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Water Quality Management Guidelines to Reduce Mortality Rate of Red Tilapia (*Oreochromis niloticus* x *Oreochromis mossambicus*) Fingerlings Raised in Outdoor Earthen Ponds with a Recirculating Aquaculture System Using Machine Learning Techniques

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Abstract: Machine learning techniques have been widely adopted over the last few decades, especially in fisheries. This study aimed to determine the best practice of machine learning techniques with a decision tree algorithm in reducing the mortality rate of red tilapia (*Oreochromis niloticus* x *Oreochromis mossambicus*) fingerlings raised in outdoor earthen ponds with a recirculating aquaculture system. The study phase begins with collecting water quality parameters. The parameters were measured in the form of dissolved oxygen (mg L^{-1}), pH, temperature (˚C), total ammonia nitrogen (mg L^{-1}), nitrite-nitrogen (mg L^{-1}), alkalinity (mg L^{-1}), transparency (cm), and mortality rate (fish day^{-1}). Data Modelling was carried out using 10-fold cross-validation. The results of the performance measurement obtained an accuracy of 89.67% with ± 5.11% (micro average: 89.60%), a precision of 86.71% ± 18.02% (micro average: 80.00%), and recall of 72.50% ± 24.86% (micro average: 71.79%), with the most influential water quality parameter being nitrite-nitrogen (mg L^{-1}). Based on the results of this study show that data classification using a decision tree algorithm can be used as a reference to determine the decisions or actions of fish farmers in reducing the mortality rate of red tilapia fingerlings raised in outdoor earthen ponds with a recirculating aquaculture system.

Keywords: Machine learning, Decision tree algorithm, Red tilapia, Water quality, Mortality rate.

1. Introduction

Red tilapia does not have black pigment derived from hybridization between species in the genus, especially between *Oreochromis niloticus* and *Oreochromis mossambicus* [1]. This fish is still a superior commodity for freshwater aquaculture with important economic value throughout the world, including the whole world, especially Thailand. In Thailand, red tilapia farming is gaining popularity because the red color of the fish is like that of expensive marine fish species, and both domestic and international markets have shown an increasing demand for live fish and fish meat [2]. Based on data from the Food and Agriculture Organization of the United Nations, Tilapia is the third major species produced in world aquaculture after Grass carp (*Ctenopharyngodon idellus*) and Silver carp (*Hypophthalmichthys molitrix*), with a production contribution of 4.5 million tons in 2018 [3].

The increase in consumption of tilapia in the world illustrates that the pattern of fish consumption in the community is increasing and fish production needs to be increased to meet demand. However, the increase in tilapia production in meeting consumer needs will be limited by several factors, including a decrease in water quality due to nitrogen (N) waste originating from uneaten feed residue, feces, and excretory products on the gills. This waste will decompose, causing a decrease in water quality in the rearing system [4-5]. Although tilapia fingerlings reproduce freely in ponds, farmers must consider using properly produced fingerlings. Determination of optimal environmental conditions to achieve the best fingerlings growth performance is important to maximize and optimize production [6, 7]. The availability of good quality tilapia fingerlings at competitive prices is very important to maintain farm profitability [8]. Hence, water quality in the rearing system needs to be appropriately managed for the optimal life needs of red tilapia fingerlings. One way to overcome this problem is to use recirculating aquaculture system.

Recirculating aquaculture system (RAS) is an aquaculture system that implements efficient use of water to maximize the production of aquatic organisms by minimizing pollution and water costs [9-11]. RAS for tilapia cultivation has several advantages. Namely, it can be placed in areas that do not have sufficient water sources for cultivation [12] because this system can simultaneously increase water circulation and oxygenation in fish rearing [13]. RAS has a fish culture tank, a particulate filter to remove solids, a pump for water circulation, and an oxygenation device [14].

Automation and intelligence technology development has gradually influenced aquaculture towards the direction of intensive and intelligent aquaculture. This could significantly improve aquaculture efficiency worldwide [15-17]. They are combined with high-performance computers, namely machine learning technology that can mine information in data, thus offering solutions for smart aquaculture and introducing the fishing industry into a new era [17-19]. Machine learning algorithms and their applications in aquaculture have been widely applied, such as fish biomass estimation, fish identification and classification, fish behavioral analysis, and prediction of water quality in aquaculture activities [17].

