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Research article

Innovative Prototype of Zero-Waste Food Production System to Support Integrated Farming

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Abstract: The research aims to develop the prototype of a zero-waste food production system innovation to support integrated farming. The innovation is a process innovation consisting of 4 processes. The results can be summarized as follows: 1) Commercial Azolla cultivation could cultivate 4 kg/m3 in 10 days using a specific formula from the research. Formula C consists of 58 kg of cow manure and 1.2 kg of rock phosphate, the best formula for Azolla cultivation. 2) Catfish cultivation in cement pipes is a recirculating catfish cultivation system that saves costs and is environmentally friendly. No wastewater is released from the system (Zero-waste). It uses treated water from Azolla cultivation in process 1. Catfish was cultivated with pellet fish foods at FF: AZ ratio of 50: 50, which was the best ratio from this research. To reduce the cost, within 12 weeks (3 months), the catfish weighed approximately 155 grams per fish (6 fish per kilogram) and was processed into pickled catfish. 3) Soil development using the ratio of Worm castings (WC) 1: Fresh Azolla (FA) 1: Black rice husk (BRH) 1: Soil (S) 1 was the best formula from the research. Using treated water from Azolla cultivation (process 1) with a drip irrigation system to grow eggplant could help the eggplant to grow well. It could yield the highest eggplant up to 1,869 kg/rai. Finally, 4) All processes use a solar cell electricity system (renewable energy system) that is used in the system to reduce electricity costs.

Keywords: Innovation; Zero-Waste agriculture; Integrated farming; Azolla

1. Introduction

The Zero waste agriculture approach is an agricultural production system free from waste materials. It is considered a new trend gaining popularity in the current situation. Due to the continuous growth of the population in large quantities, the consumption rate has also increased. Of course, agricultural products are in high demand in all sectors worldwide. All consumer goods are based on agricultural production. The conceptual zero-waste agriculture has been gaining popularity in Thailand in the past decade. Thailand's agriculture policies continue to follow the global trends of the Green Economy, including agriculture for energy (Green Energy), agriculture for the environment (Green Environment), and agriculture for tourism (Green Tourism). Both government and private organizations aim to create national policies according to the 20-year national strategy [1]. The zero-waste agriculture approach must apply the zero-waste Management approach or the zero-waste concept. It adheres to the principle that "waste has economic value and can be reused" and adheres to the objective of "minimizing waste and disposing of the residue (residue) with effective technology." Zero waste management is a new approach that will change the attitudes and behaviors of consumers, making them aware and cooperating in following the practice. To add value to post-consumer waste by recycling or recovering some of its energy [2].

Under the current crop production systems worldwide, achieving sustainable development goals related to agriculture, nutrition, and food security is challenging, as increased crop yields have negative environmental impacts. Therefore, it is crucial to design and implement optimal soil improvement cropping strategies that allow industrial fisheries to balance these vulnerabilities [3]. Organic farming has consistently shown positive environmental impacts, promotes nutrient recycling, and improves soil-plant fertility, especially by maintaining organic matter and reducing the amount of synthetic fertilizers delivered to farms. Although the market for organic products is growing locally and globally, and the demand is expected to continue to increase in the coming years, the costs involved in producing high-quality nutrients from organic waste are still quite expensive [4].

Currently, fish farming uses too much water and energy, creates a lot of pollution, and causes great damage to the ecosystem. Therefore, a new approach to fish farming sustainability emphasizes increasing production efficiency while reducing the amount of wastewater and wastewater sludge. Sustainable operation techniques require advanced technology that is still expensive. Farmers still have difficulty accessing such technology. As mentioned, researchers are interested in developing efficient tools and processes for farmers to produce catfish and vegetables in an integrated farming system using Azolla as a bioremediation agent and as an ingredient in catfish feed under a sustainable and efficient ecosystem without creating waste in the process. Phdungpran and Wangwiboonkit [5] used *Azolla spp.* and duckweed (*Lemna minor*) to treat the excrement of Nile tilapia raised in concrete ponds. They found that they were effective in wastewater treatment and had the best nutrient absorption efficiency, resulting in the best growth of the Azolla. This showed that *Azolla spp.* and *Lemna minor* can effectively treat wastewater from Nile tilapia ponds. Using a solar cell energy system, which is clean energy, as the driver of the entire process, the zero-waste approach will positively affect the full use of waste in the supplementary production chain and improve production efficiency and profitability of the business. The design and development of agricultural production groups are important because they promote a circular economy by making the most of resources and waste, creating secondary product value, protecting the ecosystem, and improving farmers' work efficiency sustainably.

2. Materials and Methods

The strategic objective of this research is to develop new ecological businesses that aim to replace the traditional linear production life cycle by developing innovative zero-waste food production systems to support integrated farming, where three different parts of the agricultural system (aquaculture, horticulture, and soil amendments) come together to demonstrate effective synergies between residues and other essential raw materials in the production stages, enabling us to achieve the goal of zero-waste agriculture. Nenciu et al. [6] studied a “zero waste” food production system that promotes positive interactions between aquaculture and horticulture. The prototype of a zero-waste food production system innovation to support integrated farming is shown in Figure 1, which has 4 processes as follows;

