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Performance evaluation of a taro (*Colocasia esculenta*) assisted vermifilter for swine wastewater treatment

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ABSTRACT

Untreated swine wastewater is one of the main contributors to the problem of water pollution in areas where swine farming is prevalent. Lack of wastewater treatment facilities can cause nutrient buildup in bodies of water, that result in adverse environmental effects such as eutrophication and can cause the buildup of pathogens in bodies of water. This study evaluated the feasibility of a vermifilter using African Night Crawlers (*Eudrilus eugeniae*) and taro (*Colocasia esculenta*) in treating swine wastewater. The cylindrical vermifilters each had a diameter of 35cm, 50cm of freeboard, 15cm of soil substrate, and 35cm of gravel of mixed sizes. One vermifilter was planted with taro plants (TAVF) while the other was not (VF). Water samples were collected from the effluent of the respective setups, and were analyzed for electrical conductivity (EC), total dissolved solids (TDS), oxidation-reduction potential (ORP), dissolved oxygen (DO), and pH.

Results from the Taro Assisted Vermifilter showed an average of 70.45% and 70.50% removal efficiencies for EC and TDS, respectively. The observed average increase in pH was 0.66, while the effluent ORP values for the TAVF exceeded 220mV. The TAVF showed no signs of clogging throughout the wastewater loading period, and a significant increase in the earthworm mass was observed. The plants used were also observed to have grown significantly throughout the experiment. The

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TAVF, however, did not perform better than the VF in terms of removal efficiency. Overall, the system demonstrated potential as a treatment facility for swine farms with significant wastewater effluent and showed efficiency with extended periods of acclimatization.

Keywords: *Colocasia esculenta*, *Eudrilus eugeniae*, macrophyte assisted vermifilter, nutrient removal, wastewater

INTRODUCTION

With the rise of pollution caused by several human practices, freshwater has become scarce. Farm activities, such as raising livestock, can contaminate several freshwater sources. In raising animals, such as swine, feces and other waste matter are often washed away with water, leading to the creation of wastewater. The animal excreta, along with discharges and wash water from the farm, constitutes livestock wastewater with high concentrations of heavy metals, pathogens, organic matter, xenobiotics, etc., and is a potent cause of environmental pollution and antibiotic resistance (Sakshi et al 2023).

Wastewater, with its various components, poses a significant threat to groundwater contamination. This escalating issue, coupled with the reduced dissolved oxygen, negative redox potential, and promotion of eutrophication, underscores the pressing need for effective wastewater treatment (Samal et al 2017).

In treating wastewater, several methods exist, including chemical and mechanical means. Another technique, classified as biological means, is through vermifiltration. Vermifiltration is often seen as one of the more eco-friendly methods of wastewater treatment (Samal et al 2018). One particular technique in vermifiltration is the inclusion of macrophytes, which results in a sustainable and more natural wastewater treatment method (Singh et al 2019). Singh et al describe macrophytes as macroscopic plant species that float on water or thrive in submerged or partially submerged conditions. Macrophytes have been generally used in natural wastewater treatment, such as in waterways where wastewater passes through. However, the presence of floating macrophytes tends to clog up waterways, negatively impacting the environment (Zhao et al 2014).

Vermifiltration allows for treatment of wastewater directly on the farm, reducing or removing contaminants, thus effectively improving water quality. Furthermore, other plants, such as taro (*Colocasia esculenta*) may be used in treating wastewater as an alternative to floating macrophytes (Bindu et al 2008).

METHODOLOGY

Design and construction of the taro assisted vermifilter

The live organisms used for the study were taro (*C. esculenta*) and earthworms (*E. eugeniae*). Each vermifilter was inoculated with the same mass of earthworms. The rest of the materials included a gauge 18 galvanized iron sheet, garden soil, rice hull, gravel, influent feeding system, and swine wastewater. The taro seedlings were obtained from the Philippine Root Crop Research and Training Center at the Visayas State University (VSU), Leyte, Philippines. The variety chosen for the study was PSB-

VG 2. The African Nightcrawler earthworms (*E. eugeniae*), were obtained from the Ecological Farm and Resource Management Institute (Eco-FARMI) also located at VSU.

The design used for the study was the tower-type vermifilter design presented by Samal et al in their 2017 study. The first component of the design was a source tank, which served as the source for the wastewater to be loaded into the vermifilters. Inside the source tank was a dipper, which was used to load the wastewater into two constructed vermifilters. The two vermifilters differed in that one vermifilter was planted with taro plants, while the other was not. Each vermifilter has its basin at the bottom, which collects the effluent treated wastewater.