In this study, data on the water quality parameters of red tilapia fingerlings raised in outdoor earthen ponds with a recirculating aquaculture system will be observed, which will then be analyzed for the effect of each measured water quality parameters on the mortality rate of red tilapia using a machine learning with decision tree algorithm. A decision tree algorithm is a popular machine learning tool. It is often used to identify possible consequences such as the outcome of chance events, investment risk, decision-making, and interest rates [20-22]. This classifier modeling method performs well even with complex data sets to identify pattern behavior [23]. On the other hand, the use of decision trees is very easy to understand and is similar to how humans make decisions [24]. In contrast to other models, such as the random forest, which is more complicated to interpret because it has many decision trees, naïve bayes, whose precision could decrease if the data used is few, and the neural network, which requires high processing time when the neural network is large.

The main aim of this study is to determine the best practice of machine learning techniques with a decision tree algorithm in reducing the mortality rate of red tilapia fingerlings raised in outdoor earthen ponds with a recirculating aquaculture system. By applying machine learning with a decision tree algorithm to water quality parameters data, we hope that the aquaculture management system will provide many recommendations and insights to support fish farmers' decisions and actions to reduce fish mortality of red tilapia fingerlings in outdoor earthen ponds with recirculating aquaculture system.

2. Materials and Methods

2.1 Study Area

This study was conducted at the Patthamarach Farm, Lam Plai Mat District, Buriram Province, Thailand, located at coordinates (15.067192, 102.788965) from November 2020-January 2021. The farm consists of a reservoir pond with a size of 9,210.18 m^2, 2 treatment ponds with a size of 3,609.86 m^2 and 4,593.06 m^2, 4 nursing ponds with a size of 1,600 m^2, 18 grow out/culture ponds with a size 1,600 m^2, 1 sedimentation pond with size 2,078.03 m^2, 1 biological treatment pond using water hyacinth with size 8,224.83 m^2, and 1 ready-to-use pond with size 7,183.4 m^2.

2.2 Data Collection

Red tilapia fingerlings were reared in the earthen ponds with Polyethylene (PE) using recirculating aquaculture system (RAS) with mono sex. Using 4 ponds with a size of 1,600 m^2 per each pond. The average initial weight of the fish was 50 g $fish^{-1}$, and the stocking density was 25 fish m^{-2}. Each pond was provided with 4 aerators in the form of a waterwheel which will be operated 24 hours a day to maintain the quality of dissolved oxygen during maintenance. Red tilapia fingerlings were fed a commercial diet (floating pellets) with 35% crude protein. Frequency of feeding 3 times a day at 08.00, 11.30, and 16.30 with ad satiation using the automatic feeder.

Water quality parameters were measured in the form of dissolved oxygen/DO (mg L^{-1}), temperature (°C), pH, total ammonia nitrogen/TAN (mg L^{-1}), nitrite-nitrogen/NO_2-N (mg L^{-1}), alkalinity (mg L^{-1}), and transparency (cm) every day. Where dissolved oxygen, temperature, and pH were measured using YSI Professional Plus (Yellow Springs, OH, USA) twice daily in the morning and evening. The DO, pH, and temperature are divided into 2 parts: average and different. DO average, pH average, and average temperature state the central or typical value in water quality measurements carried out in the morning and evening. Meanwhile, DO, pH, and temperature are the different values of water quality measurements carried out in the morning and evening. Total ammonia nitrogen, nitrite-nitrogen, and alkalinity were measured following the American Public Health Association [25] once a day. And the water transparency in the maintenance pond was measured using a Secchi disk once a day.

Red tilapia fingerlings will be reared until they reach the average weight of 200 g $fish^{-1}$. The mortality rate of red tilapia fingerlings was measured during rearing by counting the number of fish that die per day. If the fish that died were less than 10, it was categorized as low mortality. If more than 10 fish died, it was categorized as high mortality.

2.3 Data Cleaning

Dataset obtained from a study object generally has imperfect entries, such as missing or unfilled data. In this study, the first step in managing missing values is understanding the reasons behind why they are missing by tracing the data lineage (origin) from the data source can lead to the identification of systemic problems during data retrieval or errors in data transformation. In the second step, knowing the source of the missing value will often guide which mitigation methodology to use. Missing values can be replaced with various artificial data to manage problems with little impact at the next step in the data science process. Missing values can be replaced with values that come from the data set (mean, minimum, or maximum values, depending on the characteristics of the attribute). This method is useful if the missing values occur randomly and the frequency of occurrence is quite rare. It is better to discard the irrelevant data because its existence can reduce the quality or accuracy of the expected data mining later [24].