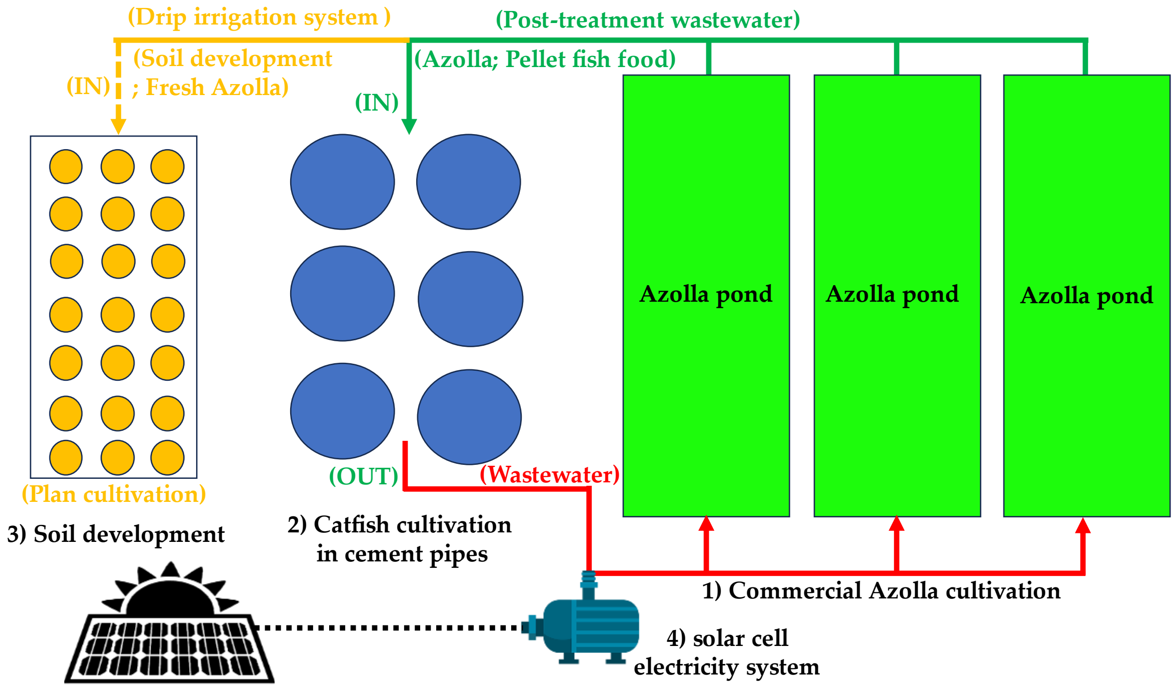

Figure 1. Prototype of a zero-waste food production system innovation to support integrated farming

2.1 Commercial Azolla Cultivation

Commercial Azolla Cultivation pond prepared to size 38.40 m^3 (W=6 m x L=24 m x H=0.30 m). Ponds covered with plastic pond liner – black (HDPE) 500 microns and 0.5 mm thick and filled with water to 10-20 cm height when waiting for the soil to settle and sink in the pond. Fresh Azolla added 100 g of fresh per m^2 in the pond to reduce sunlight intensity using a 60 percent black shade net. The condition studied is shown in Table 1. Every 60 days, remove the sediment from the pond and add a new Azolla [7]. The Azolla used in the experiment was *Microphylla* sp. The post-treatment wastewater from Commercial Azolla Cultivation (Process 1) was circulated to return in Catfish cultivation in cement pipes (Process 2).

Table 1. The condition studied for Commercial Azolla Cultivation

Formulas	Cow manure (kg)	Rock phosphate (kg)	Soil (kg)
A	58	1.20	154
B	58	-	-
C	58	1.20	-

2.2 Catfish Cultivation in Cement Pipes

The experiment was conducted by raising catfish in cement pipes by sizing 100 cm for diameter and cultivating as 50 fish/pond (sizing 2-3 cm). The depth of the water in the pond should be approximately 50 cm. Water transfer should start after about 1 month of cultivation by changing about 20% of the water in the pond for 7 days/time. Wastewater from cultivation is removed by collecting in a holding pond used in the drip irrigation system for growing eggplant (process 3) and released into Commercial Azolla Cultivation (Process 1). Feeding catfish when the catfish fry is still small, 2-3 cm in size, by mixing the food with water and forming it into pellets for the fish fry to eat twice daily. It is distributed throughout the pond. When the fish fry is about 5-7 cm, food pellets obtained from this experiment can be used for cultivation. The effect of catfish growth on different food formulas will be studied through the difference in the ratio between pellet fish foods (FF) and Azolla (AZ) as 0:100, 75:25, 50:50, 25:75, and 100:0, respectively. Each experiment was performed with 3 replications per experiment.

2.3 Soil development for growing eggplant

Source of Worm castings (WC), Fresh Azolla (FA), Soil (S), and Oil palm bunch fertilizer (OPBF) is used from Community Innovation Learning and Transfer Center "Thung Yai Sarapee Model" Songkhla Rajabhat University, Satun campus, Satun. Soil formula for growing eggplant was developed by studying the growth effect of eggplant with different soil formulas, as shown in Table 2. According to the experimental formula, eggplants were grown in 10*20 inch planting bags (Table 2). Each experiment was performed with 3 replications. All experiments used a drip irrigation system to water the eggplants, which was water from the catfish pond. The eggplant used in the experiment was *Tomahawk sp.* The eggplant experiment was to test whether the soil formula used in the experiment could be used to grow fruit-bearing vegetables.

Table 2. The soil formula studied for soil development in growing eggplant

Formulas	Soil formulas (Ratio)
A	Worm castings (WC) 1: Fresh Azolla (FA) 1: Black rice husk (BRH) 1: Soil (S) 1
B	Oil palm bunch fertilizer (OPBF) 1: Fresh Azolla (FA) 1: Black rice husk (BRH) 1: soil (S) 1
C	Fresh Azolla (FA) 1: soil 1
D	Soil (S) 1 (control)

2.4 Solar cell electricity system (renewable energy system)

A 12-volt Off-Grid solar system is used in this experiment from Community Innovation Learning and Transfer Center "Thung Yai Sarapee Model" Songkhla Rajabhat University, Satun campus, Satun, consisting of three 160 W solar panels (Solar Besttech), a 200 Ah gel battery (LVTOPSUN, Germany), and a 5,000 W Pure Sine Wave Inverter (CJ-5000Q), which can convert 12 V electricity to 220 V home electricity. This system can reduce electricity costs, making the system's energy costs zero.

2.5 Analytical methods

Soil composition analysis (NPK) was determined using the standard method [8]. Soil pH was measured using a soil pH meter (Shinwa PH Soil Meter, Japan). Dissolved oxygen (DO) using a DO meter (Model: PDO-519). Water pH was measured using a pH meter (Hanna, HI98107). Dry matter (DM), Crude protein (CP), Crude fat (CF), Crude fiber (CF), Ash, Nitrogen extract (NFE), Acid detergent fiber (ADF), and Neutral Detergent Fiber (NDF) were analyzed by AOAC method [9].

3. Results and Discussion

3.1 Effect of Commercial Azolla Cultivation

The system for Commercial Azolla cultivation (Figure 2) can produce up to 4 kg of fresh Azolla per square meter in 10 days using formula C, which consists of 58 kg of cow manure (nitrogen source) and 1.2 kg of rock phosphate (phosphorus source) in a pond area of 38.40 square meters. The following best is formula A and formula B, which can produce 2.4 and 1.9 kg of fresh Azolla per square meter, respectively (Figure 3).