A G.I. sheet was divided into two (2) equal parts with 1.2mx1.2m dimensions. The two were then trimmed and coiled up to form two identical cylindrical vermifilters with height of 100cm and each having a diameter of 35cm. The filter bed and substrate filled up 50cm of the cylinder, while the remaining 50cm became the freeboard. The filter bed had two (2) layers, with the bottom layer being 35cm deep and the top layer being 15cm deep. The top layer of bedding served as the substrate for the earthworms and the soil for the taro, and was composed of a 5:1 mixture of garden soil and rice hull,. The bottom layer was composed of gravel of mixed sizes sitting on a metal screen, while effluent catch basins were placed under each vermifilter for effluent collection. Loading of influent was done with the use of a dipper. The influent was stored in a separate 200L tank. Figure 1 shows the schematic diagram of vermifilters.

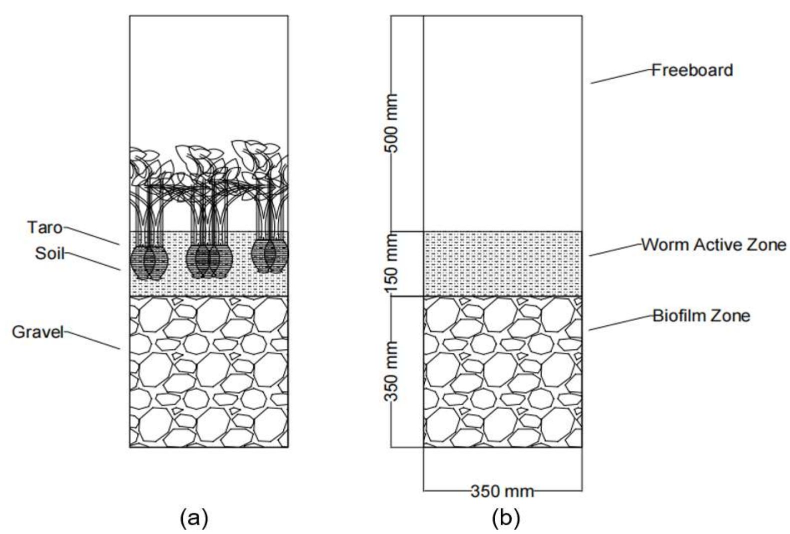

Figure 1. Schematic Diagram of the (a) Taro Assisted Vermifilter (TAVF) and (b) Control Vermifilter (VF)

Setting Up of Biofilter and Wastewater

Each vermifilter was inoculated with earthworms of the *E. eugeniae* species. The vermifilters were initially inoculated with 500g of earthworms each, followed by an additional 100g each at the time of planting the taro plants. The earthworms were weighed using a digital scale. Since the substrate adhered to the earthworms, 10% of the weighed mass was assumed to be substrate. As such, 555g of earthworms and substrate mixture were loaded initially, followed by 111g on the 5th day.

After the earthworms were added to the vermifilters, the organisms were given a period of 14 days in order to acclimatize to the new environment, Only one vermifilter was planted with *C. esculenta* plants. A total of seven (7) plants were planted 5 days after the initial inoculation with earthworms. The plants were plantedsuch that the root system reached at least halfway through the worm active zone. This allowed for a further 9 days of acclimatization following planting. During this time, the conditions and behaviors (eg, escape attempts, leaf development, etc.) of the organisms were monitored. The wastewater loading was started 14 days after the initial inoculation.

Swine feces were collected from swine farms located in Barangay (village). Patag, Leyte, Philippines. Seven (7) kilograms of waste were collected over a period of 7 days. The collected fecal matter was mixed thoroughly with water at a waste-to-water ratio of 1:10 to form a wastewater slurry. The parameters for the analysis of the samples were electrical conductivity (EC), total dissolved solids (TDS), oxidation-reduction potential (ORP), dissolved oxygen (DO), and pH. The wastewater slurry was stirred before testing and loading. A Yiery C-600A multi-water quality meter was used to measure the slurry's EC, TDS, pH, and temperature in situ. Dissolved oxygen was tested using a DO meter. The devices used were calibrated first before they were used to analyze the resulting slurry quality. The analysis was taken every 2 days throughout the wastewater loading period.

