Wiley
Aquaculture Research
Volume 2025, Article ID 2016940, 12 pages
https://doi.org/10.1155/are/2016940

WILEY

Research Article

Evaluation of Productivity and Profitability of Integrated Nile Tilapia (*Oreochromis niloticus* Linnaeus, 1758) and Swiss Chard (*Beta vulgaris* L. var. cicla) Production

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Received 14 October 2025; Revised 20 October 2025; Accepted 23 October 2025

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The growth of the human population requires the establishment of additional food-producing sectors to meet the increasing demand for animal protein sources. In this context, integrated fish farming presents a viable option for enhancing yield diversification with minimal investment costs. The objective of this study was to evaluate the productivity and profitability of Nile tilapia (*O. niloticus*) and Swiss chard (*Beta vulgaris* L. var. cicla). The experiment was conducted at Hawassa University's Centre for Aquaculture Research and Education (CARE) from February 2023 to May 2023. It involved stocking 150 fingerlings of Nile tilapia (*O. niloticus*) with an average weight of 9.8 g in 80 m^2 ponds, alongside the cultivation of Swiss chard in 15 plots measuring 2 m × 2 m, arranged in a randomized complete block design (RCBD). Swiss chard was grown under five different treatments: compost, chemical fertilizer, Black Soldier Fly larvae Frass Fertilizer (BSFFF), tap water as a control, and pond water. Data on fish and vegetable growth parameters and yields were collected and analyzed using SAS software (version 13) at a 95% confidence interval. Results indicated that *O. niloticus* attained a higher final body weight of 98.6 g. Swiss chard treated with fish pond water showed significantly higher growth improvements in leaf length, width, and number ($p < 0.05$) compared to all treatments except BSFFF. Yields at harvest from compost, chemical fertilizer, BSFFF, tap water, and pond water were 49, 52.4, 53.5, 30.6, and 58.7 kg, respectively, with differences among treatments that were not significant, except for the control plots yielding 30.6 kg, which was significantly lower than the others ($p < 0.5$). A cost–benefit analysis revealed that Swiss chard treated with pond water attained higher profitability than the other treatments. Based on the findings of the present study, it is recommended that fish-vegetable integration especially that of Nile tilapia and Swiss chard enhances yield and economic benefits.

Keywords: integrated aquaculture; *Oreochromis niloticus*; profitability; Swiss chard production

1. Introduction

The current 8 billion global population is estimated to reach 8.5 billion by 2030, 9.7 billion by 2050, and 11.2 billion by 2100 [1]. Simultaneously, the global food demand is also expected to increase by 50%–60% in 2050 [2]. 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 fish demand and supply [3]. 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 [4]. Despite aquaculture being one of the rapidly growing sectors in developing food security, it is facing several challenges 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 sources [5]. To address the challenges posed by human activity, several technologies have been identified, including the practice of integrated aquaculture systems [6].

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 [3]. 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 benefits the others. As a result, this symbiotic relationship provides a source of affordable, high-quality food. Incorporating vegetables into fish farming, known as integrated fish farming, not only promotes sustainability but also enhances food affordability and quality. This innovative practice utilizes nutrient-rich water from fish ponds to irrigate vegetables such as onions, tomatoes, and cabbage. By doing so, it reduces dependance on chemical fertilizers, as the fish waste naturally enriches the water, providing essential nutrients for the crop [7]. In return, vegetable waste can serve as a food source for fish, eliminating the need for small-scale farmers to purchase expensive, specially formulated diets.

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 [8]. 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 [9]. This farming technique 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. Fish-vegetable farming also provides a sustainable source of protein through fish production [10]. 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 [11]. The fish waste acts as a natural fertilizer, eliminating the need for synthetic fertilizer.

Integration of aquaculture and agriculture has been practiced for several years in Southeast Asia, especially in Vietnam, India, and China [12]. 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 IAA systems in Malawi and Nigeria have produced encouraging outcomes in terms of reducing poverty and malnutrition [13]. In Ethiopia, the agricultural sector plays a vital role as the mainstay, providing food, employment, and income generation [14]. 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 [15]. Moreover, the declining soil fertility in the country poses additional obstacles to food production [16]. To address these challenges, aquaculture has emerged as a viable additional sector for sustainable food production [17]. To diversify aquaculture technologies, integrated fish farming, which incorporates organic nutrient sources, offers a promising model for sustainable food production [13]. 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.