2.4 Data Modelling

The dataset that has been cleaned using Microsoft Excel 365 will be imported into the RapidMiner studio version 9.10 software. Next, change the role in the outlook (mortality rate) column as a label. Then, store the dataset in the local repository or temporary repository. After that, input the cross-validation operator with 10 folds in the process page to get an accurate validation result. Choose stratified sampling with a split ratio of 90% of training data samples and 10% of testing data samples. Stratified sampling will ensure that training and testing samples have the same distribution of class values. After that, input the decision tree model in the training subprocess with parameters are gain ratio as a criterion, 10 as maximal depth, 0.1 as confidence, 0.01 as minimal gain, 2 as minimal leaf size, 4 as minimal sizes for the split, and 3 as a number of pre pruning alternatives. The model is ready for the training subprocess. After that, input two more operators in the testing subprocess, and apply the model and performance consisting of accuracy, precision, and recall. The model is ready for the testing subprocess. Return to the main process and connect the output ports model. Finally, hit the run process locally in the dataset. The flowchart to determine the best water quality management practice to reduce the mortality rate of red tilapia fingerlings using the decision tree algorithm can be seen in figure 1. And the model configuration within cross-validation in RapidMiner Studio can be seen in figure 2.

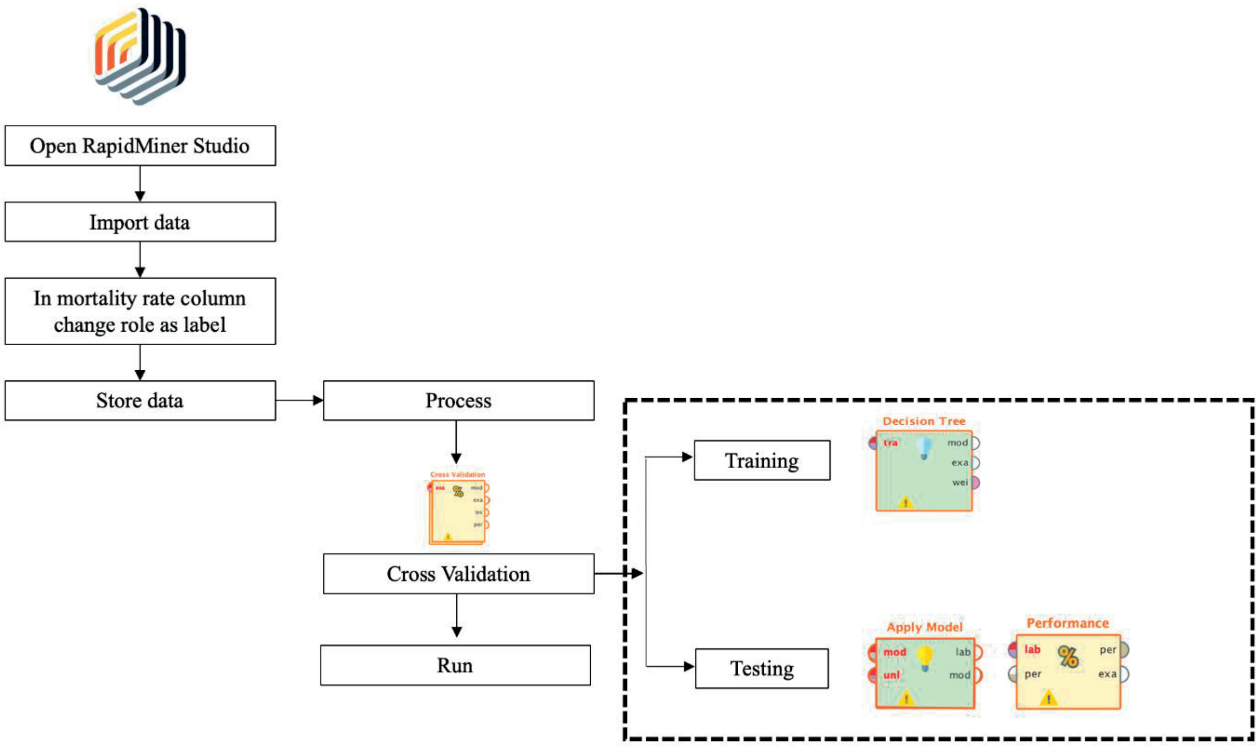

Figure 1. The flowchart to determine the best water quality management practice to reduce the mortality rate of red tilapia fingerlings using the decision tree algorithm