Wastewater Loading and Sample Collection

Wastewater loading began after the earthworms had acclimated to the new environment for 14 days. The prepared wastewater slurry was loaded into each vermifilter twice a day over the course of 8 days. The slurry was stirred each time the load was done. The loading times were at 8:00AM and 5:00PM. The morning loading was 2L for each vermifilter, while the afternoon loading was 1L. The setup was placed where the rain could not reach it so as not to affect the effluent and influent data. The water requirements of the plants and earthworms were met by the wastewater added to the vermifilter. As such, no additional water was added to both setups. The conditions of the vermifilter were monitored so as to maintain the health of the organisms. The pH levels of both setups were monitored to stay between pH5.0 and pH8.0. Visual observation for waterlogging within the vermifilter was also done. The worm active zone was kept away from direct sunlight to better improve earthworm activity.

At the wastewater loading stage, the visual changes were observed and the parameters for growth and development of the plants were recorded. Every 2 days of feeding, samples were collected from the effluent liquid collected in the catch basins.

Measurement of Growth and Development in Taro and E. Eugeniae

For the taro plants, the parameters measured were the plant height, number of leaves, leaf sizes, and root length. The plant height and number of leaves were monitored throughout the experiment, with data being recorded every 2 days. The rest of the aforementioned parameters were measured before acclimation, and at the end of the experiment. The plant height was recorded every 2 days from the start of wastewater loading using a measuring tape. The number of leaves were also counted every 2 days. As for the leaf sizes and root lengths, the plants were dug up on the last day of data collection. The leaf sizes were determined by measuring the leaf length and width using a tape measure. The root lengths were determined by measuring the longest root of the plants using a tape measure.

The main parameter for earthworm growth and development was earthworm mass. Similar to the initial weighing conditions, 10% of the weight of the earthworms was assumed to be from substrate adhering to the worms. The difference between the mass of earthworms at the start and at the end of the experiment was then computed and it was determined whether there was positive or negative development in the mass of earthworms in the vermifilter. The equations used for determining the mass changes of the earthworms are shown in the following equations (Samal et al 2017):

$$\text{Actual Mass (AM)} = M_F x 0.90$$

$$\text{Mass Difference (AM)} = AM - M_I$$

where:

M_F= Mass of the earthworms during the final weighing

M_I= Mass of the earthworms inoculated in each vermifilter

Percent Change Determination

In all samples, the percentage changes in the influent and effluent data were computed using the same formula, which is given as follows:

$$\text{Percent Change } (\%C) = \frac{C_f - C_i}{C_i} x100$$

where:

C_f=Parameter Value of Effluent or Final Stage

C_i=Parameter Value of Inluent of Initial Stage

After the samples were analyzed using the water parameter testers, the removal efficiency for each parameter was calcutated using a modified version of the previous equation, as shown below:

$$\text{Removal Efficiency } (\%C) = \frac{C_i - C_f}{C_i} = x100$$

where:

C_f=Concentration of the parameter analyzed in the influent

C_i=Concentration of the parameter analyzed in the effluent

Research Design

The study used a true experimental research design, as samples were not grouped prior to experimentation. A completely randomized design was utilized during effluent sampling. Samples were collected from different random points in the basin during sample collection. Data collection was replicated three times for every setup. Before collection, stirring of the wastewater during loading allowed both setups to receive the same type of wastewater during each loading.

Statistical Analysis

Paired sample t-tests between TAVF and VF units were performed for each parameter to analyze the statistical differences. The T-tests were performed with the use of Microsoft Excel. The level of significance for each test was α=0.05.

A regression analysis was also done for between the TDS and EC values of both setups in order to determine the correlation between the two parameters. The Pearson correlation coefficient for the TDS and EC values of the VF and TAVF were then analyzed, as to whether both parameters were highly correlated or not.

RESULTS AND DISCUSSION

The calculated removal efficiencies for each pair of influent and effluent samples are tabulated in Tables 1 and 2, with the average values for each treatment being used on their respective dates. Values for the control setup are denoted by "VF" for "Vermifilter", while values for the experimental setup are denoted by "TAVF" for "Taro Assisted Vermifilter".