In Ethiopia, several studies have been conducted on integrating fish farming, particularly Nile tilapia (*Oreochromis niloticus*), with various crop species. However, the development of integrated fish farming production systems remains limited. Therefore, further evaluation of integrated fish farming practices for diversified yield and cost minimization is necessary. The objective of this study was to evaluate the productivity and profitability of fish-vegetable integration through integration of Nile tilapia (*Oreochromis niloticus*) and Swiss chard (*Beta vulgaris* L. var. cicla). It was hypothesized that integrating Nile tilapia with Swiss chard would result in higher growth performance, yield, and income compared to separate cultivation.

2. Materials and Methods

2.1. 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. 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 such as fish fingerlings, a constructed fish pond, and laboratory equipment to MSc and PhD students specializing in Aquatic Sciences, Fisheries, and Aquaculture. The site is located 275 km 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 1 to May 27, 2023.

2.2. Experimental Design. The experiment was conducted to integrate *O. niloticus* production with vegetable cultivation. 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 1). A total of 15 plots, each measuring 2 m × 2 m, were prepared on 96 m^2 of land, including space between blocks and plots. These plots were randomly assigned to five treatments: Treatment 1 (T1) received compost, Treatment 2 (T2) received chemical fertilizer, Treatment 3 (T3) received Black Soldier Fly larvae Frass Fertilizer (BSFFF), Treatment 4 (T4) received tap water as a control, and Treatment 5 (T5) received pond water (Table 1).

To facilitate nutrient accumulation in the fish pond for vegetable growth, the cultivation of Swiss chard began 1 month after stocking the fish. During the seeding process, three Swiss chard seeds were initially sown per planting point and later thinned to one plant per point [21]. The vegetable was planted in five treatments, each with three replications. The spacing between the blocks, plots, rows, and each seedling was 1 m, 50, 40, and 30 cm, respectively. Five rows per plot and six plants per row resulted in a total of 30 plants per

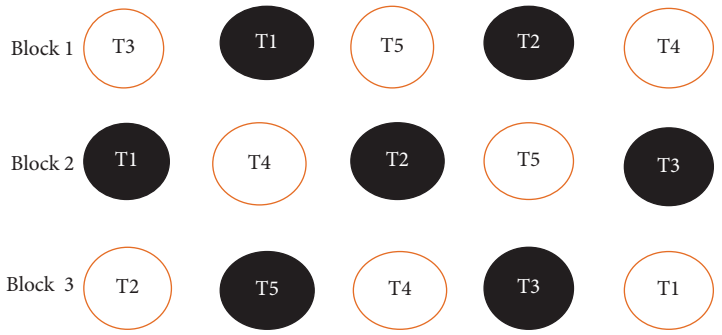

Figure 1: Experimental design of the vegetable plot.

Table 1: Treatment design for vegetable production.

Code	Treatments
T1	Compost (20 t/ha) [18]
T2	Chemical fertilizer (100 kg/ha) [19]
T3	Black soldier fly larvae frass fertilizer (BSFFF) (10.3 t/ha) [20]
T4	Tap water only (control)
T5	Pond water

plot. After proper land preparation, compost and inorganic fertilizer were applied at the seedling stage of Swiss chard. Additionally, a BSFFF was applied 1 week before planting 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 plots that were 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 role of vegetables in this integration is to effectively utilize the nutrients from the fish pond, thereby promoting sustainable agricultural practices. The comparison between pond water and tap water is crucial, as it highlights the advantages of using nutrient-rich water from the fish pond over conventional tap water, which lacks these additional nutrients. The vegetables were grown for 3 months, and follow-up plant management practices were consistent across all treatments throughout the cropping period, with the only variation being the application of different treatments.

2.3. Pond Fertilization and Supplementary Feed Preparation. The pond was fertilized with chicken manure at a rate of 0.1 kg/m^2 [22]. After drying and crushing, the manure was distributed equally in the pond every 2 weeks. Additionally, 30 kg of supplementary fish feed was formulated from locally available ingredients, resulting in a crude protein content of ~26%. The ingredients were ground into flour using a milling machine, mixed, and then pellets were prepared using a pelletizer machine (HOBART, 4812). 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 [23] and was fed twice a day: 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.