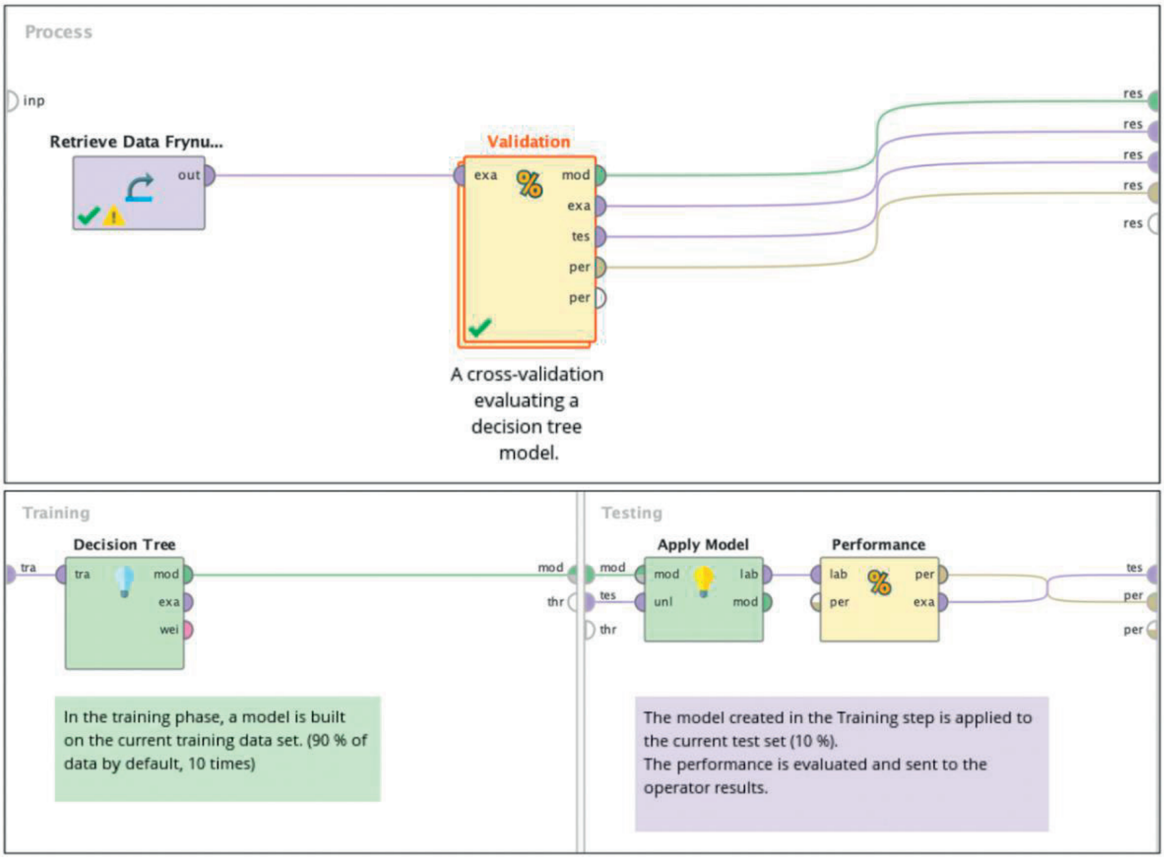

Figure 2. The model configuration within cross-validation in RapidMiner Studio

2.5 Performance Measurement

2.5.1 Confusion Matrix

The confusion matrix is a test method to minimize errors and ensure that the output is as desired. The confusion matrix describes the true and false results of a classification model. The value of the confusion matrix is usually shown in percent (%). The confusion matrix can be seen in figure 3.

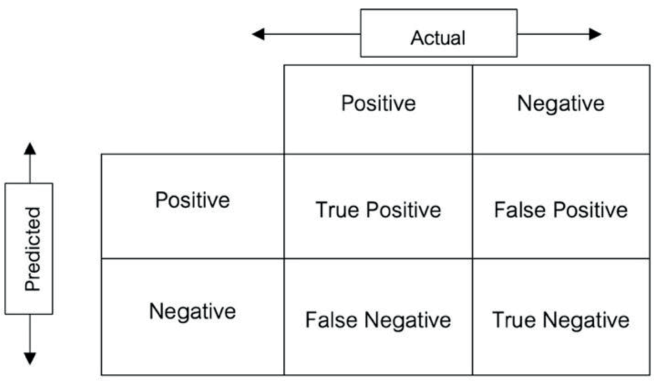

Figure 3. Confusion Matrix

2.5.2 Accuracy, Precision, and Recall

In performance measurement, there are three classification metrics: Accuracy, Precision, and Recall. Accuracy is how accurately the system can classify the data correctly. In other words, accuracy is a comparison between the data that is classified correctly and the whole data. Accuracy can be seen in equation 1. Precision describes the number of positive data categories classified correctly divided by the total data classified as positive. Precision can be seen in equation 2. Meanwhile, recall shows how many the system correctly classifies percent of the positive category data. Recall can be seen in equation 3.

$$\text{Accuracy} = \frac{TP + TN}{TP + TN + FP + FN} \times 100\% \quad (1)$$

$$\text{Precision} = \frac{TP}{TP + FP} \times 100\% \quad (2)$$

$$\text{Recall} = \frac{TP}{TP + FN} \times 100\% \quad (3)$$

True Positive (TP) was the number of positive data correctly classified by the system. True Negative (TN) was the number of negative data correctly classified by the system. False Positive (FP) was the number of positive data classified incorrectly by the system. False Negative (FN) was the number of negative data classified incorrectly by the system.