Figure 2. The system for Commercial Azolla cultivation

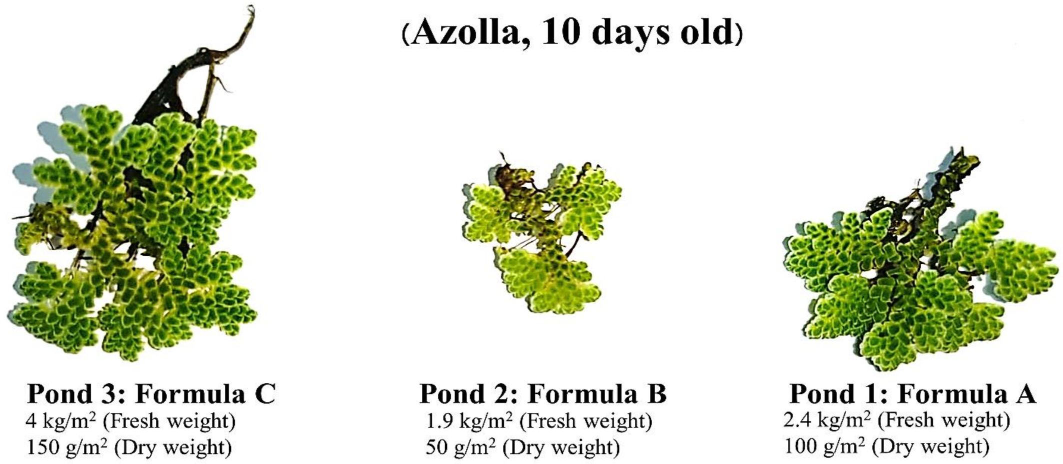

Figure 3. Azolla yield from commercial cultivation systems in different food formulas

The commercial cultivation of Azolla in a 38.40 square meter pond in 10 days could produce the highest fresh Azolla of 153.60 kg (4 kg/m^2), 96.00 kg (2.4 kg/m^2), and 72.96 kg (1.9 kg/m^2), respectively, or about 6.40, 3.84 and 3.04 tons/rai from media formulas C, A, and B (Figure 3). This is higher than the report of Wongbung [10], who explained that Azolla can reproduce rapidly and yield up to 3 tons/rai if in a suitable environment. Then, the fresh Azolla was dried in a solar dryer (parabola dome greenhouse) for 24 hours at 60 °C. The fresh Azolla weight decreased to 5.76 kg (150 g/m^2), 3.84 kg (100 g/m^2), and 1.92 kg(50 g/m^2), from media formulas C, A, and B, respectively. The weight decreased from fresh Azolla was 26.67, 25.00, and 38 times the fresh weight. This is consistent with the report by Rattanakul [11] that dried Azolla could produce up to 25 times more than fresh Azolla at 7 days of cultivation. From the study of the growth rate of Azolla per area in the pond from the commercial farming system in different food formulas, the experimental results showed that in 7 days. Food formula C had the best growth rate per area, followed by formulas A and B (Figure 4). Azolla could grow well in the pond, with the best growth area having formula C within 10 days of full pond farming on an area of 38.40 m^3, a 100% growth rate. The following best was food formulas A and B, which could grow in the full pond area (38.40 square meters) within 14 days, as shown in Figure 4. As a result, formula C is the best formula, consisting of cow manure (58 kg) and rock phosphate (1.2 kg), suitable for commercial Azolla cultivation because rock phosphate is added as a phosphorus source, allowing the Azolla to receive complete nutrients, resulting in rapid growth. It is not necessary to add soil to the cultivation pond because the soil may contain pathogens or contaminants that affect the growth of the Azolla. From resulting of the experiment, one of the problems in raising Azolla is duckweed, which grows well in clean water or with low nutrients in the water source. If the nutrients in the pond are reduced, it can be observed that the Azolla will grow less, but the duckweed will grow well. So, the nutrients must be added again according to the experimental cultivation formula. The Aazolla will boom again, and the duckweed will die because it cannot grow. This experiment shows that we do not need to eliminate the duckweed in the Azolla cultivation process. The proper cultivation system will manage itself, allowing the Azolla to be continuously cultivated to the commercial cultivation process.

The experiment was operated using food formula C in commercial Azolla cultivation with 3 replications to study the efficiency of Azolla wastewater treatment. The wastewater treatment capability of Azolla was tested by collecting the results of changes in pH and DO values, as shown in Figure 5. The experimental results showed that the pH of the Azolla pond was relatively neutral, with a pH range of 7.5-7.8. The change in DO, or the amount of oxygen dissolved in water, showed that the DO value of the system was in the range of 6-6.7 when the system reached a steady state in weeks 8-12. The experimental results showed that Azolla had a good wastewater treatment capability. The standard of good quality water will have a DO value of approximately 5-8 milligrams per liter (mg/l) [12]. Chartchumni et al. [13] reported that the parameter indicating deteriorated water quality in climbing perch farming areas must have a minimum dissolved oxygen (DO) value of no more than 2.20 mg/l. If the DO value is lower than this, it will affect the quality of aquatic animals, slow growth, and may be more susceptible to disease. The treated water from Azolla cultivation is recirculated for catfish farming and used in the drip irrigation system for growing eggplant. Corresponding with Weirich et al. [14] reported that Azolla is effective in treating wastewater because it has many fibrous roots under the water, allowing it to absorb nutrients and other pollutants mixed with water well. Using Azolla, which can absorb nutrients present in wastewater from the decomposition of organic matter, improves water quality [15].

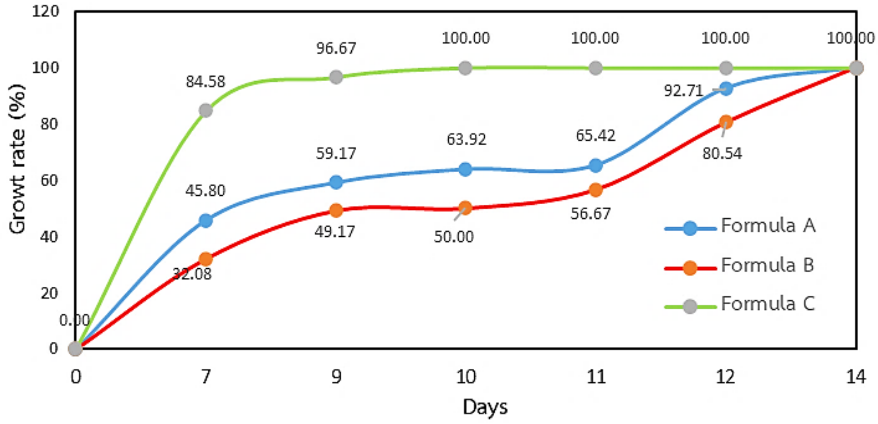

Figure 4. The growth rate of Azolla per area in the pond from commercial culture systems in different food formulas