2.4. Source and Origin of Experimental Materials: O. niloticus Fingerlings and Swiss Chard. A total of 150 mixed *O. niloticus* fingerlings, with an average weight of 9.8 g and an average length of 10.7 cm, were stocked in a pond measuring 10 m × 8 m × 1.70 m at a density of 2 fingerlings per square meter [24]. The fingerlings used for stocking were obtained from the experimental site of the CARE at Hawassa University, located in the Sidama Region of Ethiopia. The fish were reared in the pond for 4 months. Swiss chard was chosen for evaluation due to its adaptability to various soil types and its ability to tolerate hot climate conditions [23]. The seeds of the Swiss chard variety Fordhook Giant were purchased from a seed supplier in Hawassa city.

2.5. Data Collection

2.5.1. Estimation of Growth Parameters of O. niloticus. Fish body weights were recorded twice a month to the nearest 0.1 g with a weighing balance (SF 400A, Electronic Compact Scale). The initial and final lengths of the fish were also determined using a graduated ruler to the nearest 0.1 cm. Daily growth rate (DGR), specific growth rate (SGR), Fulton's condition factor, and survival rate were calculated using the following formulae, as adopted [25].

$$\text{Average initial weight (g)} = \frac{\text{Sum of individual weight at the beginning}}{\text{Total number of individuals}},$$

$$\text{Average final weight (g)} = \frac{\text{Sum of the individual weight at the end}}{\text{Total number of individuals}},$$

$$\text{Daily growth rate (g/fish/day)} = \frac{\text{Average final weight} - \text{Average initial weight}}{\text{Culturing period (days)}},$$

$$\text{Body weight gain (g)} = \text{Final weight (g)} - \text{Initial weight (g)},$$

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

$$\text{Fulton condition factor} = \frac{\text{Weight}}{\text{Length}^3} \times 100,$$

$$\text{Survival rate}\,(\%) = \frac{\text{Final number of fish}}{\text{Initial number of fish}} \times 100.$$

2.5.2. 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 collected, such as plant height (cm), number of leaves, leaf width (cm), and leaf length (cm), were measured using a ruler. 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 7-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 (Yongkang Zhengya, Model No. ZYOO5). The yields of all the Swiss chard in the five treatments were reported as kg/plot and kg/ha.

2.5.2.1. Plant Height. The 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.

2.5.2.2. 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.

2.5.2.3. 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.

2.5.2.4. 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 [26].

2.5.2.5. 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 [27].

$$La = Ll \times Lw \times 0.68,$$

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.

2.5.3. 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. Data for the cost-benefit analysis were obtained through direct observation and record-keeping during the study period. Variable costs included expenses for pond maintenance, fertilizer, supplementary feed, purchasing vegetable seeds, and labor costs. Fixed costs were determined based on land preparation and other initial investments. Net profit was calculated by subtracting total costs from 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 formulas, as cited in [22]:

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

$$\text{TVC} = Px \times Qx,$$

$$\text{Total cost} = \text{TVC} + \text{fixed cost},$$

$$\text{Profit} = \text{Total revenue} - \text{Total cost},$$

where TVC is the total variable cost, P is the unit price of input, and Q is the total quantity of input.

2.5.4. Water Quality Parameters in the Fish Pond. Throughout the implementation period of the experiment, various water quality parameters, including temperature, pH, transparency, and dissolved oxygen (DO), were regularly measured. The measurements were conducted once per week between 10:00 a.m. and 11:00 a.m., as this time overlapped with the sampling of fish weight. Temperature and DO 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 Secchi disc to measure the Secchi depth.

2.6. Data Analysis. Prior to the actual statistical analysis, data were tested for normality using the Shapiro–Wilk test. The results showed that the data were normally distributed for all the variables, as the p-value was greater than 0.05. Therefore, ANOVA was appropriate for the data analysis. The collected quantitative data on the growth and yield of vegetables and fish were analyzed using analysis of variance (ANOVA) with the JMP procedure in SAS software Pro 13. The Least Significant Differences (LSDs) were used to determine specific significant differences among variables using Tukey's HSD test. Percentage data were converted to proportions before analysis to meet the assumptions of normality. The results were presented and interpreted through tables and figures. Statistical significance was determined at a significance level of $p \leq 0.05$.

3. Results

3.1. Growth Parameters of O. niloticus. The results on growth performance, including DGR, SGR, Fulton's condition factor, weight gain, and survival rate, are presented in Table 2. The average initial length and body weight were 10.7 cm and 9.8 g, respectively. After 4 months, *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 DGR of 0.74 g/day/fish, a SGR of 1.92%, and a condition factor of 2.1.

