental site of Hawassa University in the Sidama Region, Ethiopia (Figure 1). The center offers various community services, including the distribution of fish fingerlings to model farmers in different districts of the Sidama Region. Additionally, it provides free services to MSc and PhD students specializing in Aquatic Sciences, Fisheries, and Aquaculture fields.

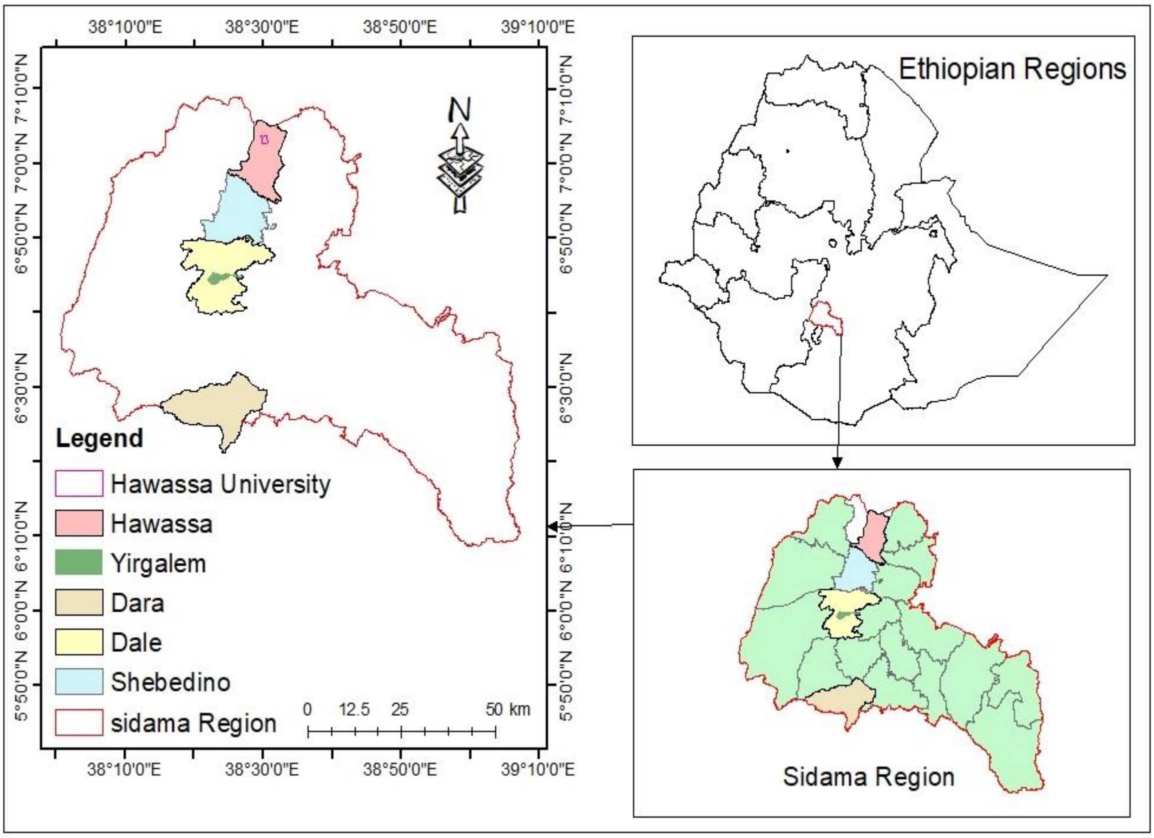


Figure 1. Location map of the experimental site

The site is located 275 km to the South of Addis Ababa, the capital city of Ethiopia. It is located at 7°3'7" N latitude and 38°3'17" E longitude, and the study area has a mean altitude of 1721 m above sea level. The experiment was carried out from February 2023 to

May 2023. The survey study was conducted in five districts of the Sidama Region (Shebedeno, Dale, Yirgalem, Dara, and Dara Otilcho).

3.2. Research design and sampling procedure

3.2.1. Survey study

In the first phase, a cross-sectional survey was carried out in five districts namely Shebedeno, Dale, Yirgalem, Dara, and Dara Otilcho, in the Sdiama region, Ethiopia. The selection of these districts was purposive, based on the criteria of having fish farming practices (IAA and non-IAA). Due to the manageable size found in all districts, all fish farmers involved in fish farming practices were selected for the survey study. The survey was conducted through direct observation, five key informant interviews from each district, and informal interviews of 78 households. Interviewer-administered questionnaires were used to assess the contribution of fish farming, including integrated fish farming systems, to productivity, and profitability. Additionally, the study was aimed to assess the constraints that affect fish farming practices and the farmers' perception regarding future plans for the system. Key informant interviews and field observations were primarily used to cross-check some of the data collected through questionnaires, especially regarding constraints, fishpond characteristics, and management activity. This helped to understand and ensure the idea between reality and what participants said.

Figure 2. Field observation and farmer interview on the fish farming system

The survey questionnaire used in this study was designed to collect data on various aspects of fish farming practices and economic factors. The questionnaire is composed of four sections. The first section focused on the demographic and socioeconomic characteristics of fish farmers, including age, gender, education level, and family size. The second section collected data on fish pond characteristics such as pond size, pond depth, pond ownership, and water source, species farmed. The third section explored fish pond management practices and production including pond fertilization method, feed and feeding regimes, integration practices, and the purpose of the yield. Finally, the fourth section assessed the cost and returns associated with fish and integrated crop production including expenses such as pond construction, labor, fingerling, water, transport, feeds, seeds, fertilizers, and net income.

3.2.2. Experimental design

During the second phase of the study, a field experiment was conducted to integrate *O. niloticus* production with vegetable cultivation. For this experiment, a pond was prepared to stock *O. niloticus* fingerlings and vegetable plots were designed adjacent to the fish pond. The experiment was laid out in a randomized complete block design (RCBD) with three replications (Figure 3). A total of 15 plots with 2 m × 2 m size were prepared on 96 m² land including space between block and plot and randomly assigned into five treatments. The treatments were: treatment 1 (T_1)- the plot treated with compost, treatment 2 (T_2)- the plot treated with chemical fertilizer, treatment 3 (T_3)- the plot treated with black soldier fly larvae frass fertilizer treatment 4 (T_4)- the plot treated with tap water (control) and treatment 5 (T_5)- the plot treated with pond water (Table 1).

Table 1. Treatment design for vegetable production

Code	Treatments
T1	Compost (20 t/ha) (Law-Ogbomo *et al.*, 2012)
T2	Chemical Fertilizer (100 kg/ha) (Dinku Getu *et al.*, 2017)
T3	Black Soldier Fly larvae Frass Fertilizer (BSFFF) (10.3t/ha) (Abiya *et al.*, 2022)
T4	Tap Water only (control)
T5	Pond Water

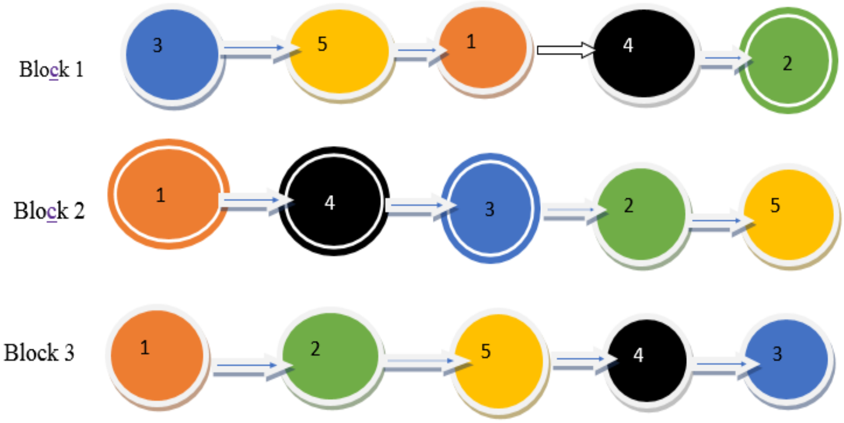


Figure 3. Experimental design of the vegetable plot (RCBD)

Figure 4. Land preparation for growing vegetable seeds

3.2.3. Pond fertilization and supplementary feed preparation

The pond was fertilized with chicken manure, at a rate of 0.1kg/m² (Mlelwa, 2016). After drying and crushing, the manure was distributed equally in the pond every two weeks. In addition, 30kg of supplementary fish feed was formulated from locally available ingredients such as maize (18.3%), wheat (27.5%), bone meal (20.8%), and soya bean (33.4%). The ingredients were ground into flour by a milling machine, mixed, and then pellets were prepared using a pelletizer machine (HOBART, 4812) (Figure 5). The daily feed requirement was determined based on the average weight calculated from the initial sample of weight measurements. It was calculated based on 4% body weight of fish (El-Sayed, 2013) and fed two times per day. The feeding schedule was in the morning from 9:00 A.M. to 10:00 A.M. and in the afternoon from 4:00 P.M. to 5:00 P.M.

Figure 5. Supplementary feed preparation process

3.2.4. Fish stocking and vegetable growth

A total of 150 mixed *O. niloticus* fingerlings, with an average weight of 9.8 g and average length of 10.7 cm, were stocked in a pond measuring 10m x 8m x 1.70m in size. The stocking density was 2 fingerlings per square meter (Shoko *et al.,* 2011). The fingerlings used for stocking were obtained from the experimental site of the Centre for Aquaculture Research and Education (CARE), Hawassa University, located in the Sidama Region of Ethiopia. The fish were reared in the pond for four months.

The vegetable chosen for evaluation was Swiss chard due to its adaptability to various soil types and its ability to tolerate hot climate conditions (Drost, 2020). The seeds of the Swiss chard variety Ford hook Giant were purchased from a seed supplier in Hawassa city. To facilitate nutrient accumulation in the fish pond for vegetable growth, the cultivation of Swiss chard started one month after fish stocking. During the seedling, three Swiss chard seeds were initially sown per planting point, and later thinned to one plant per point (Mulokozi, 2021). The vegetable was planted in five treatments, each with 3 replications. The space between the block, plots, row, and each seedling was 1m, 50cm, 40 cm, and 30 cm, respectively. Five rows per plot and six plants per row with a total of 30 plants per plot were established.

After proper preparation of the land, compost, and inorganic fertilizer was applied at the seedling stage of Swiss chard. Additionally, black soldier fly larvae frass fertilizer was applied one week before the seedling to the soil using the row application method. For irrigation, tap water at a rate of 300 L/plot/week was applied once a day in the evening for all treatments except for the plot that was treated with fish pond water. In the case of the vegetable plots treated with pond water, the same amount of water from the fish ponds was used for irrigation. The vegetable was grown for 3 months and the follow-up and plant management practices remained consistent across all treatments throughout the cropping time, with the only variation being the application of different treatments.

3.2.5. Soil sampling and analysis

The major physicochemical properties of the soil, including soil organic carbon, organic matter, total nitrogen, pH, electrical conductivity, available phosphorus, exchangeable cation (calcium, sodium, magnesium and potassium), porosity, and bulk density were analyzed following the laboratory manual reported by Sahlemedhin Sertsu & Taye Bekele (2000). Soil samples were collected from the experimental site using a soil auger (0-20 cm) and a core sampler (Figure 6). The soil samples were collected randomly from 10 spots within the experimental field for pre-experimental analysis and combined to create a homogenized composite sample, representing the initial soil properties. Similarly, at the end of the experiment, another soil sample was collected from each treatment to evaluate any changes in soil properties resulting from the applied treatments. The analyses of all the samples were conducted in Aquaponics Research Facility of Debre Berhan University.

A glass electrode was used to measure the pH of the soil in a solution made up of soil and distilled water as described by Jackson (1973). The available phosphorus was determined using the Olsen extracting method, following the procedure described by Maria & Jose

(2007). The total nitrogen content of the soil samples was determined using the Kjeldahl method, as described by Belay Adugna *et al.* (2016). The electrical conductivity was determined using the saturated paste method or 1:1, 1:5, and 1:10 soil-to-water ratios. Exchangeable calcium, sodium, and magnesium were determined using atomic absorption spectrometry (AAS), while exchangeable potassium was determined using a flame photometer. The soil organic carbon content was determined following the wet digestion method outlined by Sahlemedhin Sertsu & Taye Bekele (2000). This method involves the digestion of soil samples with potassium dichromate in a sulfuric acid solution. Since soil organic matter contains 58% carbon, the conversion of % carbon to % organic matter was done using the empirical factor of 1.724.

$$\%\ \text{Organic matter} = 1.724 * \%\ \text{Organic carbon}$$

The physical properties of soil such as Bulk density and porosity were also determined using cylindrical core sampling procedures as reported by Sahlemedhin Sertsu and Taye Bekele (2000).

$$\rho b = Wd/\ Vt$$

Where ρb is the bulk density (gcm^3), Wd is the weight of dry soil (g) and Vt is the volume of the bulk soil (cm^3).

The total soil porosity was calculated from the bulk density and particle density values using the Equation:

$$f = (1 - \rho b\ /\rho s) * 100$$

Where f is the total porosity (%), ρb is the bulk density (gcm^3) and ρs is the particle density which is constant ($2.64gcm^3$).

Figure 6. Pre and post-experimental soil sampling in the experimental field

3.3. Data collection

3.3.1. Estimation of growth parameters of *O. niloticus*

The main body measurement parameters of fish such as body weight were recorded twice a month to the nearest 0.1 g with a weighing balance (SF 400A, Electronic Compact Scale). The initial and final length of the fish was also determined using a graduated ruler to the nearest 0.1 cm. The main growth parameters such as daily growth rate, specific growth rate, Fulton's condition factor, and survival rate were calculated using the following formula as cited in (Ashagrie Gibtan *et al.*, 2008).

Average initial weight (g) $=\frac{sum\ of\ individual\ weight\ at\ the\ beginning}{total\ number\ of\ individuals}$

Average final weight (g) $=\frac{sum\ of\ the\ individual\ weight\ at\ the\ end}{total\ number\ of\ individuals}$

Daily growth rate (g/fish/day) $=\frac{average\ final\ weight - average\ initial\ weight}{culturing\ period(days)}$

Body weight gain (g) = Final weight (g) - Initial weight (g)

Specific growth rate (% per day) = $\frac{ln\,final\,weight - ln\,initial\,weight}{culturing\,period(days)}$*100

Fulton condition factor = $\frac{weight}{length^3}$*100

Survival rate (%) = $\frac{final\,number\,of\,fish}{initial\,number\,of\,fish}$*100

3.3.2. Vegetable growth performance and yield

Both vegetative growth parameters and yield were collected using standard procedures. From 30 plants grown on each plot, 12 plants in the central rows were selected by using a lottery method of the sampling procedure for each treatment and tagged for data collection. The vegetative data collection such as plant height (cm), leaves number, leaf width (cm), and leaf length (cm) were measured using a ruler. Leaf area was calculated by multiplying leaf width by leaf length and the product multiplied by the correction factor (0.68). The data collection for vegetative growth parameters started during the 4th week after all the seedlings had reached the desired growth stage for measurement. Measurements were conducted at seven-day intervals until the plants were ready for harvest. At the time of harvest, the yield of each plot from every treatment was weighed using a spring weighing balance. The yields of all the Swiss chard in the five treatments were reported as kg/plot, and kg/ha.

Plant height

The plant height of 12 plants was measured from the leaf apex of the longest green leaf to the bottom of the plant at the soil level by a ruler.

Leaf length

The leaf length of 12 selected plants was measured from the base (end of the sheath) to the tip of the leaf for each plot during each time interval of measurements by using a ruler.

Number of leaves

The number of leaves (every visible leaf including the new ones) of the 12 selected plants from each plot was counted at each interval of data collection.

Leaf width

Leaf width was measured from one side of the leaf to the other side (at the widest part of the leaves) by using a ruler based on the recommendation (Shi *et al.*, 2019).

Leaf area

Leaf area was calculated from the leaf length and leaf width (distance from side to side) using a correction factor of 0.68 (He *et al.*, 2020).

$La = Ll * Lw * 0.68$

Where La is the leaf area, Ll is the leaf length, Lw is the leaf width and 0.68 is a correction factor for the leaf of Swiss chard.

3.3.3. Identification and composition of phytoplankton in pond water

Phytoplankton identification was conducted at monthly intervals to estimate the availability of natural food, as *O. niloticus* is Phytoplanktivorous. Pond water samples were collected using a plankton net with a mesh size of 20 µm (Figure 7). The collected water sample was immediately fixed with 5% Lugol's solution, which serves as a fixative, as recommended by Karlson, (2017). The fixed sample was allowed to settle in the laboratory for 24 hours. Subsequently, phytoplankton identification was conducted using a compound microscope (LEICA DME) with a magnification of 40x. The algal identification key by Janse *et al.* (2006) was used in the drop count method, as described by Ramachandra & Solanki (2007).

Figure 7. Water sampling for phytoplankton identification

3.3.4. Stomach content analysis

At the end of the experimental period, the stomach contents of *O. niloticus* were examined under a compound microscope to identify the dominant phytoplankton consumed by the fish. A total of 35 fish were sampled from the pond, and their weight and length were measured. Subsequently, the fish were dissected, and their stomach contents were carefully examined under 40x magnification. To facilitate examination, the dissected stomach contents were immediately preserved in 5% formalin. After identifying the food categories present in the stomachs, the number of stomachs in which a given food category occurs is expressed as a percentage of the total number of stomach samples. This approach allows for estimating the proportion of fish that feeds on particular food items using the frequency of occurrence method (Hyslop, 1980).