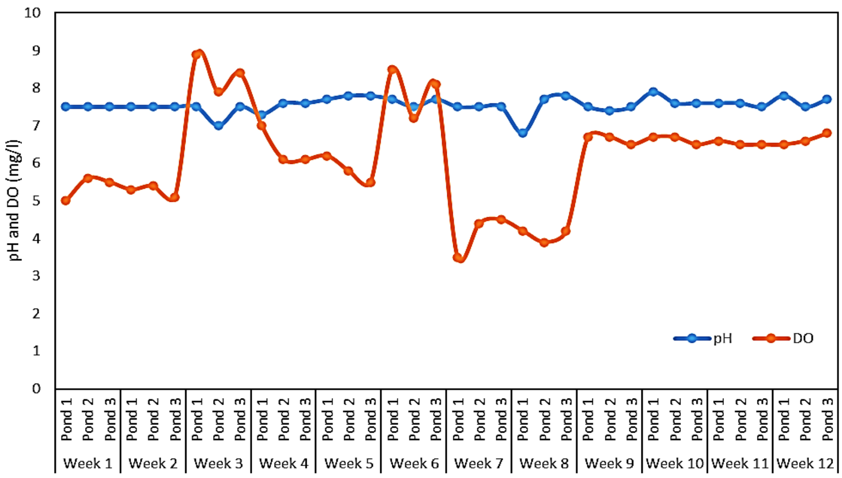

Figure 5. Changes in pH and DO (Dissolved Oxygen) values in commercial Azolla ponds using C formula food for Azolla cultivation

3.2 Effect of Catfish Cultivation in Cement Pipes

Catfish were raised in cement pipes using treated water from the Azolla cultivation process 1. The growth rate of catfish was compared by raising catfish with different formulas as a ratio between pellet fish foods (FF) and Azolla (AZ) as 0:100, 75:25, 50:50, 25:75, and 100:0 after that made with a pellet machine and then dried in a solar oven for 24 hours until completely dry before being used as food in the experiment which it is a pelleted food that can float on water and is suitable for raising aquatic animals as shown in Figure 6. Each formula was tested with 3 replications. The catfish was raised in a cement pipe system for 12 weeks using a Russian catfish of 50 per pond. The experimental results showed that catfish could grow well at a ratio of FF: AZ food formula not exceeding 50:50. The growth results of Russian catfish at 12 weeks of age were similar with an average weight of 156 ± 0.082, 154 ± 0.112, and 155 ± 0.092 grams per fish and a length of 25.21 ± 0.152, 27.70 ± 0.272, and 26.00 ± 0.192 centimeters as shown in Figures 7. However, when the ratio of fresh Azolla was increased to more than 50 percent, the growth rate decreased significantly. At FF: AZ ratio of 25:75 and 0:100 at 12 weeks of age, the catfish had an average weight of only 42 ± 0.312 and 24 ± 0.212 grams per fish and a length of only 7.28 ± 0.182 and 4.86 ± 0.112 centimeters (Figure 7), which was 3.5 and 6.5 times less than the FF: AZ formula at 50:50 ratio. The change in catfish weight at 12 weeks showed that Russian catfish could adapt to the cost-saving Azolla pellet feed well and started to have a continuous increase in growth rate during the 6-9 weeks, and the growth rate started to stabilize when the culture entered the 10-12 weeks as shown in Figure 8. When considering the surface area, weight, and length graphs of 12-week-old catfish from different proportions, the best food ratio was 50:50 (FF: AZ) (Figure 9). Therefore, the Azolla pellet feed at 50% can be used to raise Russian catfish and could reduce the cost of food by about 50%, which is commercially competitive, allowing catfish farmers to be self-reliant towards sustainability.

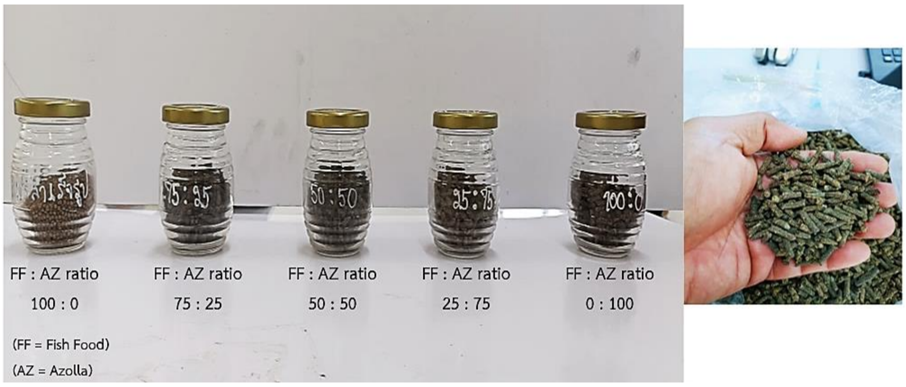

Figure 6. Pellet fish food from Azolla at different ratios

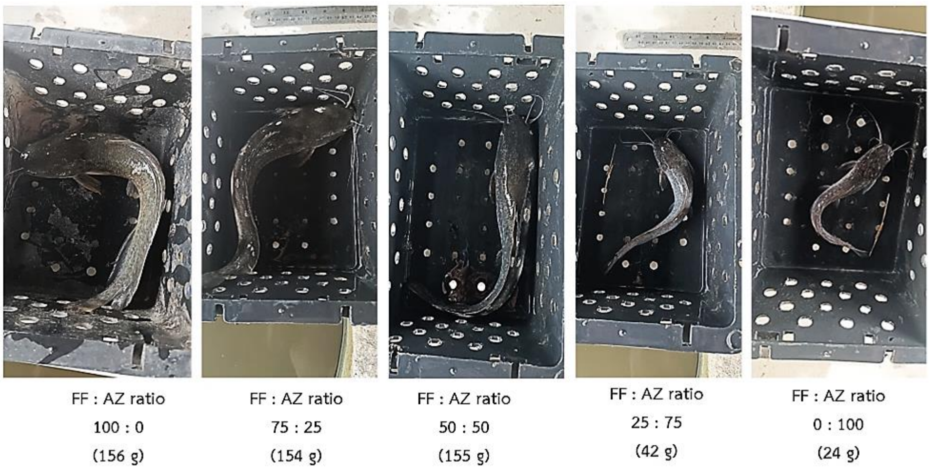

Figure 7. Weight of Russian catfish fed different food formulas at 12 weeks of age

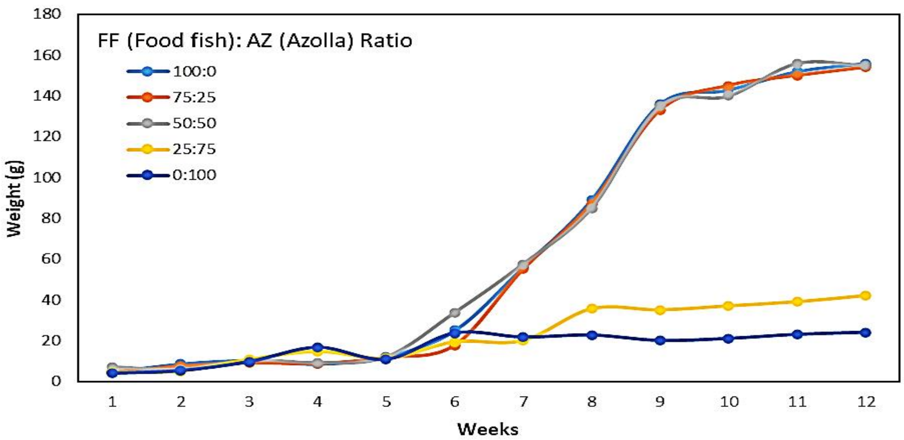

Figure 8. Weight changes of catfish over 12 weeks by rearing them in different food proportions