Table 1. EC Removal efficiencies of the TAVF and VF

Parameter	Removal Efficiency (%)				Average Removal Efficiency
Date	05/30	06/01	06/03	06/05	
EC (TAVF)	71.77%	71.72%	69.50%	68.81%	70.45%
EC (VF)	68.98%	72.65%	72.64%	73.21%	71.87%
Difference	2.79%	-0.93%	-3.14%	-4.4%	-1.42%

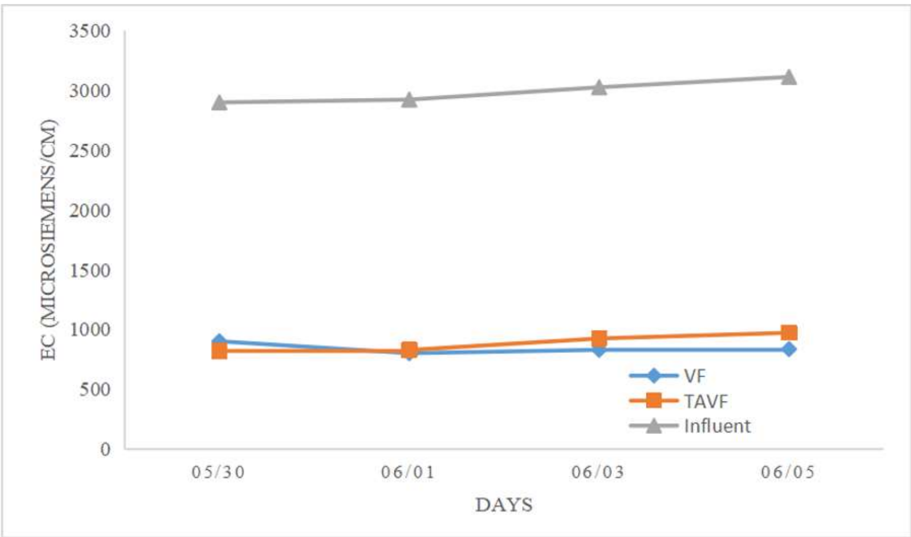

Figure 2. Electrical Conductivity (EC) of VF, TAVF, and Influent

Electrical Conductivity (EC) Reduction

As observed in Table 1 and Figure 1, the EC reduction abilities of the TAVF starts off better than the EC reduction abilities of the VF (T=0.0199, $p<0.05$). On Day 4 (June 01), there was no significant difference between the results of the effluents from both setups (T=0.067, $p<0.05$). However, as observed in Figure 2, the VF ended up with significantly better results from Day 6 (June 03) onwards (T=0.008, $p<0.05$). This was due to the reduction of water in the effluent caused by transpiration from the taro present in the TAVF. Since less water is being released as effluent from the treatment process, concentrations of dissolved salts within the effluent increase, resulting to effluents of higher EC values. Despite both setups having high removal efficiencies, the addition of the taro did not improve the EC removal efficiency when comparing the TAVF and VF.

Total Dissolved Solids (TDS) Removal

Similar to the trend in EC, the TDS removal efficiency of the TAVF was initially better than the VF (T=0.0203, $p<0.05$). At the later days, as shown by Figure 3, the VF performed significantly better than the TAVF (T=0.003 to 0.0009, $p<0.05$). The reason for this, similar to the EC values, was due to the transpiration of the taro, resulting to a higher pollutant concentration in the effluent collected from the setup. Despite both setups having high removal efficiencies, the addition of the taro did not improve the TDS removal efficiency when comparing the TAVF and VF.

Table 2. TDS Removal Efficiencies of the TAVF and VF

Parameter Date	Removal Efficiency (%)				Average Removal Efficiency
	05/30	06/01	06/03	06/05	
TDS (TAVF)	71.4%	71.42%	69.45%	69.74%	70.50%
TDS (VF)	68.58%	72.54%	72.63%	74.02%	71.94%
Difference	2.82%	-1.12%	-3.18%	-4.28%	-1.44%

Both the EC and TDS values of the influent were observed to increase throughout the experiment possibly because the fecal matter was decomposing. As the water level decreased, the pollutant concentration of the influent increased, as observed in Figures 2 and 3. For this reason, an increase in the pollutant concentration present in the effluents of both setups was also observed.

Figure 4 shows scatterplots of the data for the VF and TAVF, with the x-axis being the TDS in PPM and the y-axis being the EC in µS/cm. A regression analysis is also included in order to observe the correlation between TDS and EC values for both setups. For the VF, a high correlation is observed between the TDS and EC (R^2=0.9895). The same is true for the TAVF (R^2=0.9949). As such, it is concluded that there is a high correlation between TDS and EC for both setups, with the EC values being directly proportional to the TDS values for both. Rusydi (2017) noted that there is a strong correlation between TDS and EC in natural water and at lower TDS and EC levels. However, Rusydi does note that the correlation between both parameters is not always linear, and that the correlation becomes weaker as the salinity or material content of the water increases.

