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Treatment of Aquaculture Wastewater by Vermireactor for Wastewater Discharge or Reuse

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Abstract
Vermifiltration is an emerging technology with the potential of becoming a reliable technology for treatment of wastewaters from different sources especially in low-resource country like Nigeria. In the present study, performance evaluation of vermireactors (Trials EA and AM) for treatment of aquaculture wastewater was conducted for 67 days using earthworm species; *Eudrilus eugeniae* (EA) and *Alma millsoni* (AM). Wastewater was applied at hydraulic loading rate of 0.0085 $m^3/m^2/h$ and earthworm density of 7877 earthworms/m^3 was used for the treatments. Effluent characteristics were compared with control (without earthworm). In addition, the characteristics were also compared with Nigerian National Regulations for effluent discharges and reuse of wastewater in aquaculture. The presence of two earthworm species aided the removal of BOD_5 (69-80%), COD (46-60%), ammonia nitrogen (87-93%), nitrate nitrogen (67-81%), total phosphorus (45-65%) and potassium (72-81%) in the treated effluent. The treatment process also increased dissolved oxygen (DO) (48-49%) in the treated effluents. The recorded values in the treatment process were higher than values recorded in the control. All parameters of treated effluent from trials EA and AM were within the guideline limits for discharge and reuse of wastewater in aquaculture except for BOD (concentrations were within the permitted limit for discharge, but slightly above the limit for reuse), total suspended solids and phosphorus concentrations. The results thus showed that the two earthworm species employed in the present study were suitable for treatment of aquaculture wastewater. This treatment method provides a sustainable method for treatment of aquaculture wastewater and should be explored further.

Traitement des eaux usées d'aquaculture' par le processus de vermifiltration pour usage ou re-usage

Résumé
Vermifiltration est une technologie émergente avec un potentiel à devenir une vraie technologie pour le traitement des eaux usées de sources différentes surtout dans des pays de tiers monde comme le Nigeria. Dans l'étude actuelle…. Eaux usées ont été appliqué au chargement hydraulique taux de 0.0085 $m^3 / m^2 / h$ et ver de terre densité de 7877. le vers de terre / m^3 a été utilisé pour les traitements. Des

caractéristiques des effluents ont été comparées avec le contrôle (sans ver de terre). En outre, les caractéristiques ont été aussi comparé avec le 'Nigérian National Regulations Commission' pour la réutilisation des eaux usées dans aquaculture. Le présence d'espece d'eux de ver de terre aidé l'enlèvement de BOD_5 (69-80%), morue (46-60%), ammoniac azote (87-93%), nitrate azote (67-81%), total phosphore (45-65%) et potassium (72-81%) dans le traités effluent. Le processus de traitement aussi augmente l'oxygène dissous (faire) (48-49%) dans le traité effluent. Les valeurs enregistrées dans le processus de traitement ont été supérieur que des valeurs enregistrées dans le contrôle. Tous les paramètres d'effluent traités ont été au sein de le directive limites pour décharge et réutilisation de eaux usées dans aquaculture à l'exception de bod (concentrations ont été au sein du permis limite pour décharge, mais légèrement au-dessus de limite pour réutilisation), total solides suspendu et concentrations phosphores. Les résultats ainsi montrent que les deux espèces de vers de terre employé dans cette étude sont adaptées pour le traitement d'eaux usées d'aquaculture. Cette méthode de traitement fournit un moyen durable pour le traitement des eaux d'aquaculture usées et devrait être exploré de plus.

Introduction

Aquaculture plays a critical role in meeting the food and nutrition needs as well as providing employment opportunities for millions of people around the world. Recent estimates put the world aquaculture production at 106 million tons in live weight, with a total estimated first-sale value of US$163 billion, and it provided half of all fish for human consumption. The estimates also indicate that 56.6 million people were engaged in the primary sector of capture fisheries and aquaculture in 2014 (FAO, 2016). It is expected that aquaculture will continue to play prominent role in fish supplies for many years to come because capture fisheries are being exploited to their sustainable limit and beyond (Boyd, 2003). In Nigeria, aquaculture has also been viewed as an activity likely to meet national shortfalls in fish supplies, thereby reducing fish imports. The fisheries sector accounts for about 2% of national GDP, 40% of the animal protein intake and a substantial proportion of employment, especially in the rural areas with estimated three million people engaged in the sector (Adedeji and Okocha, 2011).