Table 2: 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

Additionally, the growth performance of male and female *O. niloticus* was assessed over 8 weeks. The average weight of male *O. niloticus* increased significantly throughout the study, reaching ~130.2 g by Week 8, while female *O. niloticus* reached an average weight of 67 g. Statistical analysis revealed significant differences in growth between the sexes starting from Week 2. Notably, these differences became increasingly pronounced in subsequent weeks, with p-values consistently less than 0.05 from Week 3 to Week 8. These results indicate that male *O. niloticus* exhibited significantly greater growth compared to females throughout the study period ($p < 0.05$).

3.2. Water Quality Parameters. Water temperature, pH, water transparency, and DO are presented in Table 3. These parameters exhibited minimal temporal variation throughout the study period. The minimum and maximum water temperatures recorded during the experimental period were 25.2 and 27.0°C, respectively, with an average temperature of 26.2°C. The pH values ranged from 8.1 to 8.4, with an average pH of 8.2. The DO content showed a monthly variation that was inversely related to water temperature, with a minimum of 4.8 mg/L and a maximum of 5.4 mg/L. The mean DO value obtained in this experiment was 5.1 mg/L. In addition, the Secchi depth values in the fish pond were measured, ranging from 32.2 to 39.2 cm, with an average visibility of 35.5 cm.

3.3. Effect of Different Treatments on Swiss Chard Growth Performance and Yield. The data on plant height, leaf length, leaf width, and leaf number for five treatments are summarized in Table 4. 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 increase the height of 87.05% compared to the tap water. Swiss chard treated with compost, chemical fertilizer, and pond water showed no significant differences in height, with increases of 76.27%, 76.77%, and 79.85%, respectively, compared to plants treated with tap water. However, as shown in Figure 2a, the height of Swiss chard treated with compost, chemical fertilizers, BSFFF, and pond water was significantly greater ($p < 0.05$) than that of the control group, which had an average height of 38.02 cm.

Figure 2b demonstrates that the mean leaf length of Swiss chard treated with pond water (47.90 cm) and BSFFF (47.22 cm) resulted in a significant increase in leaf length compared to the other treatments throughout the growing season, with percentage increases of 63.98% and 61.65%, respectively, compared to the tap water (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 tap water (control) group. The mean leaf length of the Swiss chard from tap water (control) (29.21 cm) was the smallest and significantly lower ($p < 0.05$) than that of the other treatments (Table 4).

The mean leaf width of Swiss chard treated with various treatments ranged from 14.50 to 27.34 cm (Table 4). 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 ($p < 0.05$). Swiss chard treated with BSFFF (26.53 cm), chemical fertilizer (24.59 cm), and compost (21.26 cm) showed increased leaf widths of 82.96%, 69.58%, and 46.62%, respectively, compared to the tap water group (14.50 cm). However, there were significant differences among these treatments ($p < 0.05$). This trend is further illustrated in Figure 2c, where the periodically recorded data indicate that the leaf width of Swiss chard from the tap water group was the smallest throughout the measurement period.

The mean leaf number per plant of Swiss chard from various treatments varied from 10.81 to 22.73 (Table 4). 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 plants treated with compost (18.55) and chemical fertilizer (18.47) were comparable to each other (Figure 2d). In contrast, the smallest leaf number (10.81) was recorded for plants watered with tap water (control).

The mean leaf area of Swiss chard plants grown with different treatments falls between 532.6 and 775.1 cm^2 (Table 4). 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 tap water. 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 tap water (control), and this measurement was significantly smaller than all other treatments.

3.4. Effect on Yield. The mean yields at harvest from plots treated with pond water, compost, chemical fertilizer, and BSFFF were 58.7, 49.0, 52.4, and 53.5 kg/plot, respectively (Table 5). Although there were differences in yields among these treatments, they were not significant. In contrast, the yield from the control plots (30.6 kg/plot) was significantly lower than the yields from the other treatments ($p < 0.05$).

3.5. Cost-Benefit Analysis. The cost–benefit analysis revealed significant findings regarding the economic viability of the different treatments. The total estimated production costs for pond water, compost, and BSFFF were 1625 ETB, while chemical fertilizer was slightly higher at 1725 ETB (Table 6). The revenue generated from each treatment demonstrated

Table 3: Water quality parameters of the fish pond (mean ± SE).