$\mathrm{F}i = \frac{Ni}{n} * 100$ Where F*i*: Frequency of occurrence of the *i-food* item in the sample

N*i*: Number of stomachs in which the *i* item is found

n: Total number of stomachs with food in the sample

3.3.5. Cost-benefit analysis of the system

The economic benefit of integrating fish and vegetables was determined by calculating the difference between total costs and total revenue generated from the integrated system. Total revenue was calculated by considering the income from both vegetable and fish yields. The total costs included expenses for pond maintenance, fertilizer, supplementary feed, purchasing vegetable seeds, labor costs, and land preparation. Net profit was determined by subtracting the total costs from the total revenue. The purpose of this analysis was to evaluate the financial gains obtained from the integrated fish and vegetable production system. The cost-benefit analysis was calculated based on the following formulae as cited in Mlelwa (2016):

Total variable cost is given by the price of unit (input) x quantity (input)

$TVC = Px \times Qx$

Total cost = TVC + fixed cost

Profit = Total revenue – Total cost

Where TVC = Total Variable Cost, P = Unit price of input, and Q = Total quantity of input

3.3.6. Water quality parameter in the fish pond

Throughout the implementation period of the experiment, various water quality parameters, including temperature, pH, transparency, and dissolved oxygen were regularly measured. The measurements were conducted once per week between 10:00 AM and 11:00 AM, as this time overlapped with the sampling of fish weight. Temperature and dissolved oxygen levels were measured using the (HI 9145, DISSOLVED OXYGEN METER), while pH was measured using the pH METERS. Furthermore, the vertical visibility of the pond water was assessed using a locally made Secchi disc to measure the Secchi depth.

3.4. Data analysis

In the survey section, data were analyzed using a statistical package of SPSS for Windows version 25. The results were presented through tables, narratives, percentages, and frequencies. With regard to the field experiment, the collected quantitative data on the growth and yield of vegetables and fish were analyzed using analysis of variance (ANOVA) with the JMP procedure of SAS software Pro13. The Least significant differences (LSD) were used to determine specific significant differences among variables by using Tukey's HSD test. The results were presented and interpreted through the use of tables and figures. Statistical significance was determined at a significance level of $p \leq 0.05$. To test the normality of the data, Shapiro-Wilk test was performed using SAS software. The results showed that the data were normally distributed for all the variables, as the p-values were greater than 0.05. Therefore, ANOVA was appropriate for the data analysis.

4. RESULTS AND DISCUSSION

4.1. Contribution of fish farming practice to food production, and income diversification

4.1.1. Socio-demographic profile of fish farmers

Among the surveyed districts, it was observed that small-scale fish farming was predominantly practiced by male farmers, accounting for 79.5% of the participants, while female farmers contributed only 20.5% (Table 2). This finding aligns with the results reported by Respikius *et al.* (2020), which suggest that aquaculture is often dominated by men due to its labor-intensive nature. Activities such as constructing and maintaining fish ponds, growing vegetables, applying chemicals, and irrigation operations require substantial physical labor, making them challenging for women to handle.

As observed in (Table 2), half of the fish farmers had a low level of education, and 47.4% were illiterate. The findings indicated that 30.8% of the fish farmers received training from Hawassa University (CARE) and the agricultural office before starting their fish farming practice. However, 69.2% of the farmers did not have access to training. According to Yeasmin *et al.* (2013), training provides the farmer with the essential knowledge and skills needed to successfully operate a fish farm. It enables them to understand fundamental principles related to fish farming, such as water quality management, fish nutrition, disease prevention, and environmental considerations. By providing farmers with this essential training, they can enhance their understanding and competence in successfully managing their fish farming practice.

Of the interviewed farmers, the majority (57.7%) were in the age group of 35-44 years, indicating that they were in the active and energetic phase of their lives. The next largest age group was those above 44 years old, accounting for 38.5% of the participants (Table

2). This distribution suggests that the majority of respondents were in an age range that allowed them to get experience and effectively manage the activities associated with fish farming. In terms of household size, the findings revealed that the largest portion of farmers 38.5% and 35.9% had a family size of five or fewer members and ranging from five to eight members, respectively in their households. The remaining 25.6% of fish farmers had more than eight members and the fish farming practice usually operated with family members.

Table 2.The socio-demographic character of the fish farmers

Attribute	**Classes**	**Frequency**	**Percent%**
Sex	Male	62	79.5
	Female	16	20.5
Age group	25-34	3	3.8
	35-44	45	57.7
	>44	30	38.5
Family size	1-5	30	38.5
	5-8	28	35.9
	>8	20	25.6
Educational level	Illiterate	37	47.4
	Primary	39	50.0
	Secondary	1	1.3
	Diploma	1	1.3
Training in fish farming	Yes	54	69.2
	No	24	30.8

4.1.2. Fish pond characteristics

As observed in the field, all of the surveyed fish ponds were under self-ownership, and almost all fish ponds were constructed in rectangular shape. A rectangular fish pond is considered ideal, especially for facilitating the photosynthesis process. This is because the large surface area allows the water to be easily exposed to sunlight (Alayu Yalew, 2011). Additionally, harvesting fish from a rectangular pond is easier compared to ponds of other shapes, as it can be easily swept through all the corners. In the surveyed districts, earthen ponds are the most common type of aquaculture ponds, accounting for 84.6% of the total. Concrete ponds constituted 11.6% of the ponds, while geo-membrane ponds represented 3.8% (Table 3).

The field observation also indicated that earthen ponds are more common in all districts than any other type of pond. According to Ifejika *et al.* (2007), the earthen pond is important for the maximum utilization of food sources by providing high levels of zooplankton and phytoplankton for the fish and enhancing aquaculture production of the fish. Moreover, earthen ponds are cost-effective to construct as compared to other types of ponds, such as concrete or fiber-plastic ponds, as the materials used in their construction, such as soil, are often readily available and inexpensive. However, one disadvantage of earthen ponds is their potential for leakage. If the pond is not properly constructed or maintained, there is a risk of water seeping through the soil and leaking out. This can result in a decrease in water levels, impacting overall water availability for fish and irrigation. Additionally, prolonged or significant leakage from an earthen pond can weaken the pond's structure, potentially leading to erosion, collapse, instability of the pond walls, and further water loss. The average pond size and depth were 146.6 ± 6.4 m^2 and 1.65 ± 0.016 m respectively.

Table 3. Characteristics and number of fish ponds in the surveyed districts

Attribute	Class	Frequency	Percent%
Districts	Dale	32	41.0
	Dara	14	17.9
	Dara Otelcho	11	14.1
	Shebedino	11	14.1
	Yirgalem	10	12.9
	Total	78	
Shape of the ponds	Rectangular	78	100
Water source	River	78	100
Bottom of the pond	Earthen	66	84.6
	Concert	9	11.6
	Geo membrane	3	3.8
Owner of the pond	Self	78	100
Source of fish fingerlings	Agriculture office	10	12.8
	Hawassa Universities (CARE)	36	46.2
	Agriculture office and Hawassa Universities (CARE)	32	41
Fish species stocked	*O. niloticus*	77	98.7
	O. niloticus and common carp	1	1.3

As the information obtained from the fish farmers indicated, in all districts, rivers serve as the primary water source for the fish ponds. The predominant fish species stocked in these ponds are mixed-sex fingerlings of *O. niloticus*, accounting for 98.7% (Table 3) of the stocked fish. Additionally, there is a combination of Common carp and *O. niloticus* cultured together (polyculture), representing 1.3% of the stocked fish. The advantages of producing *O. niloticus* in aquaculture, such as fast growth, high reproductive rate, adaptability, high demand, and suitability for feeding, contribute to its popularity in aquaculture production (Erkie Asmare *et al.,* 2019). Regarding fingerling sources, the main supplier in the districts is Hawassa Universities (CARE) alone, accounting for 46.2% of the fingerlings. Collaboration between the agriculture office and CARE contributed 41% of the fingerlings, while the agriculture office alone supplied 12.8% of the fingerlings (Table 3).

4.1.3. Fish pond management practice and production

According to information obtained from fish farmers in the surveyed districts, a majority of them utilized organic fertilizers for pond fertilization. The most commonly used organic fertilizers were decayed plant biomass (44.9%), followed by cow dung (16.7%) and poultry manure (11.5%) (Table 4). Furthermore, 26.9% of fish farmers used a combination of these three organic fertilizers. According to Boyd (2018), organic fertilizers can have several benefits when added to a fish pond. They can provide a source of nutrients for phytoplankton, zooplankton, and other organisms at the base of the aquatic food chain, which in turn can support the growth and health of fish. Additionally, the application of organic fertilizers can contribute to increased oxygen levels in the water. This occurs through the stimulation of aquatic plant growth, which releases oxygen as a by-product of photosynthesis. Higher oxygen levels are crucial for supporting the respiration and well-being of fish and other aquatic organisms in the pond. However, it is important to note that the application of organic fertilizers should be done optimally. Using excessive amounts of organic fertilizers may lead to a decrease in the required oxygen levels for the decomposition of organic manure (Das & Jana, 2003).

Table 4. Fish pond fertilization, integration, and other fish pond management practices

Attribute	Description	Frequency	Percent%
Source of organic fertilizer	Decayed plant biomass	35	44.9
	Cow dung	13	16.7
	Poultry manure	9	11.5
	Combination of the three organic fertilizers	21	26.9
Fish feed	Supplementary feed	22	28.2
Frequency of feeding	Regular (two/day)	14	18.0
	Depend on availability	8	10.2
Pond integration	Integrated	24	30.8
	Non integrated	54	69.2
Type of Integration	Vegetable	6	7.8
	vegetable and poultry	18	23.0
Purpose of harvested fish	Household consumption	18	23.0
	Commercial and household consumption	60	77.0

As shown in (Table 4), in addition to natural feed, 28.2 % of the fish farmers used supplementary feed to enhance the nutritional intake of their fish. This supplementary feed included unmarketable vegetables, leftovers from human meals collected from hotels and restaurants, and food waste from milling houses. This result shows that relatively few fish farmers were using supplementary feed to supplement the pond's natural food production. However, according to Hanninen (2014), providing supplementary feed to the fish from unconventional for human consumption, low-cost, nutritious, and locally available feedstuffs is important to minimize production costs and improve the productivity of the fish. Of the surveyed fish farmers, 18% fed their fish regularly twice a day. Meanwhile, 10.2% adjusted their feeding schedule based on the availability of feed resources. The fish stocking activities were carried out by Hawassa Universities (CARE) in collaboration with the agricultural office.

As observed in the field, among the surveyed ponds, nearly one third of fish ponds (30.8%) were integrated. Within this group, some ponds were integrated with vegetable cultivation (7.8%) such as cabbage, lettuce, beans, and avocados, and (23.0%) of the ponds integrated with a combination of vegetable farming and poultry rearing. The majority of ponds (69.2%) (Table 4) remained non-integrated, lacking such agricultural combinations. According to Mulokozi (2021), vegetables have many advantages for integrating with fish as compared to other crops because using vegetable remains as fish feeds and nutrient-rich pond water to irrigate vegetables grown close to their farm is very important, particularly during dry periods. This can lead to higher crop yields and lower production costs, however, the system diversification in those surveyed districts was relatively low.

This may be due to the lack of awareness and knowledge among farmers about the benefits of integrated fish farming and how to implement it effectively. During the field survey, it was observed that many interviewed farmers were unaware of the potential for integrating fish farming with other agricultural activities. Increasing awareness among farmers about the advantages of integrated fish farming and providing them with the necessary knowledge and guidance could help promote the adoption of these practices. This, in turn, can result in improved productivity, resource efficiency, and sustainable agricultural systems.

According to the information provided by the fish farmers, nearly all fish farmers used mosquito nets as harvesting material, and in some cases, gill nets were provided by CARE through loans. Furthermore, due to mixed-sex stocking, the fish reach a suitable size for harvesting after one year of being stocked. According to Erkie Asmare *et al.* (2019), mixed-sex tilapia stocking can lead to increased competition for resources such as food, oxygen, and space, which can negatively impact the growth and health of the fish and also result in poor growth and survival rates, as the male tilapia may become aggressive towards the females and disrupt the breeding process.

Figure 8. Integrated fish-poultry-vegetable farming systems

4.1.4. Financial performance of fish farming practice

The information obtained from the fish farmers demonstrated that fish farming plays a significant role in both household food production and income generation, similar to other agricultural activities. Moreover, fish farmers have expressed that selling their harvested fish as an income-generating activity helps them improve their livelihoods. The questionnaire provided to the fish farmers revealed that, the majority of the fish farmers (77.0%) harvest fish for both household consumption and commercial purposes, while 23.0% of the farmers use it for household consumption (Table 4). This result showed that fish farming has a remarkable contribution to poor household income.

According to Brummett *et al.* (2008), while the contribution of fish farming may be small, it still plays a vital role in generating significant financial resources that can be utilized for emergencies, educational expenses, and other essential needs. Beyond its direct economic contributions, fish farming also holds the potential to greatly enhance household food security and nutrition. This is primarily because fish are excellent source of protein and essential nutrients such as vitamin A, calcium, iron, and zinc. As a result, fish farmers have the distinct advantage of directly increasing their intake of these crucial nutrients through the consumption of their own farmed fish (Kawarazuka & Bene, 2011).

Although the adoption of integrated fish farming is relatively low in the surveyed districts, it proves to be more profitable than non-integrated fish farming. These results from the survey are closely related to the outcomes of the field experiment, where integrated fish farming demonstrated higher profitability compared to fish farming alone. Based on the annual household income collected from each fish farmer (n=78), it is evident that integrated fish farming, when compared to fish farming alone, generates higher revenue and net income. Integrated fish farming increases the revenue and net profit by 11.8% and 48.6%, respectively compared to the non-integrated approach. The higher revenue generated from the integrated fish farming ponds, as compared to the non-integrated ponds, can be attributed primarily to two factors. Firstly, the integrated fish farming system allows for diversified yields, expanding the range of products obtained from the farm.

Secondly, the reduced cost of feed in the integrated fish farming system is made possible through increased recycling of vegetables and other on-farm byproducts. This recycling process enhances resource efficiency and minimizes expenses. According to Prein (2002), IAA system enhances production efficiency by recycling nutrients and organic matter between fish and crops. Nutrient-rich water from the fish pond is used to irrigate vegetables, while vegetable waste becomes fish feed. This study also agrees with the finding of Yared Mesfin (2022), who reported that integrated fish farming not only reduces the reliance on chemical fertilizers but also optimizes the utilization of pond water and minimizes costs.

4.1.5. Constraints to fish farming practices and future plans of fish farmers

As observed in the field, all surveyed districts in the Sidama region are known for their agricultural productivity, including fish farming. While fish farming has the potential to provide several benefits to farmers in the region, several challenges can hinder its adoption and success. According to information from the fish farmer, the first problem related to fish farming in the surveyed area is the limitation of fish species diversity. The majority of the fish pond was stocked with *O. niloticus* and no other fish species have been distributed by any organization. However, the farmers in the area express a strong interest in producing other species, particularly catfish (ambaza) and common carp (dubba).

A key informant from Dara Otelcho expressed that ‘‘*the lack of sufficient fish seed, both in terms of quality and quantity, poses a significant challenge for farmers aiming to enhance fish production in the district. Although there are several fish ponds constructed for fish farming practice in our districts, they remain unstocked due to the scarcity of fish seed*’’.

According to Mohan (2007), the quality of fish seed is a critical factor in the success of fish farming. To optimize yield, and profitability, and ensure the sustainability of fish farming operations, fish farmers must prioritize the use of high-quality fish seeds. By doing so, they can maximize their chances of success and promote the long-term viability of their fish farming practice.

The information obtained from the fish farmers shows that the absence of proper harvesting materials is a significant problem faced by farmers in the surveyed areas.

Almost all fish farmers rely on mosquito nets for harvesting, which can be problematic. The use of mosquito nets can reduce the flow of water in the pond, leading to the accumulation of debris such as leaves and twigs. Consequently, this can result in water quality issues and an increased risk of disease. The key informant interview revealed that the progress of fish farming in the area is further hindered by a lack of appropriate technical skills. This lack of technical skills is evident from the fact that only a small number of farmers have attended fish farming training.

The key informant from the Dale district stated that ‘‘*while our district has several kebeles, I am the only fish expert in the area. This poses a challenge for me to provide technical assistance, follow-up, management, and support for fish farming practices in all kebeles*’’.

The lack of training in fish farming can have a significant negative impact on the productivity, quality, and sustainability of fish farming operations, as well as the financial viability of the farmer involved (Sheheli *et al.*, 2013). Gadisa Natea (2019), also reported that it is essential to prioritize capacity-building initiatives, including training programs, extension services, and advanced education, to enhance the interest and promote the successful development of fish farming. Therefore, by investing in comprehensive training and knowledge-sharing platforms, farmers can acquire the necessary skills and knowledge to optimize their fish farming practices, ultimately leading to improved outcomes and long-term success in the farming practice.

Moreover, the fish farmers expressed that government support, particularly in areas such as loans, was insufficient for the development of fish farming. Additionally, the unavailability of vegetable seeds and poultry breeds, the lack of good quality feeds, the shortage of hatcheries for disseminating fish seeds, and the absence of a market chain and storage materials are common problems in the surveyed districts.

One respondent from Shebedno, an experienced practitioner of integrated fish farming, mentioned, ‘'*I produce fish and use them for selling fish soup. However, the lack of storage materials forces me to conduct daily harvesting, which poses significant challenges. This constant harvesting causes stress to the fish and ultimately decreases production*’'. The challenges mentioned above, as provided by the fish farmers, were confirmed during the key informant interview.

Jha *et al.* (2020) reported that understanding the constraints and future plans in the adoption of food production technologies is essential for providing effective guidance and support, as well as ensuring long-term success and sustainability. According to the farmer's perspective, if the above-mentioned constraints are removed the practice of fish farming has a chance to be expanded.

Overall, both IAA and non-IAA farmers exhibited a positive attitude towards fish farming. In the surveyed area, a majority (94.8%) of fish farmers expressed their willingness to continue and expand fish farming. They showed particular interest in constructing new ponds and integrating different systems to enhance their operations. They are also interested in receiving support, particularly in the areas of training and government loans, to expand their fish farming operation, which can lead to an increase in their household income.