3. Results and Discussion

The best water quality management practice to reduce the mortality rate of red tilapia fingerlings was achieved under the decision tree algorithm; accuracy reached 89.67% with ± 5.11% (micro average: 89.60%), precision reached 86.71% ± 18.02% (micro average: 80.00%) and recall reached 72.50% ± 24.86% (micro average: 71.79%). Table 1. shows that the prediction of low with a true low of as many as 127 data and a true high of as many as 11 data with class precision reached 92.03%. The prediction of high with true low, as many as 7 data and for true high, as many as 28 data with class precision reached 80.00%. For class recall with a true low, it reached 94.78%. While for class recall with a true high, it reached 71.79%.

Table 1. Confusion Matrix with Decision Tree Algorithm

	True Low	True High	Class Precision
Pred. Low	127	11	92.03%
Pred. High	7	28	80.00%
Class Recall	94.78%	71.79%	

Table 2. The water quality parameters of red tilapia fingerlings are raised in outdoor earthen ponds with a recirculating aquaculture system.

Water Quality Parameter	**Unit**	**Min**	**Max**	**Mean**	**Standard Deviation**
DO average	mg L^{-1}	3.60	7.85	5.77	0.87
DO different	mg L^{-1}	0.00	3.90	1.54	0.94
pH average	-	5.15	7.60	7.29	0.23
pH different	-	0.00	0.90	0.19	0.19
Temperature average	˚C	18.50	27.00	22.67	1.92
Temperature different	˚C	0.00	4.00	1.79	0.84
Total ammonia nitrogen (TAN)	mg L^{-1}	0.00	3.00	1.11	0.73
Nitrite-nitrogen (NO_2-N)	mg L^{-1}	0.00	1.40	0.71	0.43
Alkalinity	mg L^{-1}	60.00	110.00	79.11	9.41
Transparency	cm	15.00	45.00	33.78	8.22

The water quality management practice to reduce the mortality rate of red tilapia fingerlings raised in outdoor earthen ponds with a recirculating aquaculture system shows that the most influential factor in the mortality rate of red tilapia fingerlings was NO_2-N (Figure 4). In the implementation stage using a decision tree algorithm using RapidMiner 9.10, a decision tree algorithm with 12 terminal nodes was obtained to determine the mortality rate of red tilapia fingerlings raised in outdoor earthen ponds with a recirculating aquaculture system.

Terminal node number 1 states that if the NO_2-N is more than 1.275 mg L^{-1}, the mortality rate for red tilapia fingerlings is high. Terminal node number 2 states that if NO_2-N is less than or equal to 1.275 mg L^{-1}, the DO average is more significant than 7.475 mg L^{-1}, then the mortality rate for red tilapia fingerlings is high. Terminal node number 3 has the NO_2-N is less than or equal to 1.275 mg L^{-1}, DO average is less than or equal to 7.475 mg L^{-1}, alkalinity is greater than 71.250 mg L^{-1}, transparency is greater than 44.869 cm, temperature average is greater than 22.250 ˚C, then the mortality rate for red tilapia fingerlings is high. Terminal node number 4 has NO_2-N is less than or equal to 1.275 mg L^{-1}, DO average is less than or equal to 7.475 mg L^{-1}, alkalinity is greater than 71.250 mg L^{-1}, transparency is greater than 44.869 cm, temperature average is less than or equal to 22.250 ˚C, then mortality rate for red tilapia fingerlings is low. Terminal node 5 has NO_2-N is less than or equal to 1.275 mg L^{-1}, DO average is less than or equal to 7.475 mg L^{-1}, alkalinity is greater than 71.250 mg L^{-1}, transparency is less than or equal to 44.869 cm. The mortality rate for red tilapia fingerlings is low.