Parameters	Months			
	February	March	April	May
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

Table 4: Effects of different treatments on the growth parameters of Swiss chard (mean ± SE).

Treatments	PLH (cm)	LL (cm)	LW (cm)	LN	LA (cm^2)
Compost	67.02 ± 0.54^{b}	45.03 ± 0.67^{b}	21.26 ± 0.52^{d}	18.55 ± 0.17^{b}	651.3 ± 10.62^{b}
Chemical fertilizer	67.21 ± 0.55^{b}	46.07 ± 0.32^{b}	24.59 ± 0.25^{c}	18.47 ± 0.16^{b}	770.4 ± 12.34^{a}
BSFFF	71.12 ± 0.65^{a}	47.22 ± 0.47^{a}	26.53 ± 0.45^{b}	22.16 ± 0.29^{a}	767.9 ± 8.98^{a}
Control	38.02 ± 0.57^{c}	29.21 ± 0.63^{c}	14.50 ± 0.41^{e}	10.81 ± 0.12^{c}	532.6 ± 4.44^{c}
Pond water	68.38 ± 0.55^{b}	47.90 ± 0.45^{a}	27.34 ± 0.29^{a}	22.73 ± 0.30^{a}	775.1 ± 14.32^{a}

Note: PLH, LL, LW, LN, and LA represent plant height, leaf length, leaf width, leaf number, and leaf area, respectively. NB: Different superscript letters in each column indicate significant differences among the means of the respective parameters ($p < 0.05$). Error bars represent the standard deviation of the measurements.