4.2. Estimation of growth parameters of *O. niloticus*

The findings of the current study revealed that the fish exhibited better growth performance in terms of daily growth rate, specific growth rate, Fulton’s condition factor, weight gain, and survival rate. This may be due to the application of supplementary feed in addition to pond fertilization. During the stocking of the fingerlings, the average initial length and body weight were 10.7 cm and 9.8 g, respectively. After four months of the experimental period, *O. niloticus* attained a final body weight of 98.6 g and a final body length of 16.7 cm on average with an average daily growth rate of (DGR) 0.74 g/day/fish (Table 5).

According to Respikius *et al.* (2020), the most efficient feeding regime for tilapia can be achieved with a combination of pond fertilization and supplementary feeding. This approach provides the necessary nutrients and energy required for the growth and development of fish beyond what they can obtain from their natural environment. It also helps optimize growth rates, improve feed conversion efficiency, and increase the overall profitability of fish farming operations. Furthermore, pond fertilization serves as an important management practice in fish farming, stimulating the growth of natural food organisms in the pond, which can provide a low-cost source of nutrition.

The daily growth rate observed in the current study agrees with the findings of Megerssa Endebu *et al.* (2016), who reported a daily growth rate of 0.75 g/day/fish in integrated fish farming utilizing poultry waste as pond fertilizer. However, Mlelwa (2016) reported a higher daily growth rate of 0.88 g/day/fish in integrated farming using chicken manure and supplementary feed, which is greater than the daily growth rate observed in the present study. This difference in daily growth rate may be due to the utilization of different ingredients in the formulation of supplementary feed.

As shown in (Table 5), the present study demonstrated a higher daily growth rate compared to the results reported by Tokuma Negisho *et al.* (2017). They reported a lower daily growth rate of (0.15-0.35 g/day/fish) when using various supplementary feeds for the growth of *O. niloticus*. This variation in daily growth rate may be attributed to the fact that their study solely relied on the application of supplementary feed without the utilization of poultry manure as a pond fertilizer. Poultry waste is a valuable resource that can be directly consumed by the fish or used to fertilize ponds. Its use supports the growth of the plankton community, which in turn contribute to the improved growth and development of the fish.

Specific growth rate (SGR) is a measure of the rate at which a fish grows over a given time, and it is commonly used in fish farming to monitor the growth performance of farmed fish. In the current study, the specific growth rate of *O. niliticus* was 1.92% per day (Table 5). The specific growth rate of the current study is in agreement with (Meiludie, 2013). who reported a specific growth rate ranging from 1.8 to 2.2% per day in relation to the growth performance and yield of various tilapia species. The specific growth rate obtained in the present study is higher than that reported by Teklay Gebru (2022), who found a specific growth rate of 1.72% per day in the integration of fish with vegetables using chicken manure with supplementary feed.

Furthermore, Adamneh Dagne and Abelneh Yimer (2018) also reported a lower specific growth rate of (0.8-1.1% per day) in *O. niloticus*, which is lower than the present study. Similarly, the current study has a higher specific growth rate compared to the findings reported by Daba Tugie *et al.* (2017), who reported a specific growth rate of (0.59%) in *O. niloticus*. The reason for the higher specific growth rate of the current study may be due to the use of supplementary feed in addition to chicken manure and regular monitoring of the pond's physicochemical parameters. However, the results reported by Kassaye Balkew & Gjoen (2012) showed a higher specific growth rate ranging from 2.59% to 2.73% per day, compared to the specific growth rate of 1.92% observed in the present study. This difference in specific growth rate may be due to the utilization of genetically superior strains of *O. niloticus* obtained from different areas.

During the experimental period, the growth of female *O. niloticus* was slow. According to Biswas *et al.* (2005), males grow faster by 10-20 % than females and the growth of female fish will be drastically reduced if fingerling production is not controlled. Female tilapia allocates a significant amount of energy towards reproductive functions, such as egg production. As a result, the energy available for growth is limited, leading to a smaller overall body size (Bhatta *et al.*, 2013). As observed from (Figure 9) male *O. niloticus* showed continuous growth performance throughout the experimental period; however, the growth pattern of female *O. niloticus* was comparatively weaker.

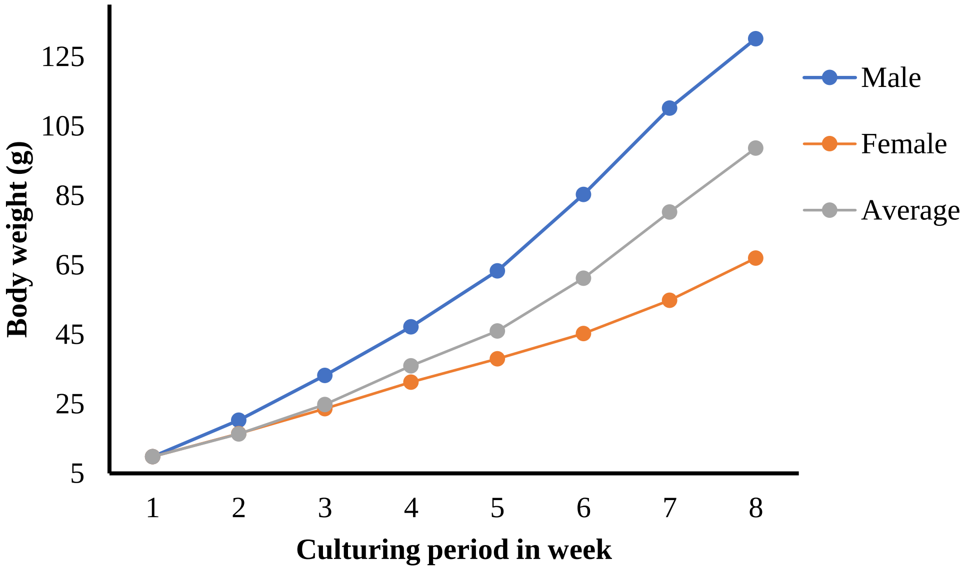


Figure 9. Growth pattern of *O. niloticus*

Several important factors can contribute to the good survival rate of fish in fish farming production. Some of these factors include water quality, feeding, stocking density, and favorable environmental conditions which have an important contribution to the higher survival rate of fish. As observed from (Table 5) the survival rate of *O. niloticus* in the present study was 98%. The survival rate of the present study is in agreement with the finding of Daba Tugi *et al.* (2017) (98.75%).

The survival rate of the current study is higher than that reported by Megerssa Endebu *et al*. (2016), who reported 73% by feeding fish with poultry manure only. Similarly, the present survival rate is higher than the findings of Tokuma Negisho *et al*. (2017) study, which reported survival rate ranging from 80% to 91% in their investigation of the effects of different supplementary feeds on the growth performance of *O. nilotices.* The lower survival rate of those reports may be due to environmental factors that can contribute to lower survival rates of *O. niloticus* in aquaculture production.

Table 5. Growth parameters of *O. niloticus*

Growth parameter	Growth performance ± SE
Average initial length (cm)	10.7 ± 0.30
Average final length (cm)	16.7 ± 0.46
Average initial weight (g)	9.8 ±0.42
Average final weight (g)	98.6 ± 4.9
Weight gain (g)	88.8
Daily weight gain (g)	0.74
Specific growth rate (%)	1.92
Fulton’s condition factor	2.1
Survival rate (%)	98

The condition factor (k) is used as an indicator of the general well-being of fish and explains the variation in fish weight with body length. Numerous factors, including feeding habits, environmental conditions, age, and reproductive status, influence the condition factor of fish (Khallaf *et al.,* 2003). The Fulton's condition factor of *O. niloticus* in the present study was 2.1 (Table 4). This finding is in agreement with the research conducted by Dinku Getu *et al*. (2017), who reported an average condition factor of 1.9 for *O. niloticus* in integrated fish farming with poultry and vegetables. Condition factor values recorded in this study also agree with the finding of Anani & Nunoo (2016), who reported condition factors ranging from 1.39 to 2.01 for *O. niloticus.* According to Shahabuddin *et al. (*2015), a condition factor higher than 1.0 suggests good fish health and indicates isometric growth, which is desirable in fish farming. Based on this criterion, the sampled fishes in the present study were in good condition (K= 2.1). Generally understanding the condition factor helps to show the environmental aspects of the culture system as well as the level of management.

4.3. Effect of different treatments on Swiss chard growth performance and yield

4.3.1. Effect on plant height

As shown in (Table 6), the height of the Swiss chard treated with (BSFFF) was significantly different ($p<0.05$) compared to other treatments, measuring 71.12 cm with a percentage of increase the height by 87.05% compared to the control. Swiss chard treated with compost, chemical fertilizer, and pond water exhibited no significant differences in height, with average heights of 67.02 cm, 67.21 cm, and 68.38 cm, respectively, and increased the height of the Swiss chard by 76.27%, 76.77%, and 79.85%, respectively, compared to the control. However, the height of Swiss chard treated with compost, chemical fertilizers, BSFFF, and pond water were all significantly greater ($p<0.05$) than those in the control group, which had an average height of 38.02 cm.

Table 6. Effects of different treatments on the growth parameters of Swiss chard

Treatments	PLH (cm)	LL (cm)	LW (cm)	LN	LA (cm^2)
Compost	67.02 ±0.45 ^{b}	45.03 ±0.26 ^{b}	21.26 ±0.18 ^{d}	18.55 ±0.15 ^{b}	651.3±20.3 ^{b}
Chemical fertilizer	67.21 ±0.45 ^{b}	46.07 ±0.26 ^{b}	24.59 ±0.18 ^{c}	18.47 ±0.15 ^{b}	770.4±20.3 ^{a}
BSFFF	71.12 ±0.45 ^{a}	47.22 ±0.26 ^{a}	26.53 ±0.18 ^{b}	22.16 ±0.15 ^{a}	767.9±20.3 ^{a}
Control	38.02 ±0.45 ^{c}	29.21 ±0.26 ^{c}	14.50 ±0.18 ^{e}	10.81 ±0.15 ^{c}	532.6±20.3 ^{c}
Pond water	68.38 ±0.45 ^{b}	47.90 ± 0.26 ^{a}	27.34 ±0.18 ^{a}	22.73 ±0.15 ^{a}	775.1±20.3 ^{a}

Where PLH, LL, LW, LN, and LA represent plant height, leaf length, leaf width, leaves number and leaf area respectively.

NB: Different letters in the column show significant differences among the means of the respective parameters (P<0.05).

As observed in (Figure 10) throughout the Swiss chard growing period all treatments increased the height of the Swiss chard however, the growth pattern of the control group was comparatively lower than that of the other treatments.

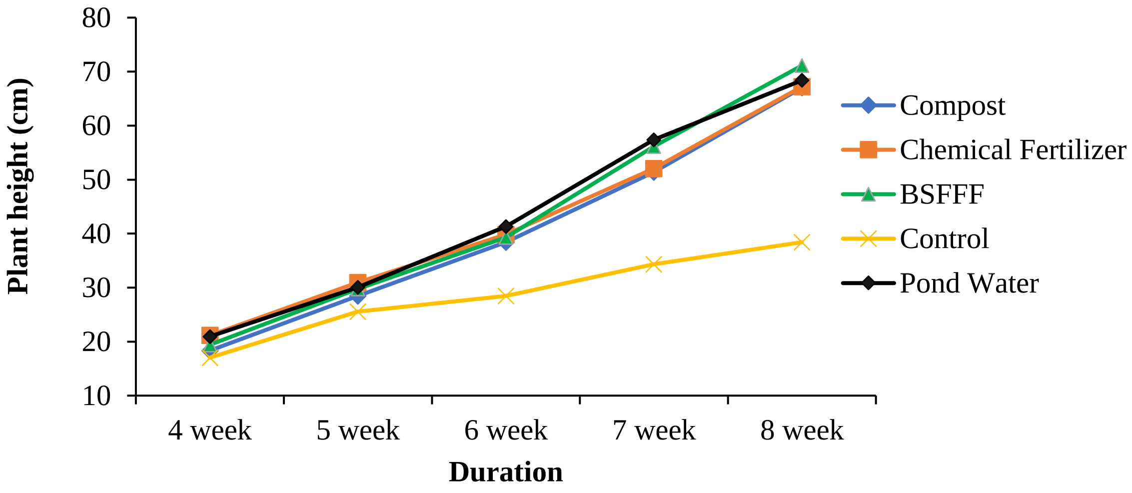


Figure 10. Plant height growth Pattern of Swiss chard

4.3.2. Effect on leaf length

The mean leaf length of the Swiss chard treated with pond water (47.90 cm) and BSFFF (47.22 cm) resulted in a significant increase in leaf length of Swiss chard than the other treatment throughout the growing season, with a percentage increase of 63.98% and 61.65%, respectively compared to the control group ($p<0.05$). Similarly, the mean leaf length of the Swiss chard treated with chemical fertilizer (46.07 cm) and compost (45.03 cm) also showed significant increases of 57.72% and 54.15%, respectively compared to the control group. The mean leaf length of the Swiss chard from control (29.21 cm) was the smallest and significantly lower ($p<0.05$) than that of the other treatments (Table 6). As observed from (Figure 11), the growth pattern of Swiss chard leaf length was relatively similar across all treatments, except for the control group.

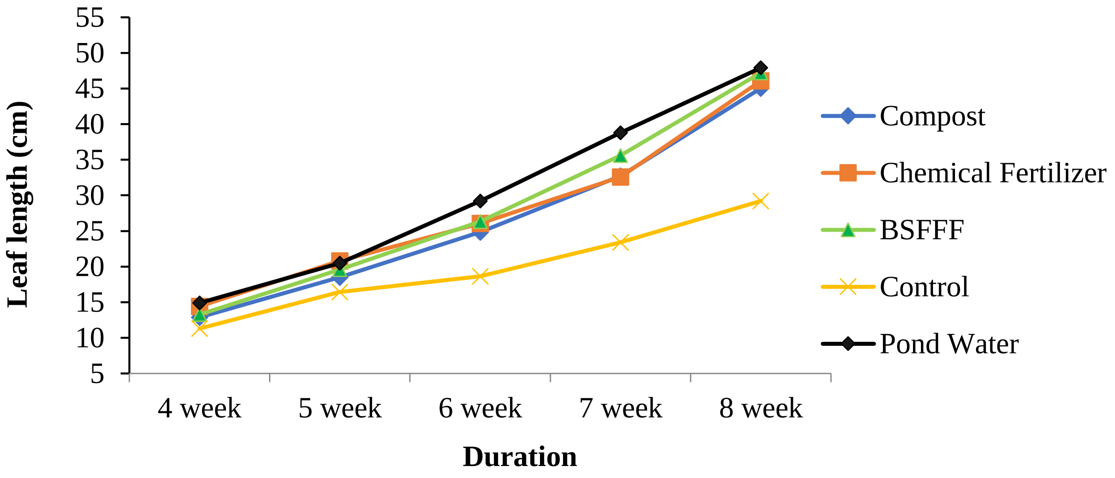


Figure 11. Leaf length growth pattern of Swiss chard

4.3.3. Effect on leaf width

The mean leaf width of Swiss chard treated with various treatments ranged from 14.50 cm to 27.34 cm (Table 6). The highest mean leaf width (27.34 cm) was observed in plants treated with pond water, resulting in an increase of 88.55% compared to the control and significantly larger than the other treatments ($p<0.05$). The Swiss chard treated with BSFFF (26.53 cm), chemical fertilizer (24.59 cm), and compost (21.26 cm) also showed increased leaf width by 82.96%, 69.58%, and 46.62% respectively compared to the control (14.50 cm). However, there were significant differences among these treatments ($p<0.05$). Moreover, the periodically recorded data indicated that the leaf width of the Swiss chard from the control was the smallest throughout the measurement period (Figure 12).

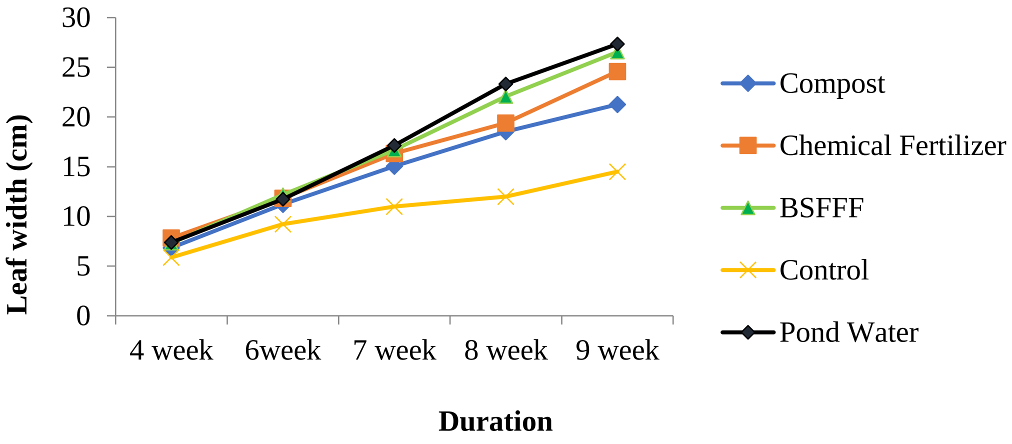


Figure 12. Leaf width growth Pattern of Swiss chard

4.3.4. Effect on leaves number

The mean leaf number per plant of Swiss chard from various treatments ranged from 10.81 to 22.73 (Table 6). The application of pond water (22.73) and BSFFF (22.16) significantly increased the leaf number of Swiss chard compared to the other treatments ($p<0.05$). The leaf numbers recorded from the plants treated with compost (18.55) and chemical fertilizer (18.47) were comparable to each other. In contrast, the smallest leaf number (10.81) of Swiss chard was recorded for the plants from the control. Moreover, as observed in (Figure 13), the growth pattern of leaf number per plant was similar across all treatments until the

6th week, except for the control group. However, after the 6th week, the leaf numbers of the plants treated with compost and chemical fertilizer showed a decrease.