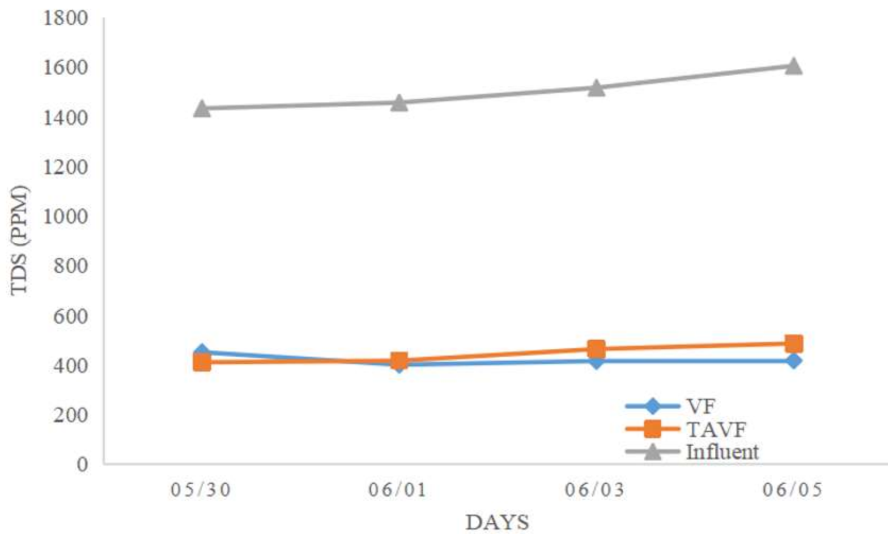

Figure 3. Total Dissolved Solids (TDS) of VF, TAVF, and Influent

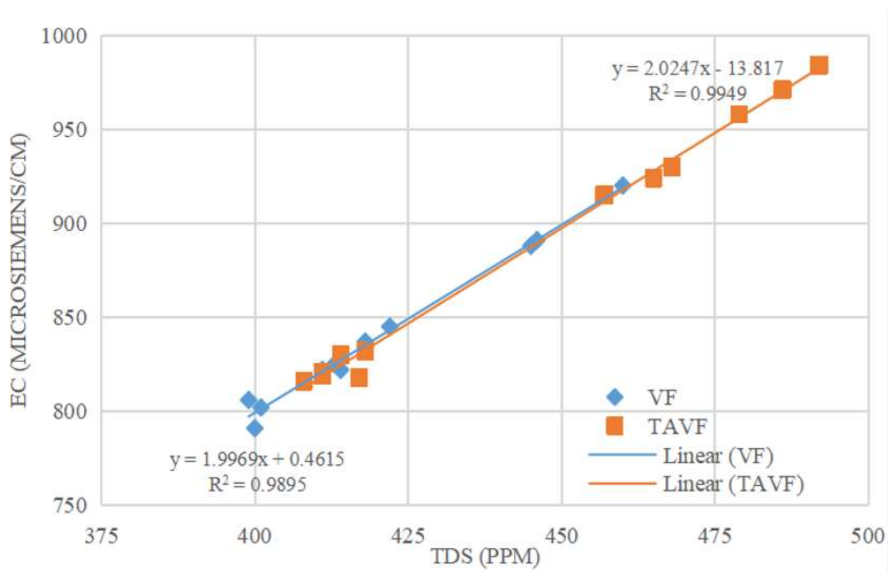

Figure 4. Correlation Between EC and TDS for VF and TAVF

Oxidation-Reduction Potential (ORP)

During the course of the experiment, the ORP values of the influent were negative, indicating high organic matter content and low dissolved oxygen. The negative ORP values, which ranged from -104mV to -66mV, can also be used to indicate the presence of several redox-active pollutants, such as ammonium. Figure 5 shows the graph for the ORP data values from the VF and TAVF obtained throughout the experiment.