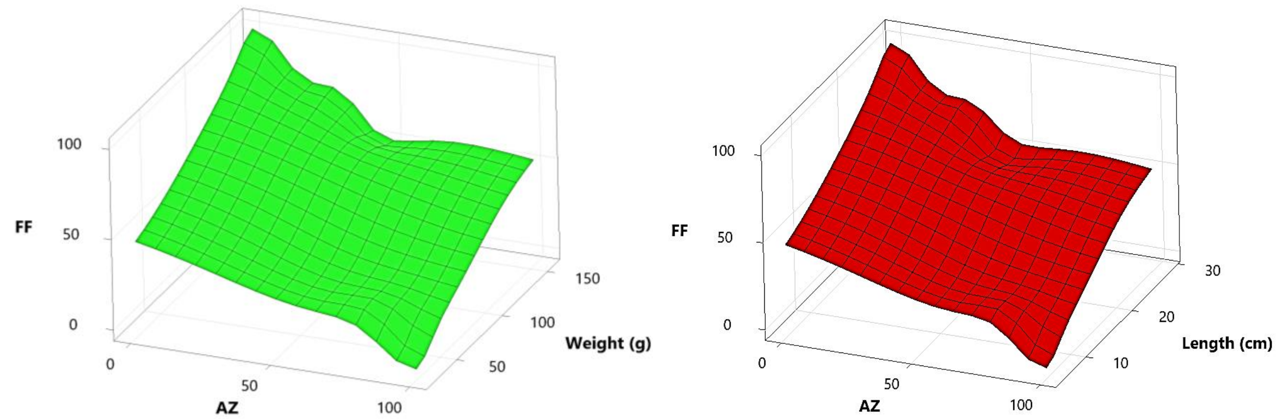

Figure 9. Surface area, weight and length graph of 12-week-old catfish reared in different food ratio (FF = Fish Food) : (AZ = Azolla)

The study of chemical composition of catfish feed in different proportions found that the FF: AZ formula at the ratio of 50:50, which is the best ratio for raising catfish in the cement pipe system, had crude protein (CP), fat, ash, crude fiber (CF), neutral detergent fiber (NFE), acid detergent fiber (ADF) and neutral detergent fiber (NDF) of 26.27 ± 0.122, 4.18 ± 0.102, 9.35 ± 0.052, 11.75 ± 0.110, 48.4 ± 0.029, 15.73 ± 0.192 and 34.58 ± 0.180 percent, respectively. The CP value was slightly lower than the ready-made catfish feed by approximately 8.26 percent. The ready-made feed, FF: AZ, at the ratio of 100:0, had a total protein (CP) of 28.44 ± 0.089 percent. The FF: AZ formula at the ratio of 50:50 had a lower fat value than the ready-made feed, allowing animals to eat more and be stored longer. If the food contains a lot of unsaturated fatty acids, it will easily go rancid, and if used in large amounts, the food will have more energy, causing animals to eat less. In addition, the ash content is similar, indicating that the food is of comparable quality and does not contain other materials such as sand. The CF value is 11.75±0.110 percent, higher than the prepared food. The prepared food for catfish has a CF value of 9.59±0.082 percent. It does not affect catfish farming because catfish do not have digestive enzymes to digest the fiber content, which is only found in ruminant animals. However, the FF: AZ formula at a ratio of 50:50 has an NFE value of easily digestible carbohydrates of 48.40 percent, which was higher than the prepared food with an NFE value of only 47.03±0.159 percent. The NFE value is carbohydrates that all animals can easily digest and utilize. As for the ADF and NDF values, this dry matter only benefited ruminants. It does not affect catfish farming because catfish cannot use this nutrient. Therefore, if the value is low, it is good for catfish food. The best formula from the experiment (50:50) had ADF and NDF values of 15.73±0.192 and 34.58±0.180 percent, respectively, but the prepared food had ADF and NDF values of 13.13±0.182 and 42.65±0.192 percent, respectively, as shown in Table 3. When the ratio of Azolla was increased to more than 50 percent, the nutritional value of the food decreased, resulting in the produced food having poor quality and not suitable for raising catfish. However, if the proportion of Azolla did not exceed 50 percent, the quality of the food was no different from the prepared food, making it suitable for raising catfish. As a result, food costs are reduced by approximately 50 percent. The chemical composition of 100 percent Azolla (FF: AZ at a ratio of 0:100) from the experiment was close to and consistent with the experiments of Khatun et al. [16], Basak et al. [17], and Alalade & Lyavi, [18], as shown in Table 3.

Table 3. Chemical composition of catfish food in different food proportions (FF = Fish Food) : (AZ = Azolla)

EXP.	FF: AZ (ratio)	Dry matter (%)	On dry basis						
			CP (%)	Fat (%)	Ash (%)	CF (%)	NFE (%)	ADF (%)	NDF (%)
1	100 : 0	90.19 ± 0.028	28.44 ± 0.089	5.47 ± 0.112	9.47 ± 0.132	9.59 ± 0.082	47.03 ± 0.159	13.13 ± 0.182	42.65 ± 0.192
2	75: 25	93.31 ± 0.058	27.03 ± 0.102	4.34 ± 0.273	9.72 ± 0.192	9.79 ± 0.092	49.12 ± 0.082	13.36 ± 0.062	52.39 ± 0.152
3	50: 50	92.45 ± 0.025	26.27 ± 0.122	4.18 ± 0.102	9.35 ± 0.052	11.75 ± 0.110	48.4 ± 0.029	15.73 ± 0.192	34.58 ± 0.180
4	25: 75	93.16 ± 0.086	25.05 ± 0.028	3.59 ± 0.092	9.96 ± 0.102	14.94 ± 0.097	46.46 ± 0.152	19.57 ± 0.152	50.04 ± 0.082
5	0: 100	93.60 ± 0.008	24.51 ± 0.088	3.59 ± 0.152	12.72 ± 0.187	17.75 ± 0.158	41.43 ± 0.182	22.95 ± 0.178	38.01 ± 0.072
Basak et al. [16] (0: 100)		90.80	25.78	3.41	15.76	15.71	ND	ND	ND
Khatun et al. [17] (0: 100)		90.50	28.50	ND	16.90	12.30	ND	33.40	44.50
Alalade & Lyavi, [18] (0: 100)		ND	21.40	2.70	16.20	12.70	ND	47.08	36.80

ND: Not Determine

Water quality testing of catfish ponds with different food formulas found the average change in DO value in catfish ponds by raising them in a different food ratio. The system will start to enter a steady-state state in the 9th week of raising. The DO value or the amount of oxygen dissolved in the pond, which is an index of stable water quality in the pond, has an average DO value between 2.67-3.37 mg/l (Figure 10). A DO value lower than 4 mg/l can cause aquatic animals raised in the system to die. The water must be changed, or wastewater must be treated in the system [12]. The pH value of the system changes between 6.5 and 7.5, which is a neutral value suitable for the catfish-raising system, as shown in Figure 10. Water from catfish raising will be circulated back to be treated by commercial Azolla raising in the system or process 1 of the experiment. When the water has been treated in the Azolla pond, it will be circulated back to raise catfish in process 2, making catfish rise in this cement pipe system. It is a recirculating catfish or low-water farming system that saves costs and is environmentally friendly, with no wastewater released (Zero-waste).