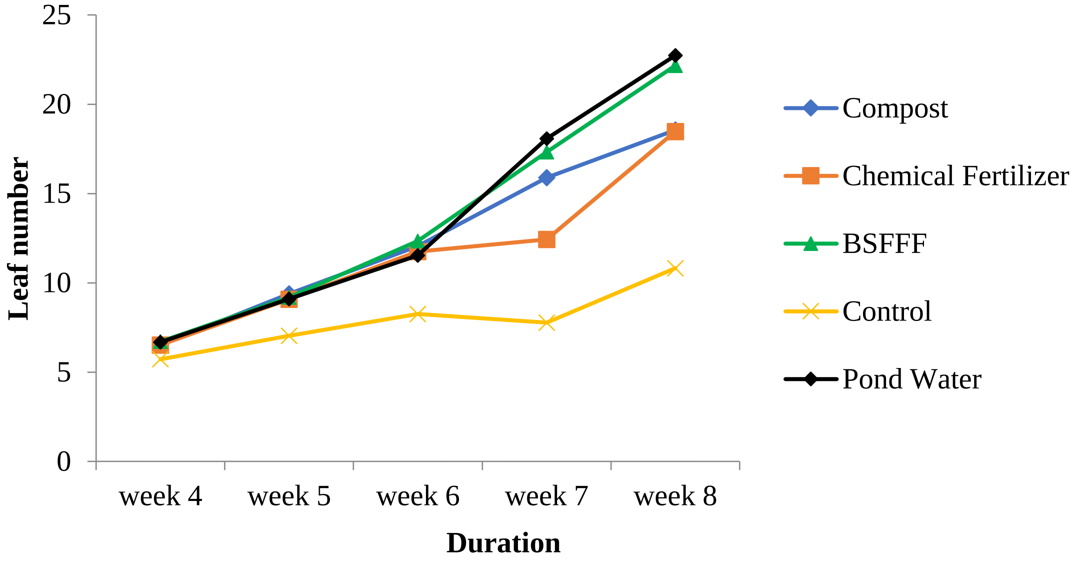


Figure 13. Leaf number growth pattern of Swiss chard

4.3.5. Effect on leaf area

The mean leaf area of Swiss chard plants grown with different treatments ranged from 532.6 cm^2 to 775.1 cm^2 (Table 6). The largest leaf area was observed in plants treated with pond water (775.1 cm^2), BSFFF (767.9 cm^2), and chemical fertilizer (770.4 cm^2), resulting in percentage increases of 45.53%, 44.17%, and 44.64% respectively compared to the control. However, there were no significant differences among these treatments ($p>0.05$). The plants treated with compost (651.3 cm^2) also showed an increase in leaf area by 22.28%. In contrast, the smallest leaf area of Swiss chard (532.6 cm^2) was recorded from the control, and this measurement was significantly smaller than all other treatments.

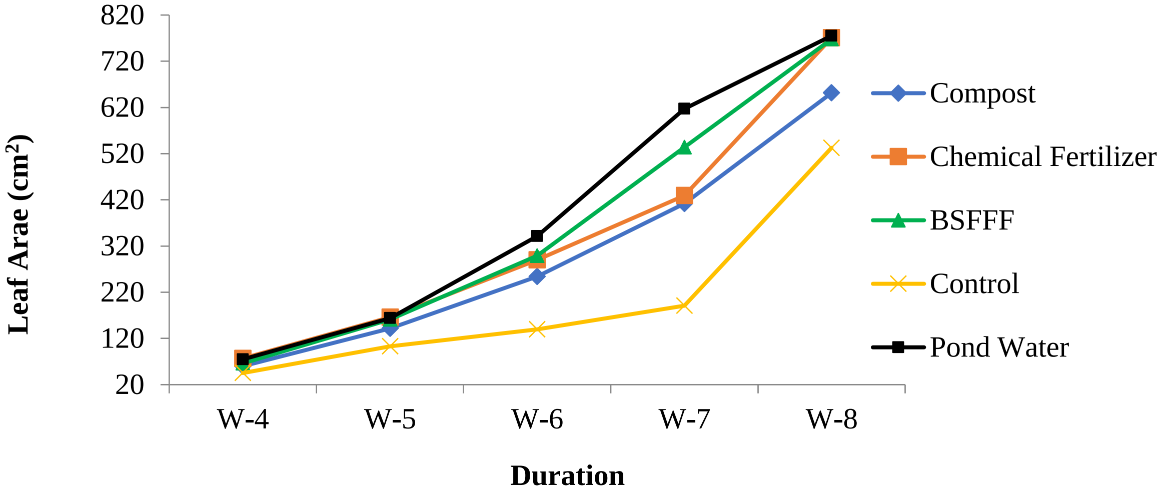


Figure 14. Leaf area growth pattern of Swiss chard

4.3.6. Effect on yield

As shown in (Table 7), the mean marketable yields obtained from plots treated with pond water, compost, chemical fertilizer, and BSFFF were 58.7 Kg/plot, 49.0 Kg/plot, 52.4 Kg/plot, and 53.5 Kg/plot, respectively. Although there were some differences in the marketable yields among these treatments, the differences were not significant. The marketable yield obtained from the control plots (30.6 Kg/plot) was significantly lower compared to the yields from the other treatments ($p<0.05$).

Table 7. Effects of different treatments on the yield of Swiss chard

Treatments	Kg/plot	Kg/ha	ton/ha
Compost	49.0±0.09 [a]	122,500	122.5
Chemical Fertilizer	52.4 ±0.09[a]	131,125	131.1
BSFFF	53.5±0.09 [a]	122,500	133.5
Control	30.6 ±0.09 [b]	76,500	76.5
Pond Water	58.7 ±0.09 [a]	146,750	146.7

NB: Different letters in the column show significant differences among the means of the respective parameters ($P<0.05$).

Treatment with pond water resulted in an increase in Swiss chard yield by 19.7%, 12.0%, 9.7%, and 91.8% when compared to compost, chemical fertilizer, BSFFF, and control, respectively. The present study on the growth performance and yield of the plant showed that the pond water performed better in most growth parameters (leaf length, leaf width, leaf number, and leaf area) of the Swiss chard. This result agrees with the findings of Mlelwa (2016), who reported that irrigating a plot with fish pond water resulted in higher yield and improved growth performance of Chinese cabbage. Parameters such as length, diameter, and number of leaves demonstrated significant improvement compared to plots irrigated with stream water. The utilization of nutrient-rich fishpond water effectively promotes the growth performance and production of crops (Payebo & Ogidi (2020).

Similarly, BSFFF also demonstrated good performance in terms of plant height, leaf length, leaf number, and leaf area. This finding is consistent with the study conducted by Abiya *et al.* (2022), who highlighted the positive influence of BSFFF on the growth performance of Swiss chard. Anyega *et al.* (2021) further emphasized that BSFFF is considered a high-quality organic fertilizer due to its sufficient composition of nitrogen, phosphorus, potassium, and other essential micronutrients. Furthermore, the application of compost and chemical fertilizer showed comparable performance in promoting the growth of Swiss chard. However, plants treated with chemical fertilizer exhibited better performance in terms of leaf width and leaf area.

The yield of Swiss chard produced using pond water was comparatively higher than that of other treatments (BSFFF, compost, and chemical fertilizer), and significantly larger than the control. However, it is recognized that the use of chemical fertilizers can significantly increase plant yield. Nevertheless, these fertilizers can also have detrimental effects on the environment, such as changes in soil pH, reduced organic matter content, and nutrient enrichment (Savci, 2012). The present result agrees with a study by Shoko *et al.* (2011) on growth performance, yields, and economic benefits of *O. niloticus* and kales (*Brassica oleracea)* cultured under vegetable-fish culture integration. They reported that vegetable plots receiving water from fish pond water attained a higher yield than those receiving water from streams.

Other studies have also shown that integrating fish pond water with vegetable production has a positive effect on the yield and other growth parameters of the plants. Belay Adugna *et al.* (2016) reported a higher number of tomato fruits and increased onion yield obtained from plants treated with pond water. Similarly, Daba Tugie *et al.* (2017) reported the highest yield of Adama red onion when integrated with poultry and fish components. They recommend incorporating horticulture components into the integration as an alternative method of vegetable production for home consumption and as a source of income. This approach can help minimize input costs and reduce environmental pollution. Dugan *et al.* (2006) also suggest that integrated agro-aquaculture farming is ecologically sound because water from fish ponds improves soil fertility by increasing the availability of nitrogen and phosphorus. Overall, this result demonstrated that the nutrients in fish pond water sufficiently replaced the input of synthetic and other conventional fertilizers in vegetable cultivation.

Figure 15. Swiss chard production in integrated fish farming experiment

4.4. Pre- and post-experimental soil physicochemical analysis

As observed in (Table 8), the analysis of the pre-experimental soil revealed a bulk density of 1.27 g/cm^3, which falls within the ideal range for plant growth. According to USDA-NRCS (1998), a bulk density value less than 1.4 g/cm^3 is considered acceptable for plant growth. Additionally, the pre-experimental soil exhibited a porosity of 51.8%, indicating the presence of proper pore spaces for air and water movement within the soil. According to Sheard (1991), soil with a porosity of 50% is considered ideal, as it benefits root growth and nutrient availability to plants.

In terms of pH, the pre-soil was measured at 6.2, indicating a slightly acidic nature. According to Oshunsanya (2018), when soil pH falls within the range of 6.1–6.5 it is considered to be slightly acidic. This pH level is considered suitable for the cultivation of Swiss chard, as stated in the production guidelines for Swiss chard, which recommend a soil pH level of 6.0 to 7.0. The pre-experimental soil analysis revealed the following values for soil organic carbon, organic matter, total nitrogen, available phosphorus, and electrical conductivity: 1.01%, 1.74%, 0.23%, 27.3 mg/kg, and 0.8 dS/m, respectively (Table 8).

According to Landon (2014), soil organic carbon content ranges of 1–2%, 2–4%, and 4–6% are rated as low, medium, and high, respectively. The present analysis of the pre-experimental soil indicates a low organic carbon content.

Table 8. Physico-chemical properties of pre- and post-experimental soil analysis

Parameters	**Pre - soil**	**Post-experimental soil physicochemical analyses**				
		Compost	Chemical fertilizer	BSFFF	Pond water	Control
Bulk density (g/cm^3)	1.27	1.12	1.13	1.02	1.07	1.27
pH	6.2	6.8	6.4	7.2	7.1	6.2
Porosity (%)	51.8	57.5	57.1	61.3	59.4	51.8
Organic matter (%)	1.74	2.81	1.93	2.62	2.25	1.74
SOC (%)	1.01	1.63	1.12	1.52	1.31	1.01
TN (%)	0.23	0.42	0.38	0.43	0.37	0.23
A val. P (mg/kg)	27.3	33.5	30.3	32.1	31.8	27.3
EC (dS/m)	0.8	1.1	1.3	1.2	1.1	0.8
Ex. Ca (cmol kg^{-1})	1.52	3.15	3.96	3.37	3.21	1.52
Ex. Mg (cmol kg^{1})	0.65	1.33	1.35	1.32	1.31	0.65
Ex. K (cmol kg^{-1})	0.25	1.30	1.53	1.32	1.26	0.25
Ex. Na (cmol kg^{-1})	0.23	0.71	0.52	0.57	0.45	0.23

Where pH refers to power of Hydrogen, SOC-Soil organic carbon, TN -Total nitrogen, Aval. P - available phosphorus, EC- Electrical conductivity, and Exchangeable base (Ex. Ca, Mg, K, Na)

In the pre-experimental soil analysis, the total nitrogen content of the soil was found to be 0.23%, which falls within the optimum range of 0.15 – 0.25% according to Sobulo and Osiname (1981). Additionally, these authors provide a classification for available phosphorus (P) content as follows: <5 mg/kg is considered low, 5–10 mg/kg is medium, and >10 mg/kg is high. Based on this classification, the available P content in the pre-experimental soil was measured at 27.3 mg/kg, which falls within the high range. During the pre-soil analysis, the exchangeable cations such as calcium, magnesium, sodium, and potassium were measured and found to be 1.52, 0.65, 0.23, and 0.25 cmol/kg-^{1}, respectively (Table 8).

In the post-experimental soil analysis, the application of compost, chemical fertilizer, BSFFF, and pond water resulted in changes to the physical and chemical properties of the soil, including soil bulk density, porosity, pH, soil organic carbon, organic matter, available phosphorus, electrical conductivity, and total nitrogen. As observed from (Table 8), it was found that the soil treated with chemical fertilizer exhibited a slight increase in pH, reaching a value of 6.4. However, this change did not alter the soil pH classification.

On the other hand, the application of compost, BSFFF, and pond water caused the slightly acidic pH range of the pre-experimental soil (6.1–6.5) to shift towards a more neutral pH and increase by 9.6%, 16.1%, and 14.5%, respectively, compared to the control (6.2). According to Endale Bedada *et al.* (2020), soil pH is a crucial chemical property, and most important plant nutrients are readily available in the pH range of 6.5 to 7.5. Wang *et al.*, (2019), emphasize that the utilization of organic fertilizers is important for managing soil pH as they possess pH buffering capacity, stabilize pH fluctuations, and gradually release nutrients.

In the post-harvest soil analysis, the bulk densities of the soil treated with compost, chemical fertilizer, BSFFF, and pond water were measured as 1.12, 1.13, 1.02, and 1.07 (g/cm^{3}), respectively (Table 8). These results indicate that the application of these different treatments has led to a decrease in the bulk density of the experimental soil. Furthermore, the analysis results demonstrated that the application of compost, chemical fertilizer, BSFFF, and pond water has increased the porosity of the soil. The porosity values for the respective treatments were recorded as 57.5, 57.1, 61.3, and 59.4%, compared to the control with a porosity of 51.8% (Table 8). These findings suggest that the application of compost, chemical fertilizer, BSFFF, and pond water has positively influenced the soil structure by reducing bulk density and increasing porosity. These changes can enhance soil aeration, water movement, and root penetration, potentially improving overall soil health and plant growth (Hao *et al.,* 2008).

The post-experimental soil analysis revealed the soil organic carbon content of the soil treated with compost, chemical fertilizer, BSFFF, and pond water increased to 1.63, 1.12, 1.52, and 1.31%, respectively from the pre-soil value of 1.01% (Table 8). The variations in soil organic carbon content among the treatments may be due to differences in nutrient composition and organic matter content of the amendments used. Similarly, the respective treatments also increased the total organic matter to 2.81, 1.93, 2.62, and 2.25 from the pre-soil value of 1.74%. However, the soil treated with chemical fertilizer exhibited lower organic matter content compared to the other organic fertilizers. This may be due to chemical fertilizers focus more on immediate nutrient provision, while organic fertilizers contribute both nutrients and organic matter, improving long-term soil health and fertility (Kocagoz *et al.*, 2022).

The total nitrogen content of the soil treated with compost, chemical fertilizer, BSFFF, and pond water was found to be 0.42, 0.38, 0.43, and 0.37%, respectively. These findings suggest that the application of different treatments resulted in increased values compared to the control treatment, which had a total nitrogen content of 0.23% (Table 8). Nitrogen is a crucial element for the optimal growth and development of plants. It plays a vital role in increasing yield and improving quality by actively participating in the biochemical and physiological functions of plants (Leghari *et al.*, 2016).

Additionally, the concentrations of available phosphorus in the soil treated with compost, chemical fertilizer, BSFFF, and pond water were measured at 33.5, 30.3, 32.1, and 31.8 mg/kg, respectively. These values represent an increase of 22.7%, 10.98%, 17.58%, and 16.4%, respectively compared to the control treatment, which had an available phosphorus level of 27.3 mg/kg.

The present results are consistent with the findings of Belay Adugna *et al.* (2016) who worked on integrating fish with vegetables, specifically tomato and onion. They observed that the plot treated with pond water showed improvements in soil organic carbon, organic matter, and available phosphorus in the tomato plot, while the onion plot experienced a decrease. This variation may be due to factors such as differences in root depth and nutrient uptake efficiency. Similarly, Mulokozi *et al.* (2022) conducted a study on integrating *O. niloticus* with vegetables, including cabbage and amaranth. They reported that the plot treated with pond water initially fertilized with chicken manure had significantly higher concentrations of organic matter compared to the soil control plot that was irrigated with tap water.

The electrical conductivity values of the soil samples treated with compost, chemical fertilizer, BSFFF, and pond water were measured as 1.1, 1.3, 1.2, and 1.1 dS/m, respectively (Table 8). According to Gong (2021), different plants have varying requirements for soil electrical conductivity based on their fertilizer needs and growth stages. The optimal electrical conductivity value for plant growth typically falls within the range of 0.8-1.8 dS/m and should not exceed 2.5 dS/m. Based on these recommendations, the electrical conductivity values obtained from the soil samples treated with compost, chemical fertilizer, BSFFF, and pond water fall within the optimal range for plant growth.

This suggests that these treatments provide suitable electrical conductivity levels to support healthy plant development.

In the present study, the application of different treatments resulted in increased exchangeable calcium levels. Specifically, the treatments of compost, chemical fertilizer, BSFFF, and pond water led to exchangeable calcium values of 3.15, 3.96, 3.37, and 3.21 cmol kg-^{1}, respectively, compared to the control treatment (1.52 cmol kg-^{1}) (Table 8). Similarly, the application of these treatments also increased the exchangeable magnesium levels. The compost, chemical fertilizer, BSFFF, and pond water treatments resulted in exchangeable magnesium values of 1.33, 1.35, 1.32, and 1.31 cmol kg-^{1}, respectively, compared to the control treatment (0.65 cmol kg-^{1}**).**

Additionally, the application of compost, chemical fertilizer, BSFFF, and pond water treatments increased the exchangeable potassium values from 0.25 cmol kg-^{1} (control treatment) to 1.30, 1.53, 1.32, and 1.26 cmol kg-^{1}, respectively. Moreover, these treatments also increased the exchangeable sodium content to 0.71, 0.52, 0.57, and 0.45 cmol kg-^{1}, compared to the control (0.23 cmol kg-^{1}) in the compost, chemical fertilizer, BSFFF, and pond water treatments, respectively.