In recent years, concerns are growing over the environmental footprints of intensive development in the aquaculture and fishery industry. Water pollution resulting from pond effluents is one of the negative impacts of intensive aquaculture practice. Most pond aquaculture cannot be conducted without discharge (Boyd, 2003). Wastewater discharged from aquaculture contains pollutants such as nitrogenous compounds (ammonia, nitrite and nitrate), phosphorus and dissolved organic carbon. Excessive nutrients in aquaculture effluents may lead to eutrophication of the receiving water bodies and consequent imbalance in the aquatic ecosystem. Other common complaint is the excessive use of ground water and other freshwater supplies for filling ponds (Boyd, 2003). Socio-economic and environmental issues such as climate change, population growth, urbanization and increasing water scarcity are limiting water supply for agricultural uses. Therefore, there is an urgent need for development of environmentally sustainable aquaculture production systems which incorporate water saving or wastewater reuse.

A number of physical, chemical and biological methods such as biofilters, trickling filters, rotating biological contactors, and fluidized bed reactors, used in conventional wastewater treatment have been applied in aquaculture systems. However, the major drawbacks from these methods are sludge production and cost requirements in terms of capital investment, energy consumption and maintenance requirements. In addition, their utilization for treatment of aquaculture wastewater has received marginal research attention so far (Turcios and Papenbrock, 2014).

Cost requirement is the major factor considered by farmers in investing in effluent treatment to prevent or mitigate environmental footprints of wastewater discharges. This is particularly true in Nigeria where most fish farmers do not treat their effluents before discharging into the environment. Other reasons for low adoption of wastewater treatment by farmers are non-existence of treatment facilities and ignorance of possible health hazards associated with discharge of untreated wastewater (Omofunmi *et al.,* 2016).

Vermifiltration could be a low-cost alternative to other conventional treatment systems for treatment of aquaculture wastewater.

Vermifiltration is an emerging technology that relies on favourable ecosystem within the vermifilter to degrade organics in wastewater through the introduction of earthworms. Earthworms are versatile wastewater consumers and decomposers (Natarajan and Kannadasan, 2016). Treated effluent from vermifiltration process is rich in essential nutrients for plant growth, which makes it suitable for use in gardening and crop production, as well as other reuse purposes (Singh *et al.,* 2017). Although vermifiltration has been applied for treatment of different wastewaters such as domestic sewage, swine wastewater and effluent from juice making industry (Kumar *et al.,* 2015; Li *et al.* 2008; Ghatnekar *et al.,* 2012), there is limited information on application of vermifiltration for treatment of aquaculture wastewater. The need for application of vermifiltration to non-conventional sectors to treat effluents such as agro-industrial effluents, and aquacultural effluents, as a means to promote integrated farming concept, and interdependency between the vermifiltration process and the surrounding ecosystem was highlighted in a recent review on vermifiltration (Singh *et al.* 2017). In this regard, the present study examined the potential of vermifiltration process to treat aquaculture wastewater for discharge to surface water bodies or reuse in aquaculture. Inclusion of vermifiltration process in aquaculture systems will serve as a source of supplementary feed or complete diet for fish, ultimately promoting organic feeding and food safety.

The main objective of this study was to evaluate the performance of vermireactors for treatment of aquaculture wastewater. The specific objectives of the study were to: (i) compare the performance of two indigenous earthworm species; *Eudrilus eugeniae* and *Alma millsoni* with control reactor (without earthworm), (ii) compare the influent and effluent characteristics from the reactors with Nigerian National Regulations for effluent discharges into surface water bodies and wastewater reuse in aquaculture.