Terminal node number 6 has NO_2-N is less than or equal to 1.275 mg L^{-1}, DO average is less than or equal to 7.475 mg L^{-1}, alkalinity less than or equal to 71.250 mg L^{-1}, transparency is greater than 33.766 cm, DO different is greater than 0.450 mg L^{-1}, alkalinity is greater than 61.250 mg L^{-1}, the month is greater than 1.5. The mortality rate for red tilapia fingerlings is low. Terminal node number 7 has NO_2-N is less than or equal to 1.275 mg L^{-1}, DO average is less than or equal to 7.475 mg L^{-1}, alkalinity is less than or equal to 71.250 mg L^{-1}, transparency is greater than 33.766 cm, DO different is greater than 0.450 mg L^{-1}, alkalinity is greater than 61.250 mg L^{-1}, the month is less than or equal to 1.5, NO_2-N is greater than 0.013 mg L^{-1}. The mortality rate for red tilapia fingerlings is high. Terminal node number 8 has NO_2-N is less than or equal to 1.275 mg L^{-1}, DO average is less than or equal to 7.475 mg L^{-1}, alkalinity is less than or equal to 71.250 mg L^{-1}, transparency is greater than 33.766 cm, DO different is greater than 0.450 mg L^{-1}, alkalinity is greater than 61.250 mg L^{-1}, the month is less than or equal to 1.5, NO_2-N is less than or equal to 0.013 mg L^{-1}, temperature average is greater than 22.750 ˚C, then mortality rate for red tilapia fingerlings is low.

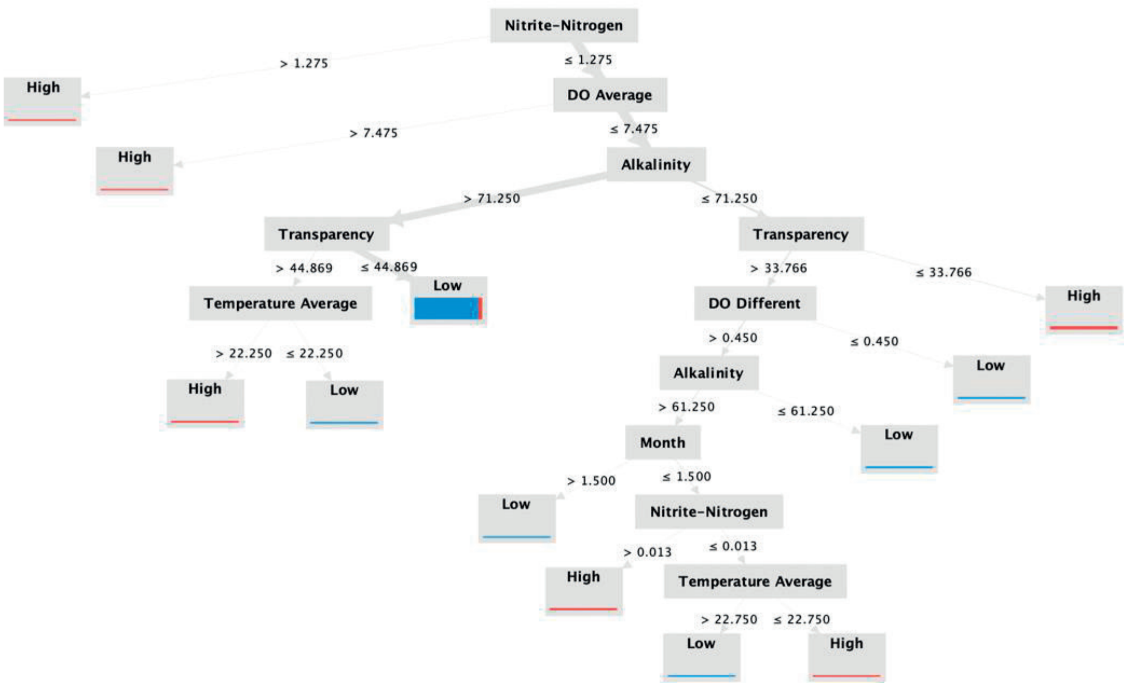

Figure 4. Decision tree of water quality management practice to reduce the mortality rate of red tilapia fingerlings raised in outdoor earthen ponds with a recirculating aquaculture system.