These results demonstrated that the application of compost, chemical fertilizer, BSFFF, and pond water effectively increased the levels of exchangeable calcium, magnesium, sodium, and potassium in the soil compared to the control (Table 8) treatment. Overall, this set of findings demonstrated that the application of fish pond water can improve soil nutrient levels and showed comparable results to other types of fertilizers, such as chemical fertilizer, compost, and BSFFF. Therefore, using pond water for vegetable production is not only for irrigation but also crucial for supplementing the vegetables with essential nutrients.

4.5. Phytoplankton identification and abundance in fish pond

Phytoplankton play a crucial role in reducing nutrient levels in the water by absorbing excess nutrients like nitrogen and phosphorus, which can be harmful to fish when present in high concentrations. Throughout the study period, the fish monoculture pond systems consisted of four groups of phytoplankton groups: Chlorophyceae, Cyanophyceae, Bacillariophyceae, and Dinophyceae (Table 9).

Among these, Chlorophyceae (42%) was the most abundant, followed by Bacillariophyceae (34%), Cyanophyceae (20%), and Dinophyceae (4%) in the ponds. The total number of identified genera was 18. From these genera, 8 genera belong to Chlorophyceae, 6 to Bacillariophyceae, 3 to Cyanophyceae, and 1 to Dinophycea. The abundance of genera varied across the different groups. Within these genera, *Scenedesmus* had the highest abundance, followed by *Closterium, Pandorina, Eudorina, Nitzschia,* and *Microcystis,* which were found dominantly in the fish pond.

As summarized in (Table 9), three types of zooplankton were identified, namely Rotifer, Protozoa (ciliate), and Cladocera. According to Rapatsa & Moyo (2013), the utilization of Chicken manure in fish farming ponds is crucial as it serves as a nutrient source that stimulates the growth of phytoplankton, leading to enhanced productivity and improved water quality. This finding agrees with the current study, which also demonstrated a good phytoplankton composition in the fish pond.

Table 9. Generic status of plankton (phytoplankton & zooplankton) with different groups in fish pond

Group	**Genera**	**Relative abundance**
Chlorophyceae (Green algae)	*Scenedesmus*	5
	Closterium	4
	Cosmarium	2
	Pandorina	4
	Zygnema	1
	Eudorina	4
	Botryococcus	3
	Tetrasturm	2
Bacillariophyceae (Diatoms)	*Navicula*	1
	Cyclotella	2
	Synedra	3
	Cymbella	2
	Nitzschia	4
	Surrirella	3
Cyanophyceae (Blue-green algae)	*Microcystis*	4
	Anabaena	3
	Merismopedia	3
Dinophyceae	*Peridinium*	2
Zooplankton	Protozoa (ciliate)	1
	Rotifer	2
	Cladocera	2

Where: 1-5 indicates the frequency of occurrence of species: 1- rare, 2 - sporadic, 3- common, 4 - abundant, 5 - very abundant).

The present result agrees with the findings reported by Chukwu & Afolabi (2017) on phytoplankton abundance and distribution. They concluded that Chlorophyceae was the most abundant group of phytoplankton, followed by Bacillariophyceae and Cyanophyceae. The current phytoplankton identification and composition study is also closely related to the work of Teklay Gebru & Kassaye Balkew (2022) on plankton composition and abundance in semi-intensive aquaculture ponds and their preference for *O. niloticus*. Their study, which utilized chicken manure as a fertilizer, suggested that green algae, diatoms, and blue-green algae were dominant in *O. niloticus* ponds.

In addition, according to Han *et al.* (2017), chicken manure has a vital role in promoting rapid growth and high biomass yield of microalgae like *Scenedesmus* by providing nutrients. The authors also recommend the use of chicken manure as a cost-effective and efficient fertilizer for large-scale production of microalgae. Overall, these findings support the utilization of chicken manure as a beneficial fertilizer in fish farming systems, promoting the growth of desirable phytoplankton groups and enhancing overall productivity.

4.6. Algal diet composition of *O. niloticus* in the pond

The diet composition of *O. niloticus* can vary depending on various factors, including fish size and age, the type and availability of food, and the surrounding environment (Abdel-Tawwab, 2003). In the present study, the algal diet composition of 35 *O. niloticus* fish was examined at the end of the experimental period, and all sampled fish were found to contain food. The analyzed fish ranged in size from 13 to 18 cm in total body length and weighed between 40 and 125 g. The analysis of stomach contents revealed a wide diversity in the stomachs of *O. niloticus,* with phytoplankton being the most abundant category, followed by zooplankton and some detritus. The genera of algae found in fish stomachs belonged to, Chlorophyceae, Bacillariophyceae, Cyanophyceae, and Dinophyceae (Table 10).

Based on the frequency of occurrence the dominant phytoplankton food items of *O. niloticus* in the pond were Bacillariophyceae and Chlorophyceae, while Cyanophyceae ranked as the third dietary component. However, Dinophyceae made a relatively low contribution to the diet of *O. niloticus*. Zooplankton groups were represented by rotifers (31.4%) and Cladocerans (37.1%) (Table 9). In the stomach of *O. niloticus*, the Chlorophyceae group comprised several genera, including *Scenedesmus*, *Closterium*, *Cosmarium*, *Zygnema*, *Pandorina*, *Eudorina*, and *Tetrasturm*. Among these genera, *Scenedesmus* (100%) exhibited the highest composition (100%) in both the fish pond and the fish stomach, suggesting a strong presence and preference. This prevalence could potentially may be due to the utilization of chicken manure, which may serve as a favorable nutrient source for *Scenedesmus* growth.

Additionally, *Tetrasturm* (94.2%), *Cosmarium* (88.5%), and *Zygnema* (82.8%) were also present as remarkable food sources for the fish (Table 10). However, their abundance in the fish pond was rare and sporadic. The high content in the stomach may be due to the fish's preference and utilization. On the other hand, *Pandorina* (37.1%), *Closterium* (25.7%), and *Eudorina* (17.1%), which were abundant in the fish pond, were rarely found in the fish stomach, suggesting a lower preference by the fish. Similarly, the commonly found *Botryococcus* genera in the fish pond were not detected in the fish stomach.

Table 10. Frequency of occurrence of the various food items in the diet of *O. niloticus* sampled from integrated fish farming system.

Food items	**Frequency of occurrence**	
	Number (35)	Percentage (%)
Chlorophyceae (Green algae)	**35**	**100**
Scenedesmus	35	100
Tetrasturm	33	94.2
Cosmarium	31	88.5
Zygnema	29	82.8
Pandorina	13	37.1
Closterium	9	25.7
Eudorina	6	17.1
Bacillariophyceae (Diatoms)	**35**	**100**
Nitzschia	35	100
Cyclotella	33	94.2
Navicula	27	77.1
Cymbella	25	71.4
Synedra	11	31.4
Cyanophyceae (Blue-green algae)	**10**	**28.5**
Merismopedia	10	28.5
Microcystis	7	20.0
Anabaena	4	11.4
Dinophyceae	**8**	**22.8**
Peridinium	8	22.8
Zooplankton	**13**	**37.1**
Cladocera	13	37.1
Rotifer	11	31.4

Bacillariophyceae, represented by genera such as *Nitzschia, Cyclotella, Navicula, Cymbella,* and *Synedra,* were found in the fish stomach (Table 10). Among these genera, *Nitzschia* (100%) had the highest composition in fish stomachs, indicating its significant presence as a dietary component. It was also observed in abundant quantities within fish ponds. This observation suggests that the plentiful availability of this genus in the pond may contribute to its prevalence in *O. niloticus* stomachs.

Furthermore, *Cyclotella* (94.2%), *Navicula* (77.1%), and *Cymbella* (71.4%) made significant contributions to the diet composition in the fish stomach while exhibiting rare and sporadic distribution in the fish pond. On the other hand, the genus *Synedra* (31.4%), which was commonly found in the fish pond, occurred relatively less in the stomach, suggesting a lower preference. Similarly, the genus *Surrirella,* commonly found in the fish pond, was not detected in the fish stomach, indicating a lower preference for this genus. As observed in (Table 10), the Cyanophyceae group was represented by the genera *Merismopedia* (28.5%), *Microcystis* (20.0%), and *Anabaena* (11.4%) in fish stomachs. However, its presence was examined in lower content in fish stomachs compared to its common and abundant occurrence in the fish pond. The Dinophyceae group, represented by the genera *Peridinium,* made a relatively low contribution (22.8%) to the diet of *O. niloticus.* This limited contribution may be attributed to the low availability of Dinophyceae in the fish pond.

In the present study, the diet composition of *O. niloticus* revealed that phytoplankton constituted the preferred diet for all size groups of the fish. This finding agrees with the study conducted by Abdel-Tawwab (2000), who reported that *O. niloticus* primarily consumes phytoplankton, with Chlorophyceae, Bacillariophyceae, and Cyanophyceae being the main components found in fish stomachs. The presence of the highest composition of phytoplankton in the present study may be due to the sufficient availability of phytoplankton in the pond. Additionally, the application of chicken manure as a pond fertilizer may have contributed to the increased occurrence of algae, as it provides a nutrient-rich environment conducive to their growth. Overall, the present study demonstrated that *O. niloticus* exhibited a distinct preference for genera within each phytoplankton group, even though it generally prefers phytoplankton.

4.7. Cost-benefit analysis

In the present study of the integrated fish farming system, the total estimated production cost for compost, BSFFF, pond water, and (control) was 1,625 ETB, while for chemical fertilizer it was 1,725 ETB, resulting in a combined estimated production cost of 8,225 ETB (Table 11). The revenue generated from compost, inorganic fertilizer, BSFFF, control, and pond water was estimated to be 3,681 ETB, 3,934 ETB, 4,018 ETB, 2,349 ETB, and 4,400 ETB, respectively. Total revenue of 22,792 ETB was generated, with a combined cost of 10,245 ETB for vegetable and fish production, resulting in a net profit of 12,547 ETB (Table 11).

Table 11. Partial budget analysis of fish and vegetable production

Total cost & revenue of vegetable production in 96 m^2	**Treatments**				
	compost	chemical fertilizer	BSFFF	Control	pond water
Vegetable land preparation	300	300	300	300	300
Fertilizer	-	100	-	-	-
Chemical to kill Mongoose	25	25	25	25	25
Vegetable seed purchase	100	100	100	100	100
Labor (per month)	400*3	400*3	400*3	400*3	400*3

Total input cost	1625	1725	1625	1625	1625
Vegetable sales (revenue)	3681	3934	4018	2349	4400
Net profit from each treatment	2056	2209	2393	724	2775
Total profit of the whole treatments	10,157ETB				

Fish production cost and net profit in Ethiopian birr (ETB)

Pond maintenance	1,000
Supplementary feed preparation	1,020
Revenue generated from fish sell	4,410
Total profit (revenue-cost)	2,390
Net profit of the whole system in Ethiopian birr (ETB)	12,547
Net profit from integrated farming (pond water only)	5,165

The net profitability in vegetable production using compost, chemical fertilizer, BSFFF, control, and pond water was 2,056 ETB, 2,209 ETB, 2,393 ETB, 724 ETB, and 5,165 ETB, respectively. The current study revealed that the integrated fish-vegetable system, utilizing chicken manure as pond fertilizer, generated the highest net profit. This may be due to the system's ability to produce multiple products within a single system. As shown in (Table 11), in terms of profitability, the study found that fish and vegetable production using pond water resulted in a net profit of 5,165 ETB, which was 2.5 times greater than vegetable production using compost, yielding 2,056 ETB. Furthermore, fish and vegetable production using pond water proved to be 2.3 times more profitable than vegetable production using chemical fertilizer, which yielded 2,209 ETB.

Similarly, fish and vegetable production using pond water was more profitable than vegetable production using BSFFF by 2.1 times which has a net profit of 2,393 ETB. The most notable difference in profitability was observed between fish and vegetable production using pond water and vegetable production using tap water (control). The former yielded a substantial net profit of 5,165 ETB, which was a remarkable 7.1 times higher than the net profit of 724 ETB (Table 11) from vegetable production using tap water.

The current result agrees with the finding of Shoko *et al.* (2011), who reported that integrated farming systems yield higher economic returns compared to non-integrated systems. Similarly, a study conducted by Belay Adugna *et al.* (2016) on the profitability of integrated fish-horticulture crops revealed that vegetable cultivation using fish pond water alone is more profitable than the conventional method of vegetable cultivation with fertilizer application. Oladimeji & Isah (2019) also reported that integrated fish-vegetable farming systems are more profitable practices compared to sole fish farming systems, contributing to food security, environmental sustainability, and ecological sustainability. Furthermore, Mlelwa (2016) reported significantly higher net income from *O. niloticus* cultured in fertilized ponds with supplementary feeding, which supports the findings of the present study.

Additionally, Alam *et al.* (2009) suggest that an integrated production approach involving poultry, fish, and vegetables is an excellent strategy for sustainable food production and income generation. The study by Gabriel *et al.* (2007) further emphasizes the benefits of integrated fish farming, highlighting its potential to reduce reliance on synthetic fertilizers and other inputs by recycling nutrients from fish waste into crops, thereby maximizing resource efficiency. Overall, the integrated fish-vegetable farming systems investigated in these studies demonstrated higher profitability and offered a range of positive impacts on food production.

4.8. Water quality parameters

Throughout the study period, the physicochemical parameters of the pond water, such as temperature, pH, water transparency, and dissolved oxygen (DO), exhibited minimal temporal variation. The analysis of the data revealed that all recorded water quality parameters during the four months showed no marked difference and remained within the acceptable range for optimal *O. niloticus* production.

As shown in (Table 12), the minimum and maximum water temperatures recorded during the experimental period were 25.2 °C and 27.0 °C, respectively, with an average temperature of 26.2 °C. The lowest temperature was recorded in January, while the highest temperature was recorded in March. According to a study by Verma *et al.* (2022), temperature is a critical aspect of aquaculture management, as it can have a significant impact on growth, metabolic activity, physiological functions (feed utilization, feed conversion, growth rate), and fish productivity. Moreover, temperature differences also affect the feeding rate of fish and hence the growth rate (Zenebe Tadesse *et al.*, 2012).

According to Abd El-Hack *et al.* (2022), a thermal range of 20–30 °C was found to be suitable for *O. niloticus* regarding the optimum growth performance and survival rate. The mean (26.2) temperature value obtained in the present study is in agreement with the findings of Megerssa Endebu *et al.* (2016), who reported growth performance in a temperature range of 22–26.5 °C in a poly-culture system of *O. niloticus* and *Cyprinus carpio*. Overall, the current result of temperature measured during the experimental period remained within the acceptable range required for normal growth of *O. niloticus.*

In aquaculture, pH is an important water quality parameter that needs to be monitored and controlled to ensure the health and growth of the fish. The pH values recorded during the experiment ranged from 8.1 in March to 8.4 in January (Table 12), with an average pH value of 8.2. This average pH value agrees with the finding of Dinku Getu *et al.* (2017), who reported an average pH value of 8.1. According to the study by Charles *et al.* (2007), the pH of pond waters should be maintained within the optimum range of 6.5-9.0 for fish. The recorded pH values of 8.1-8.4 in the present study fall within this recommended range. These findings are also consistent with the study by Stone & Thomforde (2003), which reported a desirable pH range of 6.5-9.5 for pond water. Generally, pH in the present study was optimum for the growth of *O. niloticus* fingerlings.

Dissolved oxygen (DO) is a critical parameter in aquaculture production as it is essential for the survival and growth of aquatic animals and can be affected by a variety of factors, including temperature, water movement, and the presence of aquatic plants or algae (Maloth *et al.,* 2021). In the present study, the content of dissolved oxygen showed monthly variation in an inverse relation with water temperature. The minimum dissolved oxygen recorded during the experimental period was 4.8 mg/l in March, while the maximum was 5.4 mg/l in January (Table 12). The mean dissolved oxygen value obtained in this experiment was 5.1 mg/l.

The lower dissolved oxygen content in March may be due to the relatively higher water temperature. According to Verma *et al.* (2022), warmer water holds less oxygen, which can lead to lower oxygen levels in the pond. The dissolved oxygen values obtained in the current study are consistent with the results found by Makori *et al.* (2017), who reported better growth performance of *O. niloticus* in a pond culture system with dissolved oxygen values ranging from 4.86 mg/l to 10.53 mg/l. Additionally, the mean value of the present study agrees with the recommendations of Bhatnagar & Singh (2010) and the findings of Francis-Floyd (1997), who reported that dissolved oxygen levels greater than 5 mg/l support good fish production.

Table 12. Water quality parameter of the integrated aquaculture system

Parameters	Months			
	January	February	March	April
Temperature (°c)	25.2±0.07	26.5±0.15	27.0±0.19	26.3±0.09
pH	8.4±0.06	8.2±0.02	8.1±0.02	8.3±0.04
Dissolved oxygen (mg/l)	5.4±0.04	5.0±0.1	4.8±0.07	5.2±0.04
Secchi depth visibility (cm)	39.2±0.2	36.2±0.75	34.5±0.6	32.2±1.6

Water transparency, also known as water clarity or Secchi depth, refers to the measure of how clear or transparent water appears. It is a measure of how far light can penetrate through the water column, and it is influenced by several factors such as suspended particles, dissolved substances, and phytoplankton abundance. In the present study, the Secchi depth values in the fish pond were measured and found to range from 32.2 cm to 39.2 cm (Table 12), with an average Secchi depth visibility of 35.5 cm. These findings regarding the Secchi depth are consistent with the recommendations outlined in the report by Santhosh & Singh (2007), which emphasize that maintaining a Secchi depth within the range of 30-40 cm is crucial for promoting optimal fish productivity.