Materials and Methods

Experimental set up

Two vermireactors (EA and AM) and control reactor, made from polypropylene, were set-up for treatment of aquaculture wastewater. The dimensions of the reactors were length 0.46 m, width 0.46m and depth 0.9m. The bottom of each reactor was provided with various holes for collection of treated wastewater. The filtering unit of each reactor is composed of garden soil, sandy soil and gravel up to a depth of 0.7m. Bottom most layer was made of gravel aggregate (size of 20mm) up to the depth of 0.1m, followed by another gravel aggregate (size of 10mm) up to depth of 0.15m. Sand was added up to a depth of 0.15m and partition net of 2mm mesh size was placed on the sand to prevent earthworm from escaping from earthworm culture. The topmost layer (earthworm packing bed) was filled with garden soil up to a depth of 0.3m. Vermireactors and control reactor were the same except for the presence of earthworms in the vermireactors.

The reactors EA and AM were inoculated with *Eudrilus eugeniae,* epigeic earthworms,and *Alma millsoni*, limicolous and endogeic earthworms, at earthworm density of 7877 earthworms/m^3. Sawdust was added to the vermibed. Aquaculture wastewater was collected from the concrete ponds, with no treatment facilities, from the Department of Aquaculture and Fisheries Management, University of Ibadan, Ibadan, Nigeria. The wastewater was collected weekly. Wastewater was applied by gravity at hydraulic rate of 0.0085 $m^3/m^2/h$. The experiment lasted 67 days. Influent and effluent samples were collected for analysis at specific times of the experiment. Sample collection started on 5th day and was initially done at interval of 3 or 4 days. However, when no appreciable variations in the characteristics of treated effluents were observed for different sampling time, sampling interval was changed to 7 days from the 18th day of the experiment.

Analysis

All samples were analysed for the following parameters; pH, biological oxygen demand (BOD), chemical oxygen demand (COD), total suspended solids (TSS), total dissolved solids (TDS), nitrate nitrogen (NO_3-N), ammonia nitrogen (NH_3-N), total phosphorus (TP) and potassium (K), according to standard methods (APHA, 2005). Influent and effluent characteristics were compared with Nigerian Effluent Discharges, Irrigation and Reuse Standards, and Fisheries and Recreation Quality Criteria Standards (NESREA, 2010).

Performance evaluation of reactors

Efficiency of treatment process in each reactor was determined from the reduction in indicators of pollution in the effluent as compared with the influent characteristics. The percentage reduction was calculated using the Eq. (1):

$$Percentage\ reduction = \frac{(C_{influent} - C_{effluent})}{C_{influent}} \times 100 \quad (1)$$

Where,

$C_{influent}$ = concentration in the influent wastewater

$C_{effluent}$ = concentration in the treated effluent

Results and Discussion

pH changes during treatment process

The pH is considered as an important factor in the management of aquaculture water because it determines the toxic action of other substances e.g., ammonia, hydrogen sulphide, cyanide and heavy metals on fish. The influent characteristics are presented in Table 1. The average value of pH of the influent sample was 7.62. Variations in pH of treated effluents as compared with initial pH of wastewater are presented in Fig 1. Generally, the pH of effluent samples from all the reactors showed a similar pattern of intermittent increase and decrease for the first four sampling times (until 18th day). Thereafter, the pH remained relatively stable in all the reactors, reaching 7.29, 7.49 and 7.73 in EA, AM and control reactors, respectively, on the final day (67th day). The results thus, indicated that despite fluctuation in the pH of treated effluent from all the reactors for the first few days, stability was eventually achieved in all the reactors. Various factors, which include humic fractions, organic acids, dissolved gases, inorganic salts and mineralization ability of earthworms; determined the pH of the effluent from vermifiltration process (Wang *et al.,* 2014).

Microbial conversion of organic nitrogen in the vermibed and influent wastewater to ammonia during initial stage of vermifiltration process could result in high pH (Rajpal *et al.,* 2012). On the contrary, microbial decomposition of organics in the vermibed, giving rise to production of CO_2 and subsequent acid formation in the vermifilter coupled with rapid mineralization of nitrogen and phosphorus into nitrates/nitrites and orthophosphates, or their intermediates could also lead to decrease in pH (Singh *et al.,* 2017; Khwairakpam and Bhargava 2009). These reasons may explain the fluctuations experienced during the initial stages of the experiment. During the later stages of the experiment, the pH in the effluent from the vermireactors were maintained around the neutral range, as similarly observed by Rajpal *et al.,* (2014). The observed trend could be attributed to inherent buffering ability of earthworms to neutralize the influent pH, due to the calcium content present in their gut (Hughes *et al.,* 2007).