Terminal node number 9 has NO_2-N is less than or equal to 1.275 mg L^{-1}, DO average is less than or equal to 7.475 mg L^{-1}, alkalinity is less than or equal to 71.250 mg L^{-1}, transparency is greater than 33.766 cm, DO different is greater than 0.450 mg L^{-1}, alkalinity is greater than 61.250 mg L^{-1}, the month is less than or equal to 1.5, NO_2-N is less than or equal to 0.013 mg L^{-1}, temperature average is less than or equal to 22.750 ˚C, then mortality rate for red tilapia fingerlings is high. Terminal node number 10 has NO_2-N is less than or equal to 1.275 mg L^{-1}, DO average is less than or equal to 7.475 mg L^{-1}, alkalinity is less than or equal to 71.250 mg L^{-1}, transparency is greater than 33.766 cm, DO different is greater than 0.450 mg L^{-1}, alkalinity is less than or equal to 61.250 mg L^{-1}. The mortality rate for red tilapia fingerlings is low. Terminal node number 11 states that, If NO_2-N is less than or equal to 1.275 mg L^{-1}, DO average is less than or equal to 7.475 mg L^{-1}, alkalinity is less than or equal to 71.250 mg L^{-1}, transparency is greater than 33.766 cm, DO different is less than or equal to 0.450 mg L^{-1}. The mortality rate for red tilapia fingerlings is low. And terminal node 12 has NO_2-N is less than or equal to 1.275 mg L^{-1}, DO average is less than or equal to 7.475 mg L^{-1}, alkalinity is less than or equal to 71.250 mg L^{-1}, transparency is less than or equal to 33.766 cm. The mortality rate for red tilapia fingerlings is high.

The results of measurements of DO, pH, and temperature during the rearing of red tilapia were 3.60-7.85 mg L^{-1}, 5.15-7.60, and 18.5-27 ˚C with the average of DO, pH, and temperature being 5.77 ± 0.87 mg L^{-1}, 7.29 ± 0.22 and 22.6 ± 1.92 ˚C, respectively (Table 2). These results were classified as appropriate growth for the red tilapia fingerlings in outdoor earthen ponds with RAS. The optimal DO for rearing tilapia fingerlings ranges from 6-6.5 mg L^{-1} [26] or is not less than 3 mg L^{-1} [27]. Tilapia is also known to be resistant to very low DO. Most tilapia can tolerate DO in the range of 0.1-0.5 mg L^{-1} for various periods [28]. The optimal DO will produce the best fish performance, while low DO will limit respiration, growth, and metabolic activity in fish [28-29]. On the other hand, low DO can also cause fish fingerlings to be susceptible to disease [28, 30]. Stable pH values for rearing tilapia range from 7-8. In this range, fish do not need the energy to adapt [27, 31]. According to Boyd [32], a suitable pH value for fish growth ranges from 6.5-9. Although fish can survive at pH values of 4-6 and 9-10, the production is poor. And at a pH of less than 4 and more than 11, it can cause mortality in fish. The temperature range for normal development, reproduction, and growth of tilapia fingerlings are about 20-34 ˚C depending on the fish species [33-34] with an optimum range of about 25-30 ˚C [34-35]. Tilapia can also tolerate temperatures as low as 7.4-11 ˚C, but only for short periods [36]. Prolonged exposure to tilapia at this low temperature will certainly cause mass mortality. Feeding of tilapia was reduced sharply below 20 ˚C and they stopped feeding at about 16 ˚C, while severe mortality occurred at 12 ˚C [37].

The results of measurements of TAN and NO_2-N during the rearing of red tilapia fingerlings ranged from 0-3 mg L^{-1} and 0-1.4 mg $L^{-1,}$ with the average of TAN and NO_2-N being 1.10 ± 0.73 mg L^{-1} and 0.70 ± 0.43 mg L^{-1} , respectively (Table 2). These results were inappropriate for rearing red tilapia fingerlings in outdoor earthen ponds with RAS. TAN is a combination of two forms, Unionized ammonia (NH_3), which is toxic to fish, and ammonium ion (NH_4^+), which is non-toxic [30]. The optimal TAN for tilapia growth is less than 0.01 mg L^{-1} [28], or less than 0.5 mg L^{-1} [30, 38-39]. Research from Benli and Köksal [40] found that the median lethal concentration (48 h, LC_{50}) of unionized ammonia (NH_3) tilapia fingerlings exposed to varying levels of ammonia was 1.0 and 7.40 mg L^{-1}. When the fingerlings were exposed to ammonia concentrations, they showed increased movement, ventilation, convulsions, and spiral swimming. They also had excessive mucous secretion on the gills and body surface, bleeding on the gills, and darkening of the eyes and skin.