Boyd (1998) also reports that a Secchi depth falling within the range of 30-45 cm is considered favorable for fish production. According to Wetzel & Likens (2000), the visibility and clarity of water decrease with an increase in turbidity. Since *O. niloticus* is an omnivorous filter-feeding fish (Turker *et al.*, 2003), measuring Secchi depth becomes vital for detecting turbidity that affects the feeding efficiency of filter-feeder fish species. These fish rely on filtering suspended particles from the water column as their primary feeding mechanism. A study conducted by Wing *et al.* (2021) suggests that high levels of turbidity can significantly hinder their ability to effectively filter feed by reducing visibility and clogging their feeding apparatus, such as gill rakers or specialized filters. Furthermore, Almazan & Boyd (1978) reported that Secchi depth visibility plays a crucial role in accurately estimating plankton density in fish ponds.

5. CONCLUSION AND RECOMMENDATION

5.1. Conclusion

The study evaluated the integration of fish farming with vegetable production as a strategy to enhance food production, profitability, and income diversification. The findings indicate that fish farming contributes to both household food production and income generation for farmers. Integrated fish farming generates higher revenue and net income compared to non-integrated fish farming. However, the practice faces several challenges, including limited fish species diversity, lack of proper harvesting materials, insufficient technical skills, and inadequate government support.

The study found that *O. niloticus* exhibited better growth performance in terms of daily growth rate, specific growth rate, Fulton's condition factor, weight gain, and survival rate. The use of a supplementary diet and chicken manure pond fertilization proved effective in enhancing the growth and health of *O. niloticus.*

In terms of vegetable production, the study revealed that Swiss chard treated with fish pond water showed improved growth performance in terms of height, number of leaves, leaf area, and fresh weight. The fish pond water also enhanced soil properties, such as organic matter, electrical conductivity, and exchangeable cations, when compared to the control treatment using tap water. The fish pond water treatment showed comparable results to other types of fertilizers.

Regarding the phytoplankton composition in fish monoculture pond systems, the study identified four groups: Chlorophyceae, Cyanophyceae, Bacillariophyceae, and Dinophyceae. Chlorophyceae was the most abundant, followed by Bacillariophyceae, Cyanophyceae, and Dinophyceae. A total of 18 genera were identified. The stomach contents of *O. niloticus* primarily comprised phytoplankton, zooplankton, and some detritus. Phytoplankton, particularly Chlorophyceae and Bacillariophyceae, were the dominant groups preferred by the *O. niloticus*.

In terms of economic viability, the study found that the integrated fish-vegetable system generated the highest net profit of 5,165 ETB, which was 2.5 times greater than vegetable production using compost, 2.3 times greater than using chemical fertilizer, 2.1 times greater than using black soldier fly larvae frass fertilizer, and 7.1 times greater than using tap water. The integrated system also had the highest benefit-cost ratio of 1.9, indicating its economic efficiency and viability. Generally, the integrated farming system is a valuable practice as it provides diversified yields in a single package, resulting in cost reduction.

5.2. Recommendations

Based on the findings in the present study the following recommendations are drawn.

- The constraints mentioned by fish farmers, such as the need for technical support from fish experts, availability of harvesting materials, limited diversity of fish species, and shortage of vegetable seeds, poultry breeds, and high-quality fish feed, should be addressed.
- To serve as models for fish farmers and provide practical examples and inspiration for the successful integration of fish and vegetable farming, demonstration farms or pilot projects should be prepared.
- The study used mixed-sex tilapia, which resulted in early maturation and reproduction of the fish, affecting their growth performance and yield. Future studies should use male-only tilapia to avoid this problem and achieve higher productivity and profitability.

- Integrating fish with vegetables by using chicken manure as a pond fertilizer, which has shown positive results in terms of fish growth, and phytoplankton composition, should be encouraged.
- The utilization of nutrient-rich fish pond water, which has shown remarkable outcomes in enhancing vegetable growth performance, increasing yield, and improving soil fertility, should be promoted as it helps reduce reliance on external sources of irrigation water and chemical fertilizers.
- Further research is needed to explore diverse fish-vegetable combinations, expanding options for farmers based on market demand and ensuring species compatibility between fish and vegetable species for successful integration.
- The study did not explore the social and economic factors that influence the adoption and sustainability of the integrated fish-vegetable system, such as the role of social norms, cultural values, market access, extension services, and policy support. Future studies should conduct a comprehensive socioeconomic analysis of the integrated system to understand the opportunities and challenges of promoting and scaling up the practice.

References

Abd El-Hack, E., El-Saadony, T., Nader, M., Salem, M., El-Tahan, M., Soliman, M. & Khafaga, F. (2022). Effect of environmental factors on growth performance of Nile tilapia (*Oreochromis niloticus*). *International Journal of Biometeorology*, **66** (11): 21.

Abdel-Tawwab, M. (2000). Food and feeding habits of *Oreochromis niloticus* under the effect of inorganic fertilizer with different N: P: K ratios in Abbasa fishponds. *Egyptian Journal of Agricultural Research*, ***78*** (1): 437-448.

Abdel-Tawwab, M. (2003). Occurrence of phytoplankton in stomach content and its selectivity by Nile tilapia (*Oreochromis niloticus*) cultured in fertilized earthen ponds, **23**: 153-166.

Abdul-Rahman, S., Saoud, P., Owaied, K., Holail, H., Farajalla, N., Haidar, M. & Ghanawi, J. (2016). Improving water use efficiency in semi-arid regions through integrated aquaculture/agriculture. *In Aquaculture Technology in Developing Countries*, Routledge, pp. 77-95.

Abiya, A., Kupesa, M., Beesigamukama, D., Kassie, M., Mureithi, D., Thairu, D. & Niassy, S. (2022). Agronomic Performance of Kale (Brassica oleracea) and Swiss Chard (Beta vulgaris) Grown on Soil Amended with Black Soldier Fly Frass Fertilizer under Wonder Multistorey Gardening System. *Agronomy*, **12**(9): 2211.

Adamneh Dagne & Abelneh Yimer. (2018). Growth performance of three Nile tilapia (*Oreochromis niloticus* L., 1758) populations in pond system. *International Journal of Aquaculture,* **8** (9): 65-72.

Adanech Bahiru, Marisennayya, S. & Elias Bojago. (2023). Status of household food security, its determinants, and coping strategies in the Humbo district, Southern

Ethiopia. *Journal of Agriculture and Food Research*, **11**, p.100461.

Ahmad, A., Chin, J., Harun, M. & Low, S. (2022). Environmental impacts and imperative technologies towards sustainable treatment of aquaculture wastewater: A review. *Journal of Water Process Engineering*. https://doi.org/10.1016/j.jwpe.2021.102553

Ahmed, N., Ward, D. & Saint, C. (2014). Can integrated aquaculture-agriculture (IAA) produce “more crop per drop”. *Food Security*, **6**: 767-779.

Ajibade, A., Ayodele, A. & Agbede, A. (2008). Water quality parameters in the major rivers of Kainji Lake National Park, Nigeria. *African Journal of Environmental Science and Technology*, **2** (7): 185-196.

Akinrotimi, A., Abu, O. & Aranyo, A. (2011). Environmentally friendly aquaculture key to sustainable fish farming development in Nigeria. *Continetal Journal of fisheris &Aquitic Sience*, **5** (2):17-31.

Alam, M. Robiul, M. Akkas A. Akhtar, H. Molla, H. & Islam, F. 2009. Integrated approach of pond-based farming systems for sustainable production and income generation. *Bangladesh Journal of Agricultural Research*, **34**:577-584.

Alayu Yalew. (2011). Integration of fish culture with water harvesting ponds in Amhara Region: a means to supplement family food. *In Impacts of climate change and population on tropical aquatic resources, proceedings of the Third International Conference of the Ethiopian Fisheries and Aquatic Sciences Association (EFASA)*, p. 191-199.

Allison, E. (2011). Aquaculture, fisheries, poverty and food security. Working Paper 2011–65. Penang, Malaysia: The WorldFish Center.

Almazan, G. & Boyd, C. (1978). An evaluation of Secchi disk visibility for estimating plankton density in fish ponds. *Hydrobiologia*, **61** (3): 205-208.

Amankwaah, D., Cobbina, J., Tiwaa, A., Bakobie, N. & Millicent, E. (2014). Assessment of pond effluent effect on water quality of Asuofia Stream, Ghana. *African Journal of Environmental Science and Tefchnology*, **8** (5): 306-311.

Anani, F. & Nunoo, F. (2016). Length-weight Relationship and Condition Factor of Nile Tilapia, *Oreochromis niloticus* fed Farm-made and Commercial Tilapia Diet. *Int J Fish Aquat Stud,* **4** (5): 647–650.

Anyega, O., Korir, K., Beesigamukama, D., Changeh, J., Nkoba, K., Subramanian, S., Loon, A. Van, J. & Tanga, C. M. (2021). Black soldier fly-composted organic fertilizer enhances growth, yield, and nutrient quality of three key vegetable crops in Sub-Saharan Africa. *Frontiers in plant science*, **12**:680312.

Ashagrie Gibtan, Abebe Getahun & Seyoum Mengistou. (2008). Effect of stocking density on the growth performance and yield of Nile tilapia [*Oreochromis niloticus* (L., 1758)] in a cage culture system in Lake Kuriftu, Ethiopia. *Aquaculture Research*, **39** (13): 1450-1460.

Azaza, S., Wassim, K., Mensi, F., Abdelmouleh, A., Brini, B. & Kraïem, M. (2009). Evaluation of faba beans (*Vicia faba L. var. minuta*) as a replacement for soybean meal in practical diets of juvenile Nile tilapia *Oreochromis niloticus*. *Aquaculture*, **287** (1-2): 174-179.

Bai, S., Gao, J., Sun, D. & Tian, M. (2020). Monitoring water transparency in shallow and eutrophic lake waters based on GOCI observations. *Remote Sensing*, **12** (1):163.

Beesigamukama, D., Mochoge, B., Korir, N., Fiaboe, K., Nakimbugwe, D., Khamis, F. &

Tanga, C. (2020). Exploring black soldier fly frass as novel fertilizer for improved growth, yield, and nitrogen use efficiency of maize under field conditions. *Frontiers in Plant Science*, **11**: 574-592.

Belay Adugna, Devi, L., Sreenivasa, V. & Aschalew Lakew. (2016). Study on the profitability of fish and Horticrop integrated farming at Nono District, west Shoa zone, Ethiopia. *Greener Journal of Agricultural Sciences*, **6**(2): 41-48.

Berihun Tefera & Goraw Goshu. (2010). Integrating aquaculture with traditional farming system: socioeconomic assessment in the Amhara Region, Ethiopia. *Ecohydrology & Hydrobiology*, **10** (2-4): 223-230.

Bhatnagar, A. & Singh, G. (2010). Culture fisheries in village ponds: a multi-location study in Haryana, India. *Agriculture and Biology Journal of North America*, **1** (5): 961-968.

Bhatta, S., Iwai, T., Miura, T., Higuchi, M., Maugars, G. & Miura, C. (2013). Differences between male and female growth and sexual maturation in tilapia (*Oreochromis mossambicus*). *Kathmandu University Journal of Science, Engineering and Technology*, **8** (2): 57-65.

Biswas, A., Morita, T., Yoshizaki, G., Maita, M. & Takeuchi, T. (2005). Control of reproduction in Nile tilapia Oreochromis niloticus (L.) by photoperiod manipulation. *Aquaculture*, **243** (1-4): 229-239.

Boeing, H., Bechthold, A., Bub, A., Ellinger, S., Haller, D., Kroke, A. & Watzl, B. (2012). Critical review: vegetables and fruit in the prevention of chronic diseases. *European journal of nutrition*, **51**: 637-663.

Bolner, K., Copatti, C., Rosso, F., Loro, V. & Baldisserotto, B. (2014). Water pH and metabolic parameters in silver catfish (Rhamdia quelen). *Biochemical Systematics and Ecology,* **56**:202-208.

Bostock, J., McAndrew, B., Richards, R., Jauncey, K., Telfer, T., Lorenzen, K., Telfer, T., Lorenzen, K., Ross, L., Handisydde, N., Gatward, I. & Corner, R. (2010). Aquaculture: global status and trends. *Philosophical Transactions of the Royal Society B: Biological Sciences,* **365** (1554): 2897-2912.

Boyd, C. & Hanson, T. (2010). Dissolved-oxygen concentrations in pond aquaculture. *Aquaculture,* p. 40–41.

Boyd, C. (1998). Water quality for pond aquaculture, research and development series No.43. International Centre for Aquaculture and Aquatic Environments, Alabama Agricultural Experiment Station, Auburn University, Alabama.

Boyd, C. (2016). Phytoplankton a crucial component of aquaculture pond ecosystems. *Global Aquaculture Advocate,* 1-4.

Boyd, C. (2018). Aquaculture pond fertilization. *CABI Reviews,*1–12.

Boyd, C., Tucker, C. & Somridhivej, B. (2016). Alkalinity and hardness: critical but elusive concepts in aquaculture. *Journal of the World Aquaculture Society*, **47** (1):6-41.

Boyd, C., Wood, C. & Thunjai, T. (2002). Aquaculture pond bottom soil quality management. Pond Dynamics/Aquaculture Collaborative Research Support Program, Oregon State University.

Bregnballe, J. (2022). A guide to recirculation aquaculture: an introduction to the new environmentally friendly and highly productive closed fish farming systems. In: FAO Euro fish Rep. Food and Agriculture Organization of the United Nations (FAO) and

EUROFISH International organization.

Brown, K., Adger, W. & Turner, R. (1993). Global environmental change and mechanisms for north-south resource transfers. *Journal of International Development*, **5**(6): 571-589.

Brummett, R. & Jamu, D. (2012). From researcher to farmer: partnerships in integrated aquaculture–agriculture systems in Malawi and Cameroon. In *Sustainable Intensification,* Routledge, p.282-289.

Brummett, R., Lazard, J. & Moehl, J. (2008). African aquaculture: Realizing the potential. *Food policy*, **33** (5): 371-385.

Buck, R., Rondinini, S., Covington, A., Baucke, F., Brett, M., Camoes, F.&Wilson, G. (2002). Definition, standards, and procedures (IUPAC Recommendations 2002). *Pure and applied chemistry*, **74** (11): 2169-2200.

CARDI, A. (2010). Mannual on Integrated Farming System. *Caribbean Agricultural Research and Development Institute, (Ministry of Economic Development, Belize 2010),* 1-58.

Chaka Gameda, Fikru Temesgen & Jiqin, H. (2022). Review of adoption and impact assessment on conservation agriculture in Ethiopia. *International Journal of Marketing & Human Resource Research*, **3**(4):203-210.

Channabasavanna, A., Biradar, D., Prabhudev, K. & Hegde, M. (2010). Development of profitable integrated farming system model for small and medium farmers of Tungabhadra project area of Karnataka. *Karnataka Journal of Agricultural Sciences*, **22** (1): (25-27).

Charles, N, Bowman, J. & Omolo, B. (2007). A New Guide to Fish Farming in Kenya. Corvallis, OR: Pond Dynamics/Aquaculture CRSP, Oregon State University.

Chukwu, M. & Afolabi, S. (2017). Phytoplankton abundance and distribution of fish earthen ponds in Lagos, Nigeria. *Journal of Applied Sciences and Environmental Management*, **21**(7): 1245-1249.

Colman, J. & Edwards, P. (1987). Feeding pathways and environmental constraints in waste-fed aquaculture: balance and optimization. In *Detritus and microbial ecology in aquaculture. ICLARM Conference Proceedings*,**14**:240-281.

Conte, F. (2004). Stress and the welfare of cultured fish. *Applied Animal Behaviour Science*, **86** (3-4): 205-223.

Costa-Pierce, Barry, A. & Chopin, T. (2021). The hype, fantasies and realities of aquaculture development globally and in its new geographies. *World Aquac.*, **52**(2): 23-35.

Crissman, C. & Antle, J. (2013). Economic and social impacts of Integrated Aquaculture-Agriculture technologies in Bangladesh.

Daba Tugie, Alemayew Abebe & Megerssa Endebu. (2017). Potential of integrated fish-poultry-vegetable farming system in mitigating nutritional insecurity at small scale farmer’s level in East Wollega, Oromia, Ethiopia. *International Journal of Fisheries and Aquatic Studies*, **5**: 377-382.

Das, S. & Jana, B. (2003). Pond fertilization regimen: state-of-the-art. *Journal of Applied Aquaculture,* **13**(1-2):35-66.

Dinku Getu, Fekadu Amare, Tekleyohannes Berhanu, Hizkiel Kinfo & Tsegaye Terefe. (2017). Evaluation of integrated fish farming with chicken and vegetables in Silte district of Southern Ethiopia. *Advance Research Journal of Multi-Disciplinary Discoveries,* **17**(1):20-27.

Drost, D. (2020). Swiss chard in the garden. Utah State University, Cooperative extension.

Dugan, P. Dey, M. & Sugunan, V. (2006). Fisheries and water productivity in tropical river basins: enhancing food security and livelihoods by managing water for fish, water management. *Journal of Agricultural Science,* **80** (1-3):262-275.

Edwards, P., Lin, C. & Yakupitiyage, A. (2000). Semi-intensive pond aquaculture. In *Tilapias: Biology and exploitation*, Dordrecht: Springer Netherlands, p.377-403.

Elissen, H., van der Weide, R. & Gollenbeek, L. (2023). Effects of black soldier fly frass on plant and soil characteristics: a literature overview. Wageningen Research, Report WPR- 995.

https://doi.org/10.18174/587210

El-Sayed, A. (2013). On-farm feed management practices for Nile tilapia (*Oreochromis niloticus*) in Egypt. *On-farm feeding and feed management in aquaculture*, **583**: 101-129.

Endale Bedada, Ajema Lemma, Wubalem Abera, Abera Donis & Dereje Girma. (2020). Assessment and Mapping of Soil pH and Available Phosphorus Status in Wuchale District, North Shewa Zone, Oromia. *American Journal of Environmental Science and Engineering,* **4** (1):1–6.