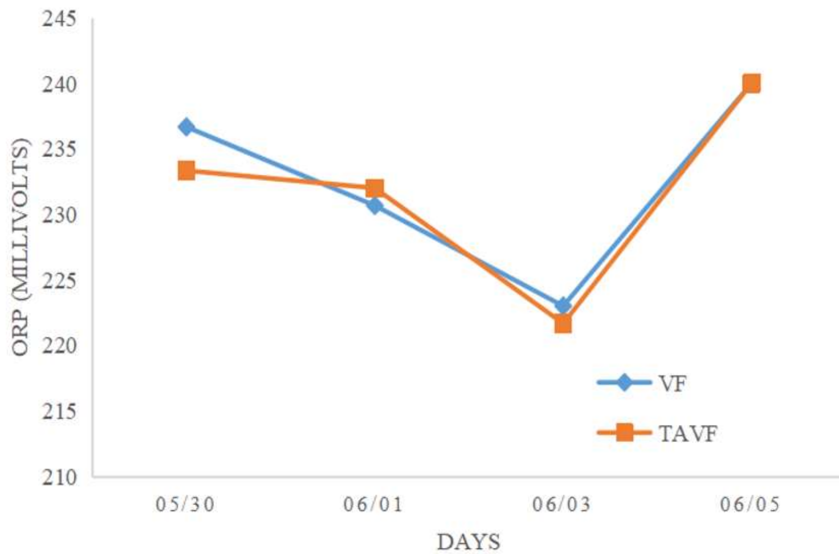

Figure 5. Oxidation-Reduction Potential (ORP) of VF and TAVF.

From the start of the experiment, both T_{VF} and T_{TAVF} showed significant changes in the ORP levels between the influent and effluent (T_{VF}=0.0003, T_{TAVF}=0.0001, p<0.05). The trend continued throughout the experiment, with the effluent for both setups having increased ORP values, with effluent ORP values exceeding 200mV for both setups throughout. However, during paired T-tests between both setups, the data was computed to have no statistical difference (T=0.299 to 1, p<0.05). As stated by Račys et al (2010), there is a strong inverse correlation between ORP and pollutants, specifically $NH4^+$. As such, the increase in ORP indicates the removal of pollutants, such as $NH4^+$, in the effluent.

Dissolved Oxygen (DO)

There was an increase in DO levels from the influent to the effluents of both setups. This increase in DO is expected when observing the trend of the ORP of the effluent and influent. Similar to the ORP, the DO levels when comparing both setups were statistically insignificant (T=0.184 to 0.25, p<0.5). Figure 6 shows the average DO levels on each day of measurement.

The DO levels, as shown in Figure 6, is quite similar to the study by Ndegwa et al (2007) in that the DO trend did not follow the trend of the ORP levels. A weak correlation between the two was observed during the experiment, and is highly attributed to the probes not being able to accurately measure DO at these levels due to lack of sensitivity.

pH Levels

The pH levels between the VF and the TAVF were only significantly different on Day 4 (T=0.034, $p<0.05$). On the rest of the days of sample analysis, the pH values had no significant difference. When compared to the influent, it was observed thatthe pH increased, with all influent values being below pH6.8, while all effluent values for both setups were above pH6.9. Given that the pH remained between 6.5 to 8.6, the earthworms were not drastically affected. The pH range also falls under the suggested range by Mandal (2014) for wastewater treatment and Jicong et al (2005) for earthworm survival.