Table 1: Characteristics of Influent Wastewater

Parameter	**Value**
pH	7.62[a] ± 0.43
Biochemical oxygen demand (BOD) (mg/l)	20.5 ± 5.1
Chemical oxygen demand (COD)	28.0 ± 0.9
Dissolved oxygen (DO) (mg/l)	4.63 ± 0.63
Total dissolved solids (TDS) (mg/l)	4.66 ± 1.81
Total suspended solids (TSS) (mg/l)	8.18 ± 1.43
Ammonia nitrogen (NH_3-N) (mg/l)	0.509 ± 0.344
Nitrate nitrogen (NO_3-N) (mg/l)	0.076 ± 0.024
Total phosphorus (TP) (mg/l)	11.96 ± 1.60
Potassium (K) (mg/l)	1.484 ± 0.441

[a]Value is mean ± standard deviation (n = 12)

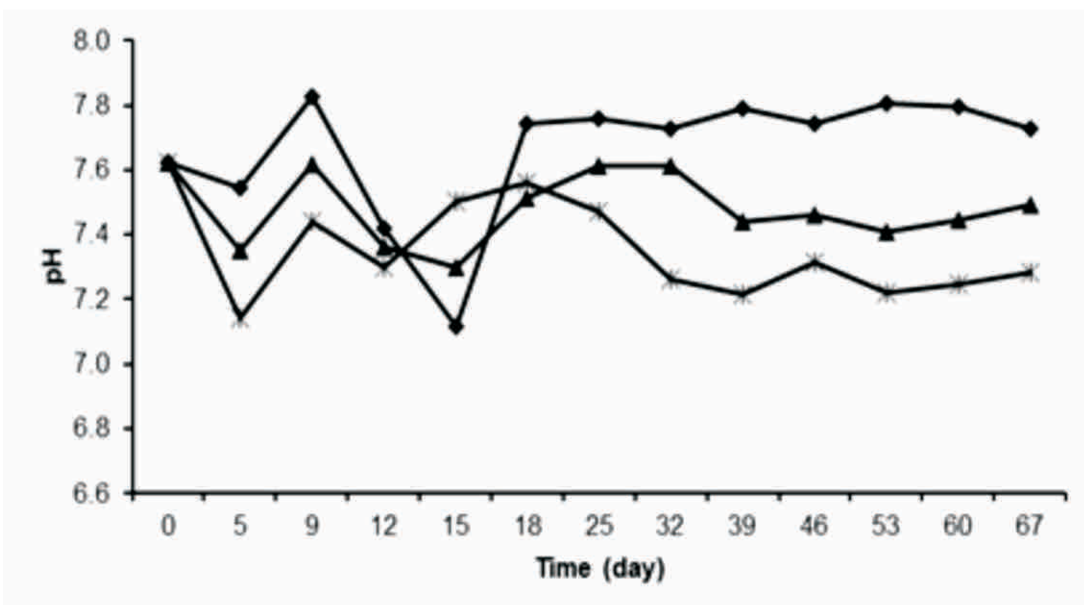


Figure 1: Variation in pH. ♦ control, *EA and AM▲

With growing concern over environmental footprints of wastewaters, various regulatory bodies have developed standards and rules for issuing and enforcing permits for individual effluent outfalls. The main reason for setting and enforcing water quality standards is to prevent negative impacts of effluents on receiving water bodies. Standards normally specify limits for selected water quality variables (Boyd, 2003). In Nigeria, National Environmental (Surface and Ground Water Quality Control) Regulations specify the concentrations of water quality variables allowed in effluent to be discharged to surface water bodies or reuse in aquaculture (Table 2). The pH values of treated effluents from all the reactors were within the range permitted in the standards.