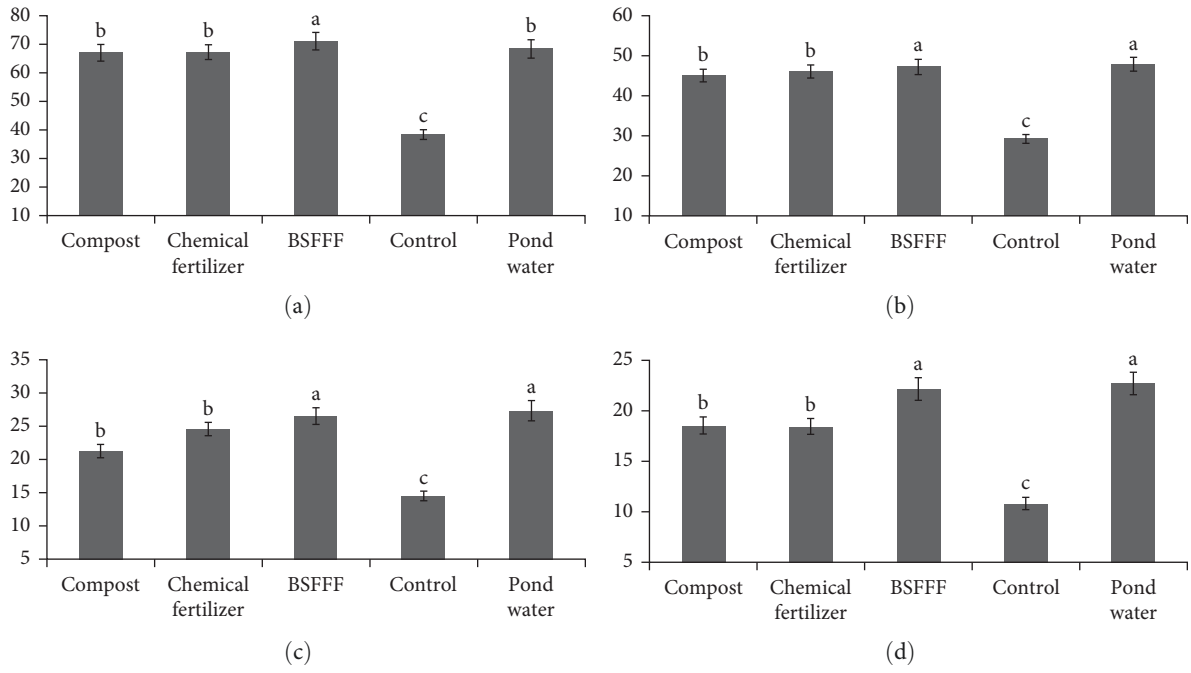

Figure 2: Final growth parameters of Swiss chard treated with various treatments. (a) Plant height (cm): final heights of Swiss chard plants treated with compost, Chemical Fertilizer, Black Soldier Fly Frass Fertilizer (BSFFF), control, and pond water. Error bars represent the mean ± SE of the measurements. Different letters indicate significant differences between treatments ($p < 0.05$). (b) Leaf Length (cm): Final leaf lengths of Swiss chard under the same treatments. Error bars represent the mean ± SE of the measurements. Significant differences are noted by differing letters ($p < 0.05$). (c) Leaf width (cm): Final average leaf width for each treatment. Error bars represent the mean ± SE of the measurements. Bars with different letters indicate significant differences ($p < 0.05$). (d) Leaf number: final count of leaves per plant for each treatment. Error bars represent the mean ± SE of the measurements. Significant differences are marked with different letters ($p < 0.05$).

varying profitability, with pond water yielding the highest net profit. The combined revenue from both vegetable and fish production resulted in a substantial net profit for the system, emphasizing the economic advantages of integrated aquaculture practices.

4. Discussion

4.1. Growth Parameters of O. niloticus. The current study revealed that the fish exhibited better growth performance in terms of DGR, SGR, Fulton's condition factor, weight

Table 5: Effects of different treatments on the yield of Swiss chard (mean ± SE).

Treatments	Kg/plot	Kg/ha	ton/ha
Compost	49.0 ± 0.09^a	122,500[a]	122.5[a]
Chemical fertilizer	52.4 ± 0.14^a	131,125[a]	131.1[a]
BSFFF	53.5 ± 0.12^a	122,500[a]	133.5[a]
Control	30.6 ± 0.05^b	76,500[b]	76.5[b]
Pond water	58.7 ± 0.12^a	146,750[a]	146.7[a]

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

Table 6: Partial budget analysis of fish and vegetable production.

Total cost and 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 the 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 treatment	10,157 ETB	—	—	—	—
Fish production cost and net profit in Ethiopian birr (ETB)					
Pond maintenance					1000
Supplementary feed preparation					1020
Revenue generated from fish sell					4410
Total profit (revenue-cost)					2390
Net profit of the whole system in Ethiopian birr (ETB)					12,547
Net profit from integrated farming (pond water only)					5165

gain, and survival rate. The most efficient feeding regime for tilapia can be achieved with a combination of pond fertilization and supplementary feeding [28]. This approach provides the necessary nutrients and energy required for the growth and development of fish beyond what they can be 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 DGR observed in this study agrees with the findings of [29], who reported a DGR of 0.75 g/day/fish in an integrated fish farming utilizing poultry waste as pond fertilizer. However, [22] reported a higher DGR of 0.88 g/day/fish in integrated farming using chicken manure and supplementary feed, which is greater than the DGR observed in the present study. This difference in DGR may be due to the utilization of different ingredients in the formulation of supplementary feed.

The present study demonstrated a higher DGR compared to the results reported by Tokuma and Endebu [30]. They reported a lower DGR of (0.15–0.35 g/day/fish) when using various supplementary feeds for the growth of *O. niloticus*. This variation in DGR 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 contributes to the improved growth and development of the fish.

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 SGR of *O. niloticus* was 1.92% per day. This rate aligns with [31], who reported SGRs ranging from 1.8% to 2.2% per day concerning the growth performance and yield of various tilapia species. The SGR obtained in the present study is higher than that reported by Gebru [32], who found a SGR of 1.72% per day in the integration of fish and vegetables using chicken manure with supplementary feed.

Furthermore, [33] also reported a lower SGR of 0.8%–1.1% per day in *O. niloticus*, which is less than that observed in the present study. Similarly, the current study has a higher SGR compared to the findings reported by Tugie et al. [34], who reported a SGR of 0.59% in *O. niloticus*. The reason for the

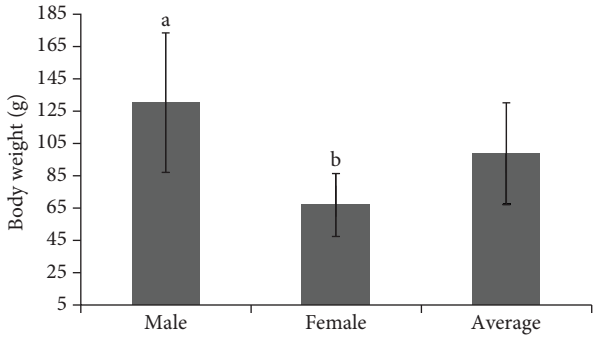

FIGURE 3: Final weight of *O. niloticus*. Data points represent the final average body weight (g) of male and female *O. niloticus* after 105 days of culturing. The letters "a" and "b" denote significant differences in body weight between male and female *O. niloticus*. Error bars represent the mean ± SE of the measurements.