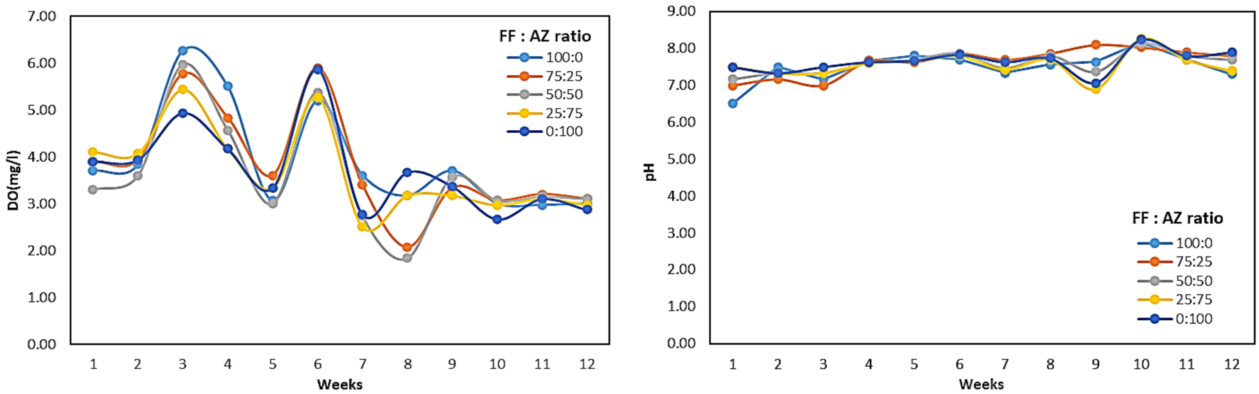

Figure 10. Average change of DO and pH value in catfish ponds by raising them in different food proportions

3.3 Effect of Soil development on growing eggplant

The eggplant cultivation experiment used different soil formulas, as shown in Table 2. The experimental results found that soil formula A made eggplant grow the best, followed by formulas B, C, and D (control). The growth of eggplant plants in different soil formulas is shown in Figure 11, which is physical growth. When the eggplant was 10 weeks old, the physical growth did not change (Figure 12), so the results of the physical change (structure) experiment were stopped. Soil Formula A can make the eggplant flower faster in the 5th week of the experiment or around day 35-40. Usually, eggplant will flower on days 50-60 (Horticultural Research Institute, 2024). In the 10th week of the experiment, it was found that eggplant grown using soil in formula A has a height of 90 centimeters and a width (length) of 87 centimeters, which is similar to the physical changes (structure) of eggplant grown in formula B as shown in Figures 12. When analyzing the nutrient composition in the soil, N, P, and K values, it was found that formulas A and B had N, P, and K values that were sufficient for the plants' needs. Still, formula B (240 mg/kg) had a higher K value than formula A (120 mg/kg) in the first week. However, K was not an important nutrient that plants used for growth in the early stages of the experiment. Formula C contained only N (10 mg/kg) and K (240 mg/kg), while Formula D (240 mg/kg) contained only K, so it was not suitable for planting plants in the early stages. As a result, the physical changes (structure) of eggplant grown in soil formula D were the lowest or did not grow significantly. Nitrogen (N) helps plants to be green and accelerate leaf growth. If plants lack this element, they will show symptoms of yellow leaves, smaller leaves, stunted stems, and low yield. Phosphorus (P) accelerates root growth and spreading to control flowering, fruiting, and seed production. If plants lack this element, the root system will not grow. Old leaves will turn from green to purple-brown and fall off. The stem will be stunted and not produce flowers or fruits. Bocchi and Malgioglio [19] reported that Azolla is a small floating plant commonly grown in rice fields to increase nitrogen content. It is used as green manure to reduce costs and increase production. It can fix nitrogen from the air (Nitrogen Fixation), resulting in Azolla having nitrogen as a component as high as 2 - 4.5% of dry weight. Potassium (K) is an element that helps to synthesize sugar, starch, and protein. It promotes the movement of sugar from leaves to fruits, helps fruits grow quickly and of good quality, and helps plants to be strong and resistant to some diseases and insects. If this element is lacking, plants will not be strong, the stem will be weak, the yield will not grow, it will be of low quality, the color will not be beautiful, and the taste will not be good [20]. When entering the 4th and 5th weeks of the experiment, it was found that there was decomposition in the soil structure. There was a change in the soil structure, resulting in a continuous increase in the nutrients N, P, and K in all experimental formulas. The experiment reached the 6th week onwards. The eggplant began to flower. Nitrogen used for growth began to decrease and run out, but the amount of P and K increased, which was good for eggplant because P and K help nourish roots, flowers, and fruits. When the experiment reached the 10th week. P was almost entirely used up by the eggplant, leaving only K, causing the eggplant to start and deteriorate (Figure 13). Earthworm manure was added to each plant by about 50 grams to increase the amount of N and P nutrients to nourish the stem and roots, allowing the eggplant to be continuously harvested until it was about 5 months old. From the results of the experiment, it can be concluded that no fertilizer was used in the experiment from the beginning of planting until it was 2.5 months old, and earthworm manure was added only once, reducing the cost of fertilizer use by about 50 percent, resulting in greater economic value. The pH value of all experiments was between 6-7, as shown in Figure 14. The pH value of soil suitable for plants should be between pH 6.0-6.5, or "mildly acidic," which allows plants to use the most nutrients. Soils with pH values lower than 5.5 (very acidic) or more than pH 8.5 (very alkaline) are classified as soils with agricultural problems because they are soils that lack nutrients and have low fertility [21].