Erkie Asmare, Brehan Mohamed & Haimanot Mulugeta. (2019). Assessment of Integrated Aquaculture Intervention System in Amhara Region, Ethiopia. *Ethiopian Journal of Economics,* **28** (2): 1-26.

Falcon, W., Naylor, R. & Shankar, N. (2022). Rethinking global food demand for 2050. *Population and Development Review*, **48**(4): 921-957.

Farrant, D., Frank, K. & Larsen, E. (2021). Reuse and recycle: Integrating aquaculture and agricultural systems to increase production and reduce nutrient pollution. *Science of the total environment*, 785, 146859.

Finegold, C. (2009). The importance of fisheries and aquaculture to development. *The Royal Swedish Academy of Agriculture and Forestry*, p. 353-364.

Fitzsimmons, K. (2016). Global tilapia market update 2015. *World Aquaculture Society, Las Vegas, NV: World Aquaculture Society*.

https://www.researchgate.net/publication/281241348

Fitzsimmons, K., Martinez-Garcia, R. & Gonzalez-Alanis, P. (2011). Why Tilapias is becoming the most important food fish on the planet. Proceedings of the ninth international symposium on tilapia in aquaculture. Shanghai Ocean University, Shanghai, China.

Food and Agriculture Organization of United Nations. (2014). Maximizing the contribution of fish to human nutrition.

https://digitalarchive.worldfishcenter.org

Food & Agriculture Organization. (2018). The State of World Fisheries and Aquaculture. Meeting the sustainable development goals.

Food & Agriculture Organization. (2020). State of world aquaculture 2020 and regional reviews: FAO webinar series. *FAO aquaculture newsletter*, **63**: 17-18.

https://doi.org/10.4060/ca9229en

Francis-Floyd, R. (1997). Dissolved oxygen for fish production. University of Florida Cooperative Extension Service, Institute of Food and Agriculture Sciences, EDIS.

Funge-Smith, S. & Bennett, A. (2019). A fresh look at inland fisheries and their role in food security and livelihoods. *Fish and Fisheries*, **20**(6): 1176-1195.

Gabriel, U., Akinrotimi, O., Bekibele, O. Anyanwu, P. & Onunkwo, D. (2007). Economic benefit and ecological efficiency of integrated fish farming in Nigeria. *Scientific Research and Essay*, **2**(8):302-308.

Gadisa Natea. (2019). Aquaculture potential, status, constraints and future prospects in ethiopia: A Review. *Int J. Adv Res.*, **7**: 336-343.

Gamba, M., Raguindin, F., Asllanaj, E., Merlo, F., Glisic, M., Minder, B. & Muka, T. (2021). Bioactive compounds and nutritional composition of Swiss chard (*Beta vulgaris L. var. cicla* and *flavescens*): a systematic review. *Critical reviews in food science and nutrition*, **61**(20): 3465-3480.

Garlock, T., Asche, F., Anderson, J., Bjørndal, T., Kumar, G., Lorenzen, K., Ropicki, A. & Tveterås, R. (2020). A global blue revolution: aquaculture growth across regions, species, and countries. *Reviews in Fisheries Science & Aquaculture,* **28**(1): 107-116.

Gong, L. (2021). Soil Electrical Conductivity (EC): What’s It, Why Important, How to Measure & More.

Gupta, M. & Acosta, B. (2004). A review of global tilapia farming practices. World Fish Centre, **9**(1):7-16.

Halwart, M. (2020). Fish farming high on the global food system agenda in 2020. *FAO Aquaculture Newsletter*, **61**: 1-3.

Han, X., Rusconi, N., Ali, P., Pagkatipunan, K. & Chen, F. (2017). Nutrients extracted from chicken manure accelerate growth of microalga Scenedesmus obliquus HTB1. *Green and sustainable chemistry*, **7**(2): 101-113.

Hänninen, A. (2014). Production and utilization of tilapia feed in Rural Zambia.

https://urn.fi/URN:NBN:fi:amk-2014112717120

Hao, X., Ball, B., Culley, J., Carter, M. R. & Parkin, G. (2008). Soil density and porosity. *Soil sampling and methods of analysis*, **2**: 179-196.

Haque, M., Islam, M., Ahmed, G. & Haq, M. (1984). Intensive culture of Java Tilapia (*Oreochromis mossambicus)* in floating ponds at different stocking densities. *Bangladesh J. fish*, **7**(1-2): 55-59.

Hart, P. & Reynolds, J. (2002). Handbook of fish biology and fisheries. (Vol. 1)., Fisheries. Oxford: Oxford, Blackwell Publishing.

Hasimuna, O., Maulu, S., Nawanzi, K., Lundu, B., Mphande, J., Phiri, C., Kikamba, E., Siankwilimba, E., Siavwapa, S. & Chibesa, M. (2023). Integrated agriculture-aquaculture as an alternative to improving small-scale fish production in Zambia. *Frontiers in Sustainable Food Systems*, 7, p.1161121.

https://doi.org/10.3389/fsufs.2023.1161121

He, J., Reddy, G., Liu, M. & Shi, P. (2020). A general formula for calculating surface area of the similarly shaped leaves: Evidence from six Magnoliaceae species. *Global Ecology and Conservation*, *23*.

Hendrickson, J., Hanson, D., Tanaka, D. & Sassenrath, G. (2008). Principles of integrated agricultural systems: Introduction to processes and definition. *Renewable Agriculture and Food Systems*, **23**(4): 265-271.

Hol, S., Elissen, H. & van der Weide, R. (2022). Combined digestion of insect frass and cow manure for biogas production. Stichting Wageningen Research, Wageningen Plant Research, Business unit Open Teelten.

Hyslop, E. (1980). Stomach contents analysis a review of methods and their application. *Journal of fish biology*, **17** (4): 411-429.

Ifejika, P., Ayanda, J. & Sule, A. (2007). Socio-economic variables affecting aquaculture production practices in Borgu local government area of Niger state, Nigeria. *Journal of Agriculture and Social research (JASR)*, **7**(2): 20-29.

Jackson, M. (1973). Soil chemical analysis, pentice hall of India Pvt. *Ltd., New Delhi, India*, 151-154.

Janse, S., Taylor, J., Gerber, A. & Van Ginkel, C. (2006). Easy identification of the most common freshwater algae: A guide for the identification of microscopic algae in South African freshwaters. *North-West University and the Department of Water Affairs*.

Jarding, S., Windmar, L., Paterson, R. & Fjallsbak, J. (2000). Quality issues in commercial processing of tilapia (*Oreochromis niloticus*) in Zimbabwe. In *Proceedings from the Fifth International Symposium on Tilapia Aquaculture*, p.588-594.

Jha, S., Kaechele, H., Lana, M., Amjath-Babu, S. & Sieber, S. (2020). Exploring farmers' perceptions of agricultural technologies: A case study from Tanzania. *Sustainability*, **12**(3): 998.

Julie, R. (2011). Why detoxifying Swiss chard is one of the healthiest greens.

Karlson, B. (2017). Preservatives and methods for algal cell enumeration. 509-517.

Kassaye Balkew & Bereket Haji. (2022). The status and potential of small-scale aquaculture development in Southern Ethiopia. *Journal of Applied Aquaculture*, pp.1-19.

Kassaye Balkew. & Gjoen, H. (2012). Comparative studies on the growth performance of four juvenile *Oreochromis niloticus* L., (1758) strains in pond culture, Ethiopia. *International Journal of Aquaculture*, ***2***(7).

Kawarazuka, N. & Béné, C. (2011). The potential role of small fish species in improving micronutrient deficiencies in developing countries: building evidence. *Public health nutrition*, **14**(11): 1927-1938.

Khallaf, E., Galal, M. & Authman, M. (2003). The biology of *Oreochromis niloticus* in a polluted canal. *Ecotoxicology*, **12**: 405-416.

Kocagoz, Y., Bellitürk, K. & Hurma, H. (2022). Comparison Of Organic and Chemical Fertilizer Use: The Case of Muratlı District of Tekirdağ Province. *Adyutayam Dergisi*, **10**(2): 108-127.

Kubala, J., Benefits, N. & It, C. (2022). benefits of Swiss chard Nutrition and how it cooks soup.

https://www.healthline.com/nutrition/swiss-chard

Landon, J. (2014). Booker tropical soil manual: a handbook for soil survey and agricultural land evaluation in the tropics and subtropics.

Laura Dolson. (2022). Swiss Chard Nutrition Information and Health Benefits.

https://www.verywellfit.com/carbohydrate-information-for-chard-2241830

Law-Ogbomo, K., Osaigbovo, A. & Ekwueme, I. (2012). Agronomic efficacy of compost manure and NPK fertilizer on some soil chemical properties and maize production in an ultisol environment. *Journal of Applied and Natural Science*, **4**(2): 172-177.

Leghari, S., Wahocho, N., Laghari, G., HafeezLaghari, A., MustafaBhabhan, G., HussainTalpur, K. & Lashari, A. (2016). Role of nitrogen for plant growth and development: A review. *Advances in Environmental Biology*, **10**(9): 209-219.

Lemma Abera & Zenebe Tadesse. (2009). The potential and prospect of aquaculture development in Ethio-pia. *ESAP Proceedings*.

Lemma Abera. (2017). Evaluation of integrated poultry-fish-horticulture production in Arsi Zone, Ethiopia. *Int J. Fish Aquat.*, **5**:562-565.

Lin, C. Kwei, Y. & Yang, Y. (2001). Developments in integrated aquaculture in Southeast Asia. In Responsible Aquaculture. *Development in Southeast Asia organized by the SEAFDEC Aquaculture Department*, Philippines, p. 77-88.

Lindsey R., Scott, M. & Simmon R. (2010). what is Phytoplankton? NASA Earth Observatory, 20-28.

Luu, L. (2021). The VAC system in northern Vietnam. In Integrated agriculture aquaculture: A primer, FAO fisheries technical paper 407. (Rome: FAO).

https://www.fao.org/3/y1187e/y1187e10.htm#l

Maia, B., Azevedo, C., da Silva, N. & Almeida, F. (2008). Effect using fish effluent and well water irrigated in biofertilizer in the culture of the lettuce, **3**(2): 36-43.

Makori, A., Abuom, P., Kapiyo, R., Anyona, D. & Dida, G. (2017). Effects of water physico-chemical parameters on tilapia (Oreochromis niloticus) growth in earthen ponds in Teso North Sub-County, Busia County. *Fisheries and Aquatic*

Sciences, **20**(1): 1-10.

Mallya, Y. (2007). The effects of dissolved oxygen on fish growth in aquaculture, United Nations University. *Fisheries Training Programme, UNU-FTP*, p*30*.

Maloth, M., Konduri, A., Swapna, M., Sravani, S. & Kisku, C. (2021). Importance of dissolved oxygen in aquaculture pond. **2**(3).

Maria D.& Jose, T. (2007). The Olsen P method is an agronomic and environmental test for predicting phosphate release from acid soils. Nutrient Cycling in Agroecosystems, **77**: 283-292.

Marwaha, N., Beveridge, M., Phillips, M., Komugisha, B., Notere Boso, D., Chan, C. & Wiebe, K. (2020). Alternative seafood: Assessing food, nutrition and livelihood futures of plant-based and cell-based seafood.

https://digitalarchive.worldfishcenter.org

Megerssa Endebu, Daba Tugie & Tokuma Negisho. (2016). Fish growth performance in ponds integrated with poultry farm and fertilized with goat manure: a case in Ethiopian Rift Valley. *Int J Fishery Sci Aquac.*, **3**: 40-45.

Meiludie, E. (2013). Comparative evaluation of growth performance and yield of four tilapia species under culture conditions. Doctoral dissertation, Sokoine University of agriculture. Morogoro, Tanzania. 83 p.

Mekonen Debara, Merkine Bekele & Bereket Haji. (2021). Pre-Extension Demonstration of Integrated-Aquaculture (Fish-Chicken-Vegetable) at Arbegona and Gedeb Woredas, Southern Ethiopia. *Research & Development*, **2**(4): 97-102.

Mlelwa, T. (2016). Growth performance and economic benefit of nile tilapia (*Oreochromis* *niloticus*) and chinese cabbage (*Brassica rapachinensis*) in aquaculture integration (Doctoral dissertation, Sokoine University of Agriculture).

Mohammed Ibrahim, Tadesse Megersa & Haile Ketema. (2016). Poverty alleviation through integrated pond fish farming with poultry and vegetable production at small-scale farmers in Dilla Zuria Woreda, southern Ethiopia. *Journal of Poverty, Investment, and Development* 24.

Mohan, C. (2007). Assessment of freshwater fish seed resources for sustainable aquaculture, *Food & Agriculture Org.*

Moriarty, D. (1986). Bacterial productivity in ponds used for culture of penaeid prawns. *Microbial Ecology*, **12**: 259-269.

Muendo, P., Verdegem, M., Stoorvogel, J., Milstein, A., Gamal, E., Duc, P. & Verreth, J. (2014). Sediment accumulation in fish ponds; its potential for agricultural use. *IJFAS.*, **1**(5):228–241.

Mulokozi, D. (2021). Integrated Agriculture and Aquaculture Systems (IAA) for Enhanced Food Production and Income Diversification in Tanzania (Doctoral dissertation, Department of Physical Geography, Stockholm University).

Mulokozi, D., Berg, H., Tamatamah, R., Lundh, T. & Onyango, P. (2022). Integration of Nile tilapia (*Oreochromis niloticus*) and vegetables (*Amaranthus hybridus* and *Brassica rapa pekinensis*) for improved production, water use efficiency and nutrient recycling. *Aquaculture, fish and fisheries*, **2**(6): 493-506.

Mustapha, A. (2020). Importance of pH Control in Aquaculture. *September 2019.*

https://www.researchgate.net/publication/340870601_

Mustapha, M. & Omotoso, J. (2005). An assessment of the physio–chemical properties of Moro Lake. *African Journal of Applied Zoology and Environmental Biology*, **7**: 73-77.

Nnaji, C., Okoye, F. & Ogunseye, J. (2004). Integrated fish farming practices with special reference to combination rates, production figures and economic evaluation. In: Eyo AA, Ayanda JO (eds) *Conference proceedings of fisheries society of Nigerian* (FISON) Owerri, p. 173–178.

Nölle, N., Genschick, S., Schwadorf, K., Hrenn, H., Brandner, S. & Biesalski, H. (2020). Fish as a source of (micro) nutrients to combat hidden hunger in Zambia. *Food Security*, **12**: 1385-1406.

Oladimeji, Y. & Isah, S. (2019). Economic and potential benefits of using fish pond water for vegetable production among fish farmers in Kwara State, Nigeria. *Nigerian Journal of Fisheries and Aquaculture,* **7**(2): 11-19.

Onada, O. & Ogunola, O. (2016). Improving food security in an eco-friendly manner through integrated aquaculture. *Open Access Library Journal,* **3**(3): 1-6.

Oshunsanya, S. (2018). Introductory chapter: Relevance of soil pH to agriculture. In *soil pH for nutrient availability and crop performance*. Intech open.

Paerl, H. W. & Tucker, C. (1995). Ecology of blue-green algae in aquaculture ponds. *Journal of the World Aquaculture Society*, **26**(2): 109-131.

Pandit, N. & Nakamura, M. (2010). Effect of high temperature on survival, growth, and feed conversion ratio of Nile tilapia, *Oreochromis niloticus*. *Our Nature,* **8**(1): 219-224.

Payebo, C. & Ogidi, I. (2020). Evaluation of fish pond water on the growth and yield of maize at Wilberforce Island, Amassoma. **8** (9): 1-7.

Pörtner, H., Langenbuch, M. & Michaelidis, B. (2005). Synergistic effects of temperature extremes, hypoxia, and increases in CO2 on marine animals: From Earth history to global change. *Journal of Geophysical Research: Oceans*, **110**: C09S10.

Prein, M. & Ahmed, M. (2000). Integration of aquaculture into smallholder farming systems for improved food security and household nutrition. *Food and Nutrition Bulletin*, **21**(4): 466-471.

Prein, M. (2002). Integration of aquaculture into crop–animal systems in Asia. *Agricultural systems*, **71**(1-2): 127-146.

Ramachandra, T. & Solanki, M. (2007). Ecological assessment of lentic water bodies of Bangalore. *The Ministry of Science and Technology*, **25**: 96.

Rapatsa, M. & Moyo, N. (2013). Performance evaluation of chicken, cow, and pig manure in the production of natural fish food in aqua dams stocked with *Oreochromis mossambicus*. *Physics and Chemistry of the Earth, Parts A/B/C*, **66**: 68-74.

Respikius, M., Ahmad, A., Lamtane, H. & Mtui, H. (2020). Potential, challenges, and opportunities for promoting integrated agri-aquaculture among vegetable growers and fish farmers in Mvomero district of Morogoro region, Tanzania. *Tanzania Journal of Agricultural Sciences*, **19**(2):78-91.

Sahlemedhin Sertsu and Taye Bekele. (2000). Procedures for soil and plant analysis. National Soil Research Centre, Ethiopian Agricultural Research Organization, Addis Ababa, Ethiopia. *Ethiopian Journal of Science and Technology*, **11**(1): 29.

Santhosh, B. & Singh, N. (2007). Guidelines for water quality management for fish culture in Tripura. *ICAR Research Complex for NEH Region, Tripura Center,* *Publication*, **29**(10).

Savci, S. (2012). Investigation of effect of chemical fertilizers on environment. *Apcbee Procedia***, 1**: 287–292.

Sener, G., Saçan, O., Yanardağ, R. & Ayanoğlu-Dülger, G. (2002). Effects of chard (*Beta vulgaris L. var. cicla*) extract on oxidative injury in the aorta and heart of streptozotocin-diabetic rats. *Journal of medicinal food*, **5**(1): 37-42.

Shahabuddin, A., Khan, M., Saha, D., Ayna, E., Wonkwon, K., Murray, W., Yoshimatsu, T. & Araki, T. (2015). Length-weight relationship and condition factor of juvenile Nile Tilapia Oreochromis niloticus (Linnaeus 1758) Fed Diets with Pyropia spheroplasts in closed recirculating system. *Asian Fisheries Science*, **28**(3): 117-129.