higher SGR 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 Workagegn and Gjoen [35] showed a higher SGR ranging from 2.59% to 2.73% per day, compared to the SGR of 1.92% observed in the present study. This difference in SGR 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. A study reported by Biswas et al. [36] stated that males grow 10%–20% faster than females, and that the growth of female fish will be drastically reduced if fingerling production is not controlled. Female tilapias allocate a significant amount of energy toward reproductive functions, such as egg production. As a result, the energy available for growth is limited, leading to a smaller overall body size [37]. As shown in Figure 3, male *O. niloticus* showed continuous growth performance throughout the experimental period; however, the growth pattern of female *O. niloticus* was comparatively weaker.

Several important factors contribute to the high survival rate of fish in aquaculture. These factors include water quality, feeding, stocking density, and favorable environmental conditions, all of which significantly influence fish survival. In the present study, the survival rate of *O. niloticus* was 98%, which aligns with the finding of [34] (98.75%).

The survival rate in the current study is higher than that reported by Megerssa et al. [38], who found a rate of 73% when feeding fish with poultry manure only. Similarly, the present survival rate is higher than the findings of the [30] study, which reported a 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 the lower survival of *O. niloticus* in aquaculture production.

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 [39]. The Fulton's condition factor of *O. niloticus* in the present study was 2.1. This finding is in agreement with the research conducted by Getu et al. [40], 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 findings of [41], who reported condition factors ranging from 1.39 to 2.01 for *O. niloticus*. A condition factor higher than 1.0 suggests good fish health and indicates isometric growth, which is desirable in fish farming [42]. Based on this criterion, the sampled fish 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.

4.2. Water Quality Parameters. The results of water quality parameters revealed that all recorded parameters over the 4 months showed no marked differences and remained within the acceptable range for optimal *O. niloticus* production. A study conducted by Verma et al. [43] reported that temperature is a critical aspect of aquaculture management, as it can have a significant impact on growth, metabolic activity, and physiological functions (feed utilization, feed conversion, growth rate), and fish productivity. Moreover, temperature differences also affect the feeding rate of fish and, consequently, the growth rate [44]. A thermal range of 20–30°C was found to be suitable for *O. niloticus* regarding the optimum growth performance and survival rate [45]. The mean temperature of 26.2°C obtained in the present study agrees with the findings of [38], who reported growth performance in a temperature range of 22–26.5°C in a poly-culture system of *O. niloticus* and *Cyprinus carpio*.

The recorded pH values of 8.1–8.4 in the present study fall within this recommended range. The average pH value of the present findings agrees with the finding of [40], who reported an average pH value of 8.1. According to the study by Charles et al. [46], the pH of pond waters should be maintained within the optimum range of 6.5–9.0 for fish. These findings are also consistent with the study by Stone and Thomforde [47], which reported a desirable pH range of 6.5–9.5 for pond water. Generally, pH in the present study was optimal for the growth of *O. niloticus* fingerlings.

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 [48]. The lower DO content in April may be due to the relatively higher water temperature. Warmer water holds less oxygen, which can lead to lower oxygen levels in the pond [43]. The DO values obtained in the current study are consistent with the results found by Makori et al. [49], who reported better growth performance of *O. niloticus* in a pond culture system with DO values ranging from 4.86 to 10.53 mg/L. Additionally, the mean value of the present study agrees with the recommendations of [50] and the findings of [51], who reported that DO levels greater than 5 mg/L support good fish production.

The findings regarding the Secchi depth are consistent with the recommendations outlined in the report by Santhosh and Singh [52], which emphasize that maintaining a Secchi depth within the range of 30–40 cm is crucial for promoting optimal fish productivity. Additionally [53], also reports that a Secchi depth falling within the range of 30–45 cm is considered favorable for fish production. The visibility and clarity of water decrease with an increase in turbidity [54]. Since *O. niloticus* is an omnivorous filter-feeding fish [55], 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. [56] 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 [57], reported that Secchi depth visibility plays a crucial role in accurately estimating plankton density in fish ponds.