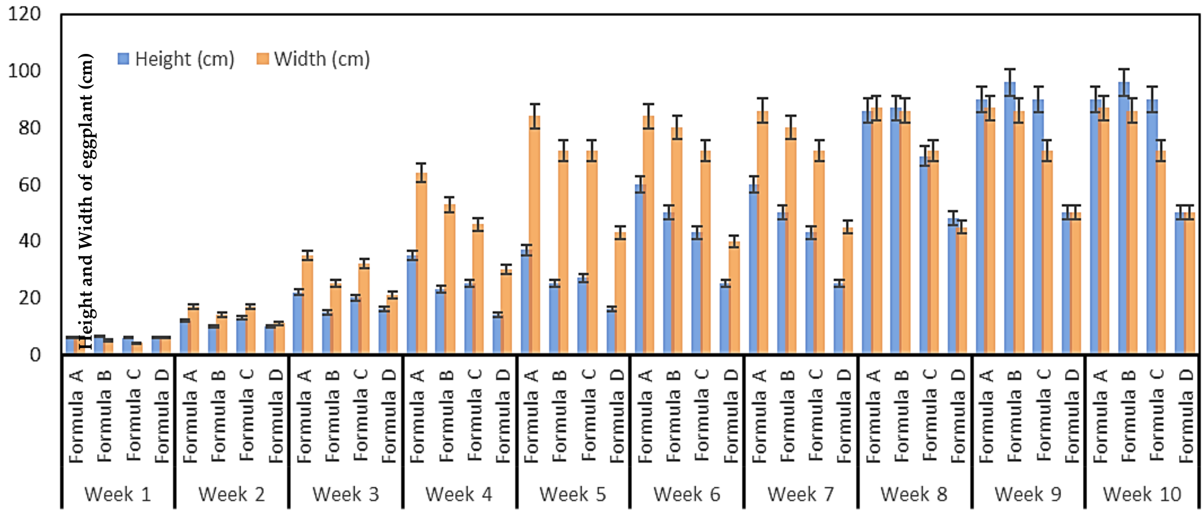

Figure 11. Physical changes (Height and Width of tree) eggplant grown with different soil formulas