Sheard, R. (1991). Soil Structure, Density and Porosity. In *Pesticide Safety Training Seminar, London*.

Sheheli, S., Fatema, K. & Haque, S. (2013). Existing status and practices of fish farming in Trishal Upazila of Mymensingh District. *Progressive Agriculture*, **24**(1-2): 191-201.

Shi, P., Liu, M., Yu, X., Gielis, J. & Ratkowsky, D. (2019). Proportional relationship between leaf area and the product of leaf length and width of four types of special leaf shapes. *Forests*, **10**(2): 178.

Shoko, A., Getabu, A. & Mwayuli, G. (2011). Growth performance, yields, and economic benefits of Nile tilapia *Oreochromis niloticus* and Kales Brassica oleracea cultured under vegetable-fish culture integration. *Tanzania Journal of Science*, **37**:37-48.

Sibilo Gashure and Desalegn Wana. (2023). Sustainability of the long-term indigenous soil and water conservation practices in the UNESCO designated cultural landscapes of Konso, Ethiopia. *Current Research in Environmental Sustainability*, *5*, p.100221.

Singh, S., Prabjeet, S., Verma, N., & Kumar, D. (2021). Integrated fish farming rationale and scope; College of Fisheries, G.B.Pant University of Agriculture and Technology, Pantnagar, India.

https://doi.org/10.3389/fsufs.2023.1161121

Sobulo, R., & Osiname, O. (1981). Soils and fertilizer use in Western Nigeria. Institute of Agricultural Research.

Solomon Melaku & Natarajan, P. (2019). Status of integrated aquaculture-agriculture systems in Africa. *Int. J. Fish Aquat.*, **7**: 263-269.

Sorathiya, L., Fulsoundar, A., Tyagi, K., Patel, M. & Singh, R. (2014). Eco-friendly and modern methods of livestock waste recycling for enhancing farm profitability. *International Journal of Recycling of Organic Waste in Agriculture*, **3**: 1-7.

Stone, N. & Thomforde, H. (2004). Understanding your fish pond water analysis report Cooperative Extension Program, University of Arkansas at Pine Bluff, US Department of Agriculture, and county governments cooperating. 1-4.

Tam, V. (2008). Economic comparison of concrete recycling: A case study approach. *Resources, conservation and recycling*, **52**(5):821-828.

Teklay Gebru & Kassaye Balkew Workagegn. (2022). Plankton Composition and Abundance in Semi-Intensive Aquaculture Pond and their Preference by Nile tilapia. *Aquaculture Studies*, **23**(2).

Teklay Gebru. (2022). Evaluation of Productivity and Profitability of Nile Tilapia (*O. niloticus*) with Beetroot (Beta vulgaris) and Carrot (Daucus carota). *Journal of Aquaculture Research & Development*.

Tipraqsa, P., Craswell, E., Noble, D., & Schmidt-Vogt, D. (2007). Resource integration for multiple benefits: multifunctionality of integrated farming systems in Northeast Thailand. *Agricultural Systems*, **94**(3): 694-703.

Tokuma Negisho, Megerssa Endebu, Daba Tugie &John Barnabas. (2017). Effect of various supplementary feedings on growth of Nile Tilapia (*Oreochromis niloticus*) in concrete ponds. *J Chem Bio Phy Sci*, **7**: 443-450.

Turker, H., Eversole, A. & Brune, D. (2003). Filtration of green algae and cyanobacteria by Nile tilapia, Oreochromis niloticus, in the Partitioned Aquaculture System. *Aquaculture*, **215**(1-4): 93-101.

Ugwumba, C., Okoh, R., Ike, P., Nnabuife, E. & Orji, E. (2010). Integrated farming system and its effect on farm cash income in Awka south agricultural zone of Anambra State, Nigeria. *American-Eurasian Journal of Agricultural and Environmental Science*, **8**(1):1-6.

United Nations Department of Economic and Social Affairs, Population Division (2022). World Population Prospects 2022: Summary of Results, United Nations Publication. New York, NY, USA.

http://population.un.org/wpp

USDA-NRCS. (1998). Soil Bulk Density/Moisture/Aeration-Soil quality kit -Guides for educators.USA. 1–9.

Valencia, E., Adjei, M. & Martin, J. (2001). Aquaculture effluent as a water and nutrient source for hay production in the seasonally dry tropics. *Communications in soil science and plant analysis*, **32**(7-8): 1293-1301.

Verma, D., Satyaveer, N., Kumar, P. & Jayaswa, R. (2022). Important water quality parameters in aquaculture: An overview. *Aquaculture & Environment,* **3**(3): 24-29.

Wang, H., Xu, J., Liu, X., Zhang, D., Li, L., Li, W. & Sheng, L. (2019). Effects of long-term application of organic fertilizer on improving organic matter content and retarding acidity in red soil from China. *Soil and Tillage Research*, p195.

Wetzel, R. & Likens, G. (2000). Limnological analyses. Springer Science & Business Media. 85-113.

Wing, J., Champneys, T. & Ioannou, C. (2021). The impact of turbidity on foraging and risk-taking in the invasive Nile tilapia (*Oreochromis niloticus*) and a threatened native cichlid (Oreochromis amphimelas). *Behavioral Ecology and Sociobiology,* **75**: 1-13.

Yared Mesfin. (2022). Demonstration of Integrated Fish Farming with Vegetables and Herb Production. *Res. Dev.,* **3**(1): 52-58.

Ye, Y. & Gutierrez, N. (2017). Ending fishery overexploitation by expanding from local successes to globalized solutions. *Nature Ecology & Evolution*, **1**(7):179.

Yeasmin, M., Hoque, M. & Rahman, M. (2013). Training needs of the fish farmers on integrated fish farming. *Progressive Agriculture,* **24**(1-2): 181-189.

Zajdband, A. (2011). Integrated agri-aquaculture systems. *Genetics, biofuels and local farming systems*, 87-127.

Zenebe Tadesse, Abeba Wolde Gebriel, Mulugeta Jovani, Fekadu Tefera & Fasil Degefu. (2012). Effect of supplementary feeding of agro-industrial byproducts on the growth performance of Nile tilapia (*Oreochromis niloticus* L.) in concrete ponds. *Ethiopian Journal of Biological Sciences,* **11**(1): 29-41.

APPENDICES

Appendix 1. Administered questionnaire for fish Farmer

Serial No…….

Date______/______/ 2015

Greetings! My name is Kokobe Teferdegn from Hawassa University, Department of Aquatic Science, fisheries and Aquaculture MSc student in Aquaculture and Fisheries management. I am doing research on integrating fish farming systems with vegetables: a strategy to enhance food production, profitability, and income diversification. The main objective of this questionnaire is to assess the status of fish farming practice (Integrated (Aquaculture and non-Integrated Aquaculture) including productivity, constraints, and management practice of fish farming in five districts of Sidama Regional State.

I. PERSONAL INFORMATION [DEMOGRAPHIC AND SOCIAL-ECONOMIC CHARACTERISTICS]

1. What is your sex?

   A. Male
   B. Female

2. Which one is your age group?

   A. 15-24
   B. 25-34
   C. 35-44
   D. 44 and above

3. What is your educational level?

   A. Illiterate
   B. Primary
   C. Secondary
   D. Diploma
   E. Degree

4. What is your family size?

A. Two
B. Three
C. Four
D. Five
E. 6 and above

5. What do you think the purpose of fish production be? (More than one answer is possible)

A. Personal consumption
B. Commercial
C. Recreation
D. Other

6. Before starting fish farming have you attended fish farming trainings?

A. Yes

B. No

7. If you get the training, from which center?

A. Agriculture office
B. Fish Research center

C. other

II. POND CHARACTERISTICS

8. What is the Shape of your ponds?

A. Rectangular
B. Circular
C. Triangular

9. What is the Bottom seal of the pond?

A. Earthen
B. Concert
C. Geo-membrane

10. How much size (Length, width, and depth) of your pond measured in cm/meters?

11. Who is the owner of the pond?

A. Self
B. Agricultural research center
C. Other

12. What is your water sources for the fish pond?

A. river
B. ground
C. other

13. Is your fish farming an integrated one?

A. Yes
B. No

14. If your fish farming system is integrated, with which type of farming system it is integrated? (More than one answer is possible)

A. Vegetable
B. Poultry
C. Pig
D. Cattle
E. other

III. FISH POND MANAGEMENT PRACTICES AND PRODUCTION

15. What type of fertilization are you using to increase pond productivity?

A. Organic fertilizers
B. Inorganic fertilizer

16. If you use organic fertilizer what is the source? (More than one answer is possible)

A. Poultry
B. Cow dung
C. Donkeys and decaying plant biomass
D. Sheep and goats
E. Other

17. What is the source of fish seed?

    A. Self
    B. Agricultural research center
    C. Wild seeds
    D. Other

18. At what stage do you stock the fish pond?

    A. Fry
    B. Fingerling
    C. Adult

19. What type of fish species are you using for fish production?

    A. Tilapia
    B. Catfish
    C. Common carp
    D. Mixed (list the species mixed)

20. Who stocks the pond?

    A. Self
    B. District with Zonal fish expert
    C. Agriculture office
    D. Other

21. Do you feed your fish?

    A. Yes
    B. No

22. If you fed the fish what type of feed are you using? More than one answer is possible

    A. Natural feed
    B. Supplementary feed
    C. Feeding with compounded diets and pelleted feed
    D. Other

23. In what frequencies do you feed your fish?

24. What type of harvesting material are using for harvesting your fish?

A. Fish gears
B. Gill net
C. Mosquito net
D. other

25. At what size do you harvest the fish?

A. six months

B. one year

C. Above one year

26. To whom do you supply the fish?

A. Consumer
B. Middle man
C. Other

27. Who manages the pond?...

IV. PRODUCTION COSTS AND RETURNS OF AQUACULTURE AND INTEGRATED AQUACULTURE

28. What is your total cost for the fish farming system?

NO.	Detail description of expenditure (For one harvesting season)	Cost estimate in Birr
1	Cost for pond construction	
2	Cost of labor	
3	Cost for water	
4	Cost for fingerling including transport	
5	Cost for fish feed	
6	Cost for fertilizer	
	Other	
	Total cost	

29. What is your total return from the fish farming system?

30. What is your net income from the fish farming system?

V. CONSTRAINTS TO AQUACULTURE AND IAA FARMING, AND FARMERS' FUTURE PLANS REGARDING FISH FARMING

31. What are the major problems for aquaculture and integrated aquaculture?

32. What is your future plans?

Thank you

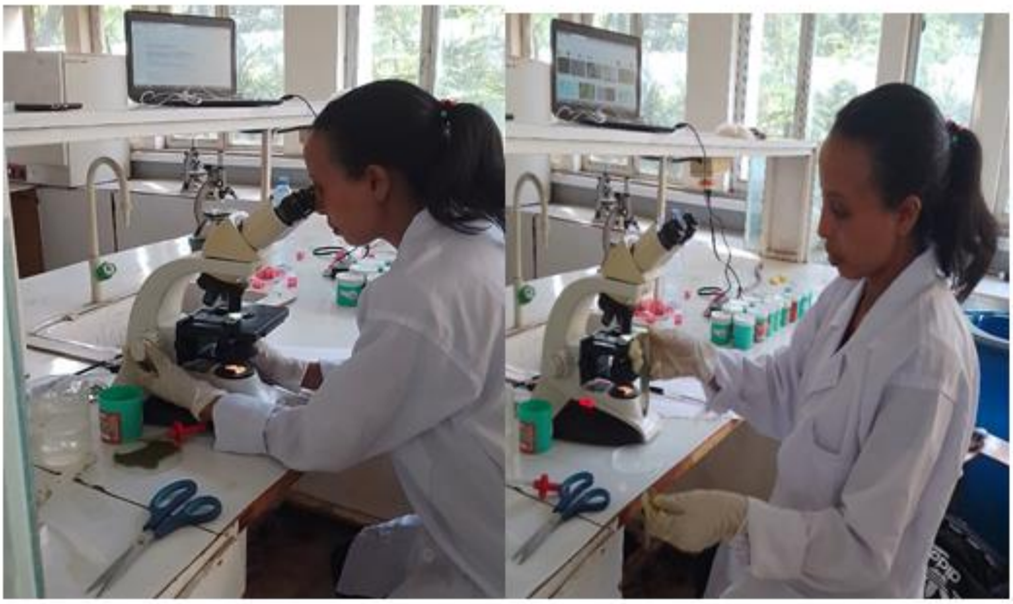
Appendix 2. Image showing seedling of Swiss chard in the field experiment

Appendix 3. Images showing Swiss chard growth and yield

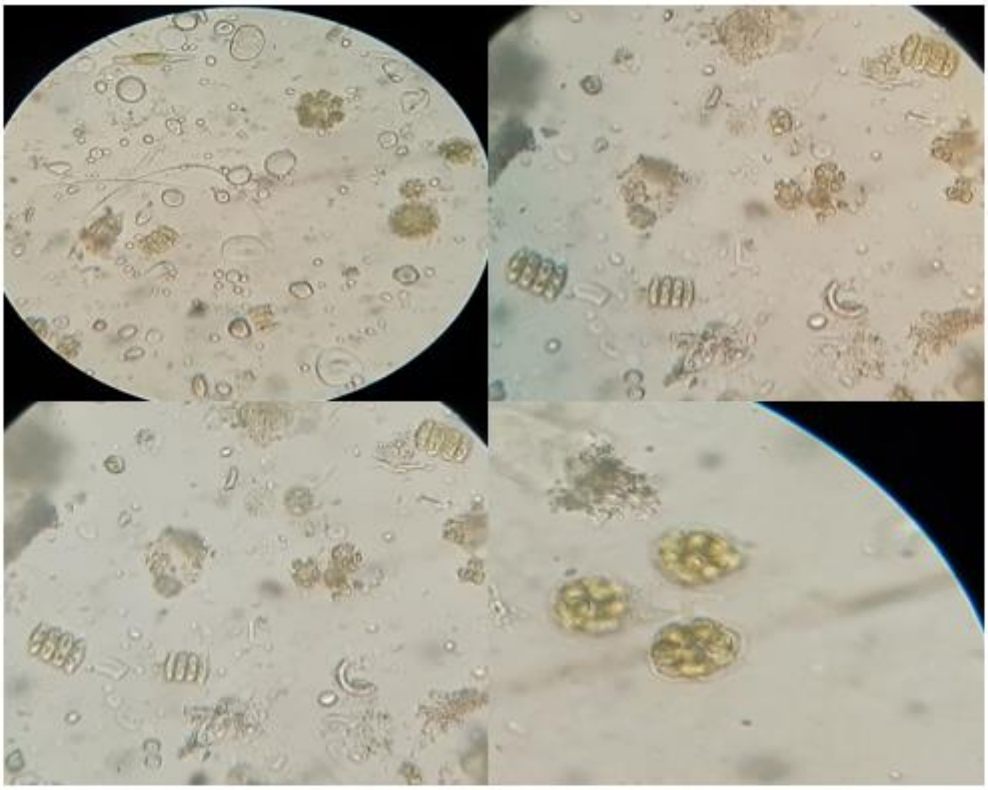

Galaxy F13

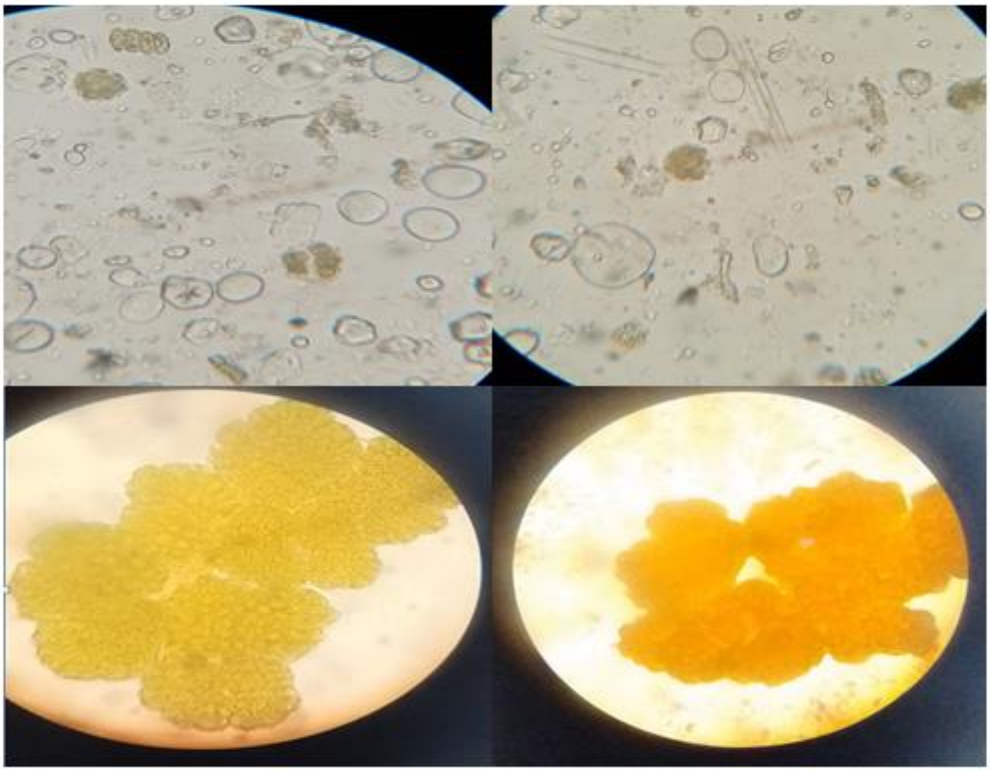
Appendix 4. Images showing field survey and observation

Appendix 5. Microscopic examination of phytoplankton and zooplankton



Appendix 6. Phytoplankton identification





Appendix 7. Final body measurements of the fish