In this study, the most influential factor in the mortality of red tilapia fingerlings was NO_2-N. This is because red tilapia fingerlings can still tolerate the toxicity of TAN during rearing. After all, it has the appropriate DO and pH values. TAN toxicity will increase if DO decreases and the toxicity of TAN will decrease if pH decreases [41-42]. This concurs with Redner and Stickney (1979), who found that the 48 h LC_{50} for *Oreochromis aureus* was 2.46 mg L^{-1}. When the fish were acclimatized to the sublethal concentration of 0.43-0.53 mg L^{-1} for 35 days, they could withstand a concentration of 3.4 mg L^{-1} NH_3 without any mortality for 48 h [43]. In eutrophic fish ponds, the concentration of NH_3 fluctuates daily due to photosynthesis and respiration. In the morning, pH is minimum, and TAN is in the form of NH_4^+. Whereas in the afternoon, when the pH is maximum (around 9.0-9.5), the TAN balance shifts towards an increase in the amount of NH_3. Therefore, in the afternoon in eutrophic ponds, fish can experience temporary poisoning because an increased environmental pH increases the NH_3 component [42].

NO_2-N is a toxic nitrogen compound in freshwater fish commodities that can affect fish culture and effectiveness [44]. The concentration of NO_2-N in fish rearing should not exceed 0.5 mg L^{-1} [45]. The high concentration of NO_2-N during the treatment period was probably caused by excessive high protein feed, the use of nitrogen fertilizers, high stocking density, and the less-than-optimal performance of the biofilter in absorbing nitrogen compounds in the pond. Frequent aeration or the action of strong winds can also increase nitrite levels due to the increased mixing of nitrite produced by ponds in the oxygen-starved bottom mud. During bacterial nitrification, ammonia is first oxidized to nitrite by ammonia-oxidizing bacteria (*Nitrosomonas* spp. or *Nitrosospira* spp.) and then to less toxic nitrate via bacterial nitrite-oxidizing (*Nitrobacter* spp., *Nitrospira* spp.). Therefore, nitrite remains available in water as an intermediate in the bacterial oxidation of ammonia to nitrate, a product of fish nitrogen excretion. Thus, an imbalance in the nitrification process of bacteria can also increase nitrite concentration in water [46, 47].

When fish absorb NO_2-N, the mechanisms of nitrite toxicity include its competition with chloride (Cl^-) for uptake in the gill epithelium, increased levels of extracellular K^+ that affect skeletal muscle contraction and membrane potential, and impaired binding of oxygen to hemoglobin due to the oxidation of Fe^{2+} to Fe^{3+}, results in the production of methemoglobin (MetHb), and causes hypoxia due to a decrease in the oxygen-carrying capacity of the blood [28, 48]. Blood containing methemoglobin is brown, so nitrite poisoning in fish is often called brown blood disease [49]. A study by Atwood et al. [50] found that small tilapia (4.4 g) was more nitrite tolerant than large fish (90.7 g). The 96-hour NO_2-N LC_{50} was 81 and 8 mg L^{-1} in small and large fish, respectively. Adding a chloride source (500 mg L^{-1} $CaCl_2$ or NaCl) to culture water can protect small and large fish from nitrite toxicity. The protection achieved in chloride: nitrite ratio of 1.5:1 for culture water can protect tilapia from nitrite toxicity [50].

The alkalinity and transparency during the rearing of red tilapia were 60-110 mg L^{-1} and 15-45 cm, with the average of alkalinity and transparency being 79.19 ± 9.41 mg L^{-1} and 33.78 ± 8.22 cm, respectively (Table 2). These results were classified as appropriate for rearing red tilapia fingerlings in outdoor earthen ponds with RAS. Alkaline water generally has a relatively high pH and concentration of bicarbonate (HCO_3^-) and carbon dioxide (CO_2) [28]. FAO [27] reported that at an alkalinity range of 80-150 mg L^{-1}, it could maintain carbon dioxide levels in the waters even when it rains. On the other hand, alkalinity of more than 50 mg L^{-1} can increase the growth of tilapia fingerlings [51]. Lack of carbon dioxide in the water can cause mortality in phytoplankton, depleting the DO in the water. A sign of oxygen depletion and overall deterioration of pool water is the color of the water changing from green to light green to brown. This can lead to mass mortality in fish kept [27]. Transparency is closely related to light penetration and attenuation of underwater ecosystems [52]. It plays an important role in understanding variations in aquatic ecological environments, such as the photosynthesis of phytoplankton and their growth [53]. The ideal water transparency in fish rearing is between 30-40 cm [54], and low transparency can affect the visual impairment of fish [35].

4. Conclusions

The results of this study indicate that machine learning techniques with a decision tree algorithm can be applied in determining the best water quality management practice to reduce the mortality rate of red tilapia fingerlings. The decisions and actions of fish farmers in preventing water quality factors can cause the aquaculture system to experience mass mortality and increase the productivity of red tilapia fingerlings raised in outdoor earthen ponds with a recirculating aquaculture system.

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