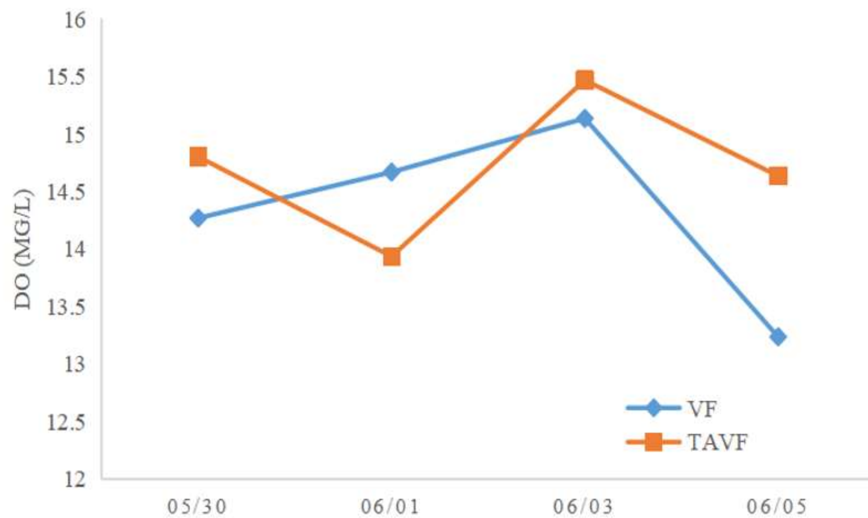

Figure 6. Dissolved Oxygen (DO) Levels of VF, TAV

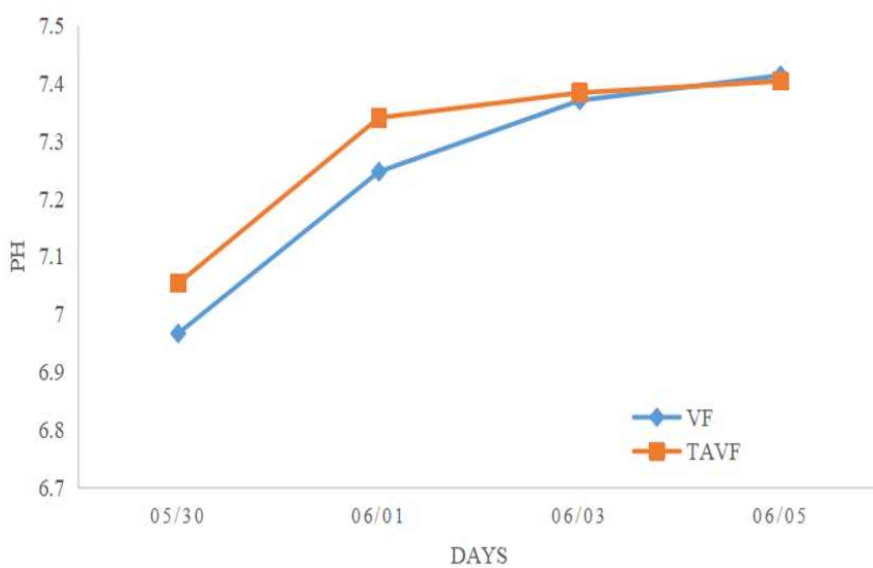

Figure 7. pH Levels of VF, TAVF.

Plant Growth and Development

After acclimatization, the plant heights were mostly below 50cm. Table 3 shows the final root length, plant height, number of leaves, and average leaf length and width of all plants present in the TAVF at the end of the experiment. For plant height, the average height was 59.1cm. The mean percent increase in height among the seven (7) plants was 13.16%.

Table 3. Root length, plant height, no. of leaves, average leaf length, and average leaf width at the end of the experiment

Plant No.	Root Length (cm)	Plant Height (cm)	No. Of Leaves	Average Leaf Length (cm)	Average Leaf Width (cm)
Plant 1	20	52.2	2	12.3	10.35
Plant 2	19.2	52.6	2	14.6	13.15
Plant 3	23.9	67.1	2	18.9	16.55
Plant 4	25.8	58	2	15.05	12.8
Plant 5	19.8	61.3	2	11.9	10.25
Plant 6	26.8	54.9	1	15.6	13.3
Plant 7	25.5	67.4	3	15	15

The longest root for each plant was also measured in order to determine the maximum root depth the plants had within the substrate. Root depth indicates the maximum depth within the worm active zone to which the plants can filter. The average root length among all plants was 23cm. This indicates that the plants were able to filter down to the gravel layer of the TAVF.

In terms of leaf number and size, the average number of leaves among all plants was two (2). The leaf width was observed to be directly proportional to leaf length. The larger leaf size was an indicator that more shade was available for the worm active zone compared to the VF which had no shade, whatsoever.

Earthworm Growth and Development

After each weighing of the earthworms, a 10% mass reduction was computed to account for the mass of the substrate adhering to the earthworms. From the corrected earthworm mass, the mass difference was computed.

As shown in Figure 8, the TAVF had a higher earthworm mass gain compared to the VF. Since both setups were inoculated with the same mass of earthworms, this indicates that the TAVF has more earthworm mass compared to the VF. The average mass percent changes for the VF and TAVF, which was computed using the Percent Change Formula, were 9.46% and 16.29%, respectively. The TAVF had a significantly higher earthworm mass compared to the VF (T=0.00001, $p<0.05$). The earthworms were observed to group together near the roots of the plants present in the TAVF, whereas the earthworms in the VF were observed at deeper areas in the substrate. Vermicast formation was also observed in both setups.