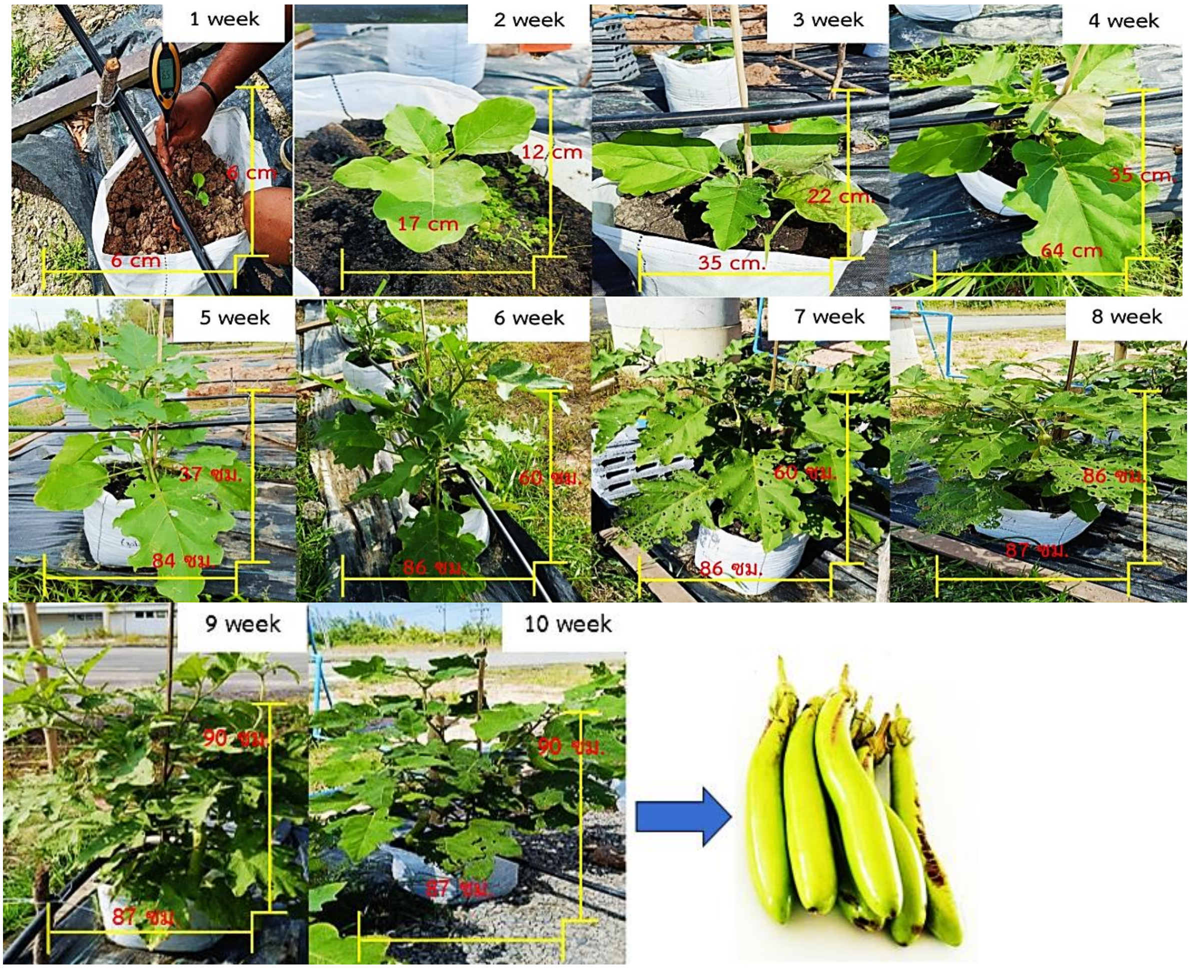

Figure 12. Eggplant growth in soil formula A (best) at age 1 -10 weeks

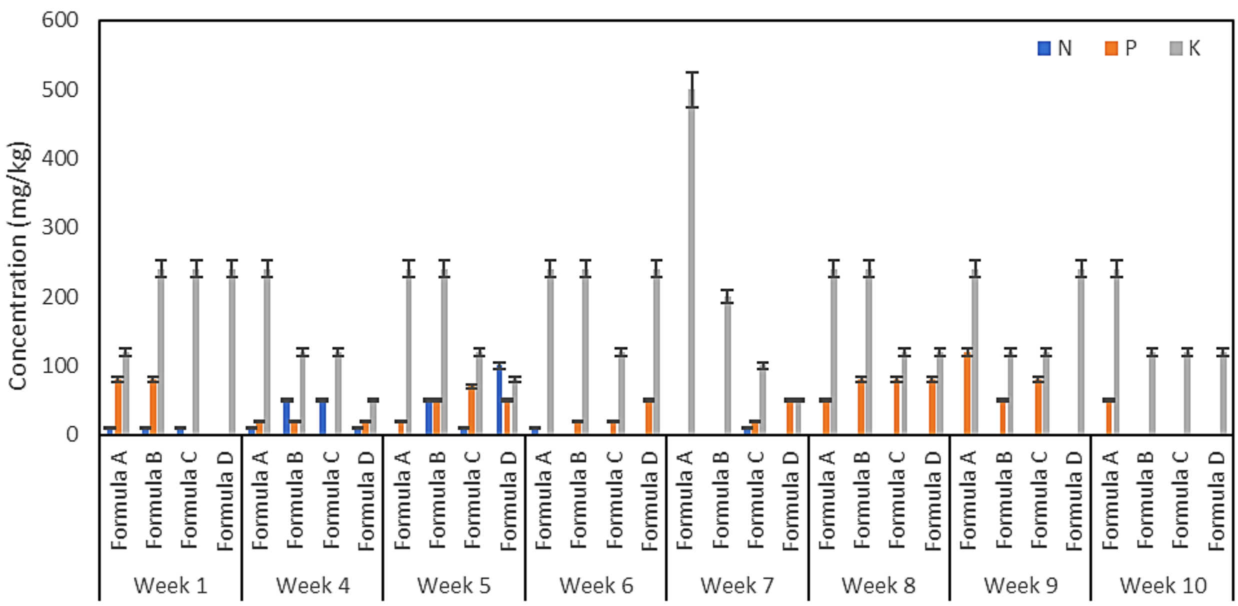

Figure 13. Nutrient changes (N, P, K) in soil used for growing eggplant with different soil formulas

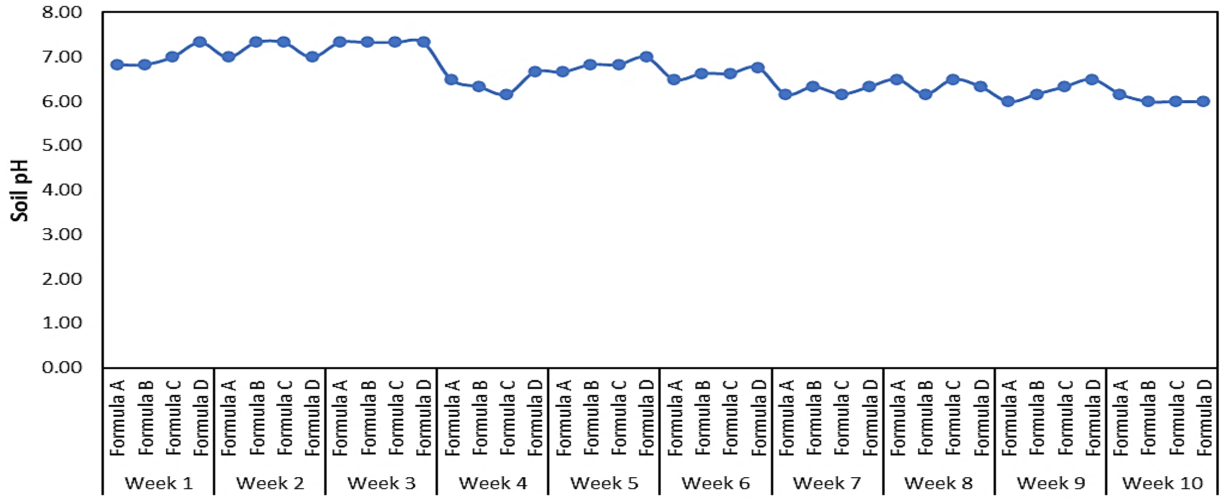

Figure 14. Changes in pH values of soils used in growing eggplant with different soil formulas

Soil formula A was the best soil formula from the experiment (1 part earthworm manure: 1 part soil: 1 part black rice husk: 1 part red duckweed) with the highest yield per plant at 267 grams per plant, followed by 133, 33 and 20 grams per plant, respectively, in soil formulas 2, 3 and 4. In addition, formula A also gave the highest yield per rai at 1,869 kg/rai, which was higher than the average eggplant cultivation in Thailand, followed by 931, 231, and 140 kg/rai, respectively, in soil formulas 2, 3 and 4. The Horticultural Research Institute [22] reported that the average yield of eggplant per rai in Thailand was 1,068 kg/rai.

3.4 Benefits of the prototype of a zero-waste food production system innovation to support integrated farming.

Summary of economic results (Table 4.) from the prototype innovation in an area of 1 rai, there was income from raising catfish of 9,360 baht, from the catfish processing process of 42,200 baht, and from selling fresh eggplant of 82,236 baht, with a total production cost of 15,900 baht, consisting of 1,000 Russian catfish at 1 baht each, totaling 1,000 baht, catfish feed of 6 bags at 500 baht each, totaling 3,000 baht, fermented catfish seasoning of 1,000 baht, 10 bags of eggplant seeds at 40 baht each, totaling 400 baht, earthworm manure of 30 baht per kilogram, totaling 350 kilograms, totaling 10,500 baht, with income from selling catfish + eggplant of 75,696 baht (after deducting costs), with an average income of 15,139 baht/month. But if the catfish is processed into pickled/sun-dried catfish, the income will increase to 108,536 baht (after deducting costs), with an average income of 21,707 baht/month, as shown in Table 5. Processing increases income by 43.38 percent.

Table 4. Summary of income (economic results) from prototype innovations in an area of 1 rai

Yield	Weight (kg)	Price (baht)	Income (baht)
1) Catfish (fresh) (20 ponds, 50 fish each)	150	60	9,360 (3 months)
2) Fermented/Dried Catfish	140	300	42,200 (3 months)
3) Eggplant (fresh)	1,869	44	82,236 (5 months)

Note: Fresh catfish price 60 baht/kilogram, pickled/sun-dried catfish 300 baht/kilogram, eggplant 44 baht/kilogram

Table 5. Summary of average monthly income from prototype innovations in an area of 1 rai

Yield	Income/rai (baht)	Cost (baht)	Profit (bath)	Income/Month (baht)
1) Fermented/Dried Catfish + Eggplant (fresh)	124,436	15,900	108,536	21,707
2) Catfish (fresh) + eggplant	91,596	15,900	75,696	15,139

Note: Income is calculated as an average of 5 months

4. Conclusions

The development of zero-waste agriculture innovation supports integrated farming, which is the convergence of three different parts of the agricultural system (aquaculture and processing, horticulture, and soil amendments) on the concept of zero-waste agriculture. The economic results from the prototype innovation in an area of 1 rai have an average income from making fermented catfish and eggplant of 108,536 baht (after deducting costs), an average income of 21,707 baht/month, in which the processing increased income by 43.38 percent. Therefore, the prototype innovation from the research is more economically worthwhile than monoculture farming, a guideline for farmers to be self-reliant towards sustainability.

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