4.3. Effect of Different Treatments on Swiss Chard Growth Performance and Yield. Treatment with pond water resulted in an increase in Swiss chard yield by 19.7%, 12.0%, 9.7%, and 91.8% 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 [22], who reported that irrigating a plot with fish pond water leads to 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 [58].

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. [20], who highlighted the positive influence of BSFFF on the growth performance of Swiss chard. A finding from [59] further emphasized that BSFFF is considered a high-quality organic fertilizer due to its sufficient composition of nitrogen, phosphorus, potassium, and other essential micronutrients. Additionally, 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 tap water (control). It is known that the use of chemical fertilizers can increase plant yield; however, these fertilizers can also have detrimental effects on the environment, such as changes in soil pH, reduced organic matter content, and nutrient enrichment [60]. The present result aligns with a study by Shoko et al. [24] 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 the fish pond attained a higher yield than those receiving water from streams.

Other studies have also shown that integrating a fish pond with vegetable production positively affects the yield and other growth parameters of the plants. A study conducted by Waktola et al. [61] reported a higher number of tomato fruits and increased onion yield from plants treated with pond water. Similarly [34], reported the highest yield of Adama red onion when integrated with poultry and fish components. They recommend incorporating horticultural 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. A finding by Dugan et al. [62] also suggests 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 demonstrates that the nutrients in fish pond water sufficiently replace the input of synthetic and other conventional fertilizers in vegetable cultivation.

4.4. Cost-Benefit Analysis. 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 framework. In terms of profitability, the study found that fish and vegetable production using pond water resulted in a net profit of 5165 ETB, which was 2.5 times greater than vegetable production using compost, yielding 2056 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 2209 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 2393 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 5165 ETB, which was a remarkable 7.1 times higher than the net profit of 724 ETB (Table 5) from vegetable production using tap water. The current result agrees with the finding of [24], who reported that integrated farming systems yield higher economic returns compared to nonintegrated systems. Similarly, a study conducted by Waktola et al. [61] 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. A study by Oladimeji and Isah [63] also reported that integrated fish-vegetable farming systems are more profitable than sole fish farming systems, contributing to food security, environmental, and ecological sustainability.

Furthermore [22], reported significantly higher net income from *O. niloticus* cultured in fertilized ponds with supplementary feeding, which supports the findings of the present study. Additionally [64], suggests 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. [65] 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.

5. Conclusion and Recommendations

The study evaluated the integration of fish farming with vegetable production as a strategy to enhance food production, profitability, and income diversification. It found that *O. niloticus* exhibited better growth performance in terms of DGR, SGR, condition factor, weight gain, and survival rate. Specifically, male *O. niloticus* performed better in growth performance than females. In terms of vegetable production, the study revealed that Swiss chard treated with fish pond water showed improved growth performance in height, number of leaves, leaf area, and fresh weight. Regarding economic viability, the study found that the integrated fish-vegetable system generated a higher net profit than other sole agricultural methods. Overall, the integrated farming system is a valuable practice, as it provides diversified yields in a single package, resulting in cost reduction.

Based on the findings of this study, three recommendations are made. First, the use of mixed-sex tilapia led to early maturation and reproduction, which negatively impacted growth and yield. Future research should focus on male-only tilapia to enhance productivity and profitability. Additionally, utilizing nutrient-rich fish pond water is recommended to improve Swiss chard growth and yield, as it reduces reliance on external irrigation and chemical fertilizers. Furthermore, additional research is needed to explore diverse fish-vegetable combinations, expanding options for farmers based on market demand and ensuring species compatibility for successful integration.

Data Availability Statement

The data that support the findings of this study are available upon request from the corresponding author.

Conflicts of Interest

The authors declare no conflicts of interest.

Author Contributions

Kokobe Teferedegn: conceptualization, designing the methodology, data collection, writing – original draft, data analysis. **Girma Tilahun:** conceptualization, data collection, writing – review and editing, validation, supervision.

Funding

The authors declare that no funding was received for this study.

Acknowledgments

Special thanks to the Centre for Aquaculture Research and Education (CARE) for providing various services, including fish fingerlings, assisting with data collection, and allowing the use of the constructed pond located at the center. The authors would also like to extend their appreciation to Hawassa University, Ethiopia.

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