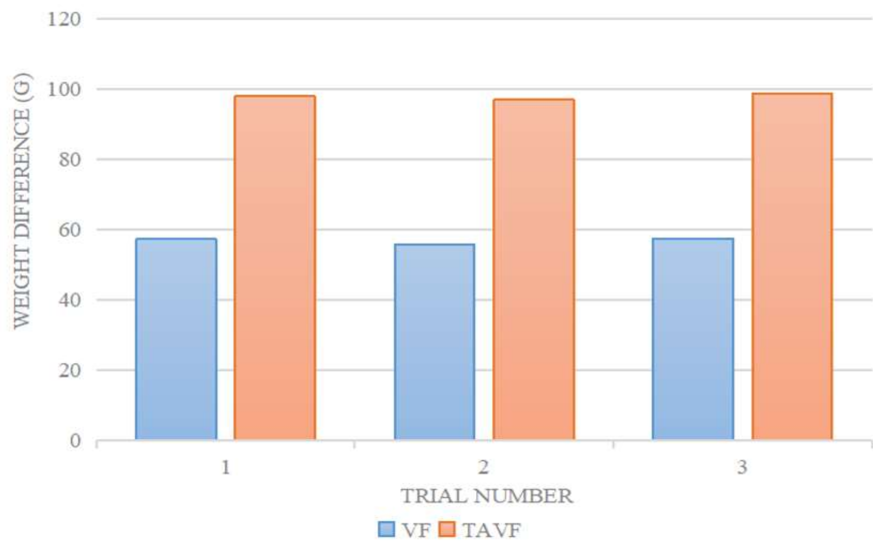

Figure 8. Earthworm Weight Differences Between VF and TAVF

Table 4. Final mass of earthworms

Treatment	Replication	Mass at Weighing (g)	Corrected Mass (-10% from substrate, g)
VF	VF_1	730.2	657.18
	VF_2	728.4	655.56
	VF_3	730.5	657.45
TAVF	$TAVF_1$	775.4	697.86
	$TAVF_2$	776.1	698.49
	$TAVF_3$	774.3	696.87

SUMMARY

Overall, the taro assisted vermifilter was found to have average removal rates of 70.45% and 70.50% for EC and TDS, respectively. A high correlation between the EC and TDS values was observed throughout the experiment. The ORP of the effluent was also observed to be increased, with the effluent ORP values exceeding 200mV for all samples as opposed to the negative values from the influent. Following the trend of the ORP values, the DO levels of the TAVF also increased. The pH levels also increased compared to the influent values.

CONCLUSIONS

The TAVF is concluded to be efficient in terms of lowering EC and TDS values. The TAVF is also effective in increasing ORP and pH values. As such, the TAVF was concluded to be effective in treating swine wastewater. However, the TAVF did not perform better than the VF. Further research is needed in order to accurately conclude whether the VF or TAVF is more efficient in treating swine wastewater. The amount of effluent recovered was outside the scope of this study so the water losses from evapotranspiration could not be determined. High transpiration rates resulted in less effluent recovery in the basins, thus resulting in higher nutrient concentrations in the effluent solutions.

RECOMMENDATIONS

Although it is clear that there is an increase in the mass of the earthworms in the TAVF compared to the VF, the nutrient removal efficiencies need further studies in order to be able to properly conclude whether the TAVF or VF is more effective. As such, for future studies, it is recommended that the influent and effluent for bacterial load, presence of E. *Coli*, Total Nitrogen (TN), Total Phosphorus (TP), Chemical Oxygen Demand (COD), and Total Suspended Solids (TSS) are added to the parameters in order to determine how TAVF differs from the VF in terms of nutrient removal efficiency. The addition of such parameters would also allow the researchers to compare the effluent parameters with the required standards from the WHO to determine whether the effluent can be safely released into bodies of water. It is also recommended that further studies include the effluent volume in the scope in order to be able to more accurately determine the nutrient removal efficiency of the TAVF, especially when compared to the VF.

Further studies should also try to find the actual number of surviving earthworms in each vermifilter in order to find the correlation between actual earthworm population and removal efficiency. Along with earthworm population, future studies should also find the correlation between root depth and volume, and removal efficiencies.

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AUTHOR CONTRIBUTIONS

JCA (main author), MGCS (co-author).

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AVAILABILITY OF DATA AND MATERIALS

All data in this undergraduate thesis are original and were collected by the main author during the conduct of the study.

ETHICAL CONSIDERATION

Not applicable.

COMPETING INTEREST

I hereby declare that the publication of my research involves no competing interests.

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