Table 2: Comparison of Physicochemical Parameters of Treated Effluents with Nigerian Acceptable Limit for Aquaculture Wastewater Reuse and Discharge

			Guideline Limit	
Parameter	EA	AM	Discharge	Reuse
pH	7.1 – 7.6	7.3 – 7.6	6.5-8.5[b]	6.5-8.5[c]
BOD (mg/l)	4.1[a]	6.1	6.0	3.0
COD (mg/l)	11.3	15.2	30.0	30.0
DO (mg/l)	9.2	9.0	Minimum 4.0	Minimum 6.0
TDS (mg/l)	0.002	0.004	500	-
TSS (mg/l)	1.26	1.03	0.75	0.25
NH_3-N (mg/l)	0.037	0.068	2.0	0.05
NO_3-N (mg/l)	0.012	0.021	40.0	9.1
P (mg/l)	4.1	6.6	3.5	3.5
K (mg/l)	0.3	0.4	50.0	50.0

[a]Lowest concentrations are reported except for DO
[bc]NESREA(2010)
EA - *Eudrilus eugeniae*; AM - *Alma millsoni*

Organics removal during treatment process

The BOD and COD are commonly used in estimating pollution strength of aquaculture wastewater. In Nigeria, the permitted limits for BOD and COD concentrations for discharges are 6.0 and 30.0 mg/l, respectively (Table 2). The average values of BOD and COD in the influent the wastewater were 20.4 and 28.0 mg/l (Table 1). During the initial stages of the experiments, BOD and COD concentration in the treated effluents increased in all the reactors as compared with influent concentration (Fig 2). This phenomenon was not expected, as the organics in aquaculture wastewater have degradation potential. The observed phenomenon was probably due to leaching of organic matter and chemical contaminant from the filtering unit into the effluents, as similarly observed in a previous study, where organic fraction of municipal solid waste was co-treated with domestic sewage using *Eisenia fetida*, *Perionyx excavatus*, and *Perionyx sansibaricus* (Rajpal *et al.* 2014).

The first appreciable reductions in BOD of treated effluents from all the reactors were observed on 12th day (Fig. 2a and Table 3) and continued until the last day of the experiments. The reduction in the BOD at the end of the experiment was observed to be in the order of EA(79.9%)> AM(69.4%) > control(44.5%). The highest BOD removal rate(79.9%) achieved in this study is close to the values obtained in other studies on vermifiltration process. The BOD removal rates of 84-87% and 89.7-96.3% have been reported in treatment of wastewater from herbal pharmaceutical wastewater and domestic sewage, respectively

a. b.

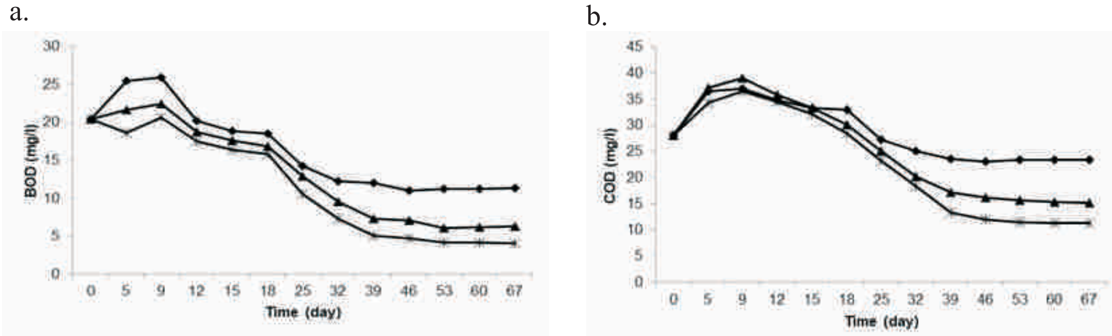


Figure 2: Variation in BOD, (a), and COD, (b). ♦ control, *EA and Am▲

(Rajpal *et al.,* 2014; Dhadse *et al.,* 2010). After treatment, the vermireactors produced effluents that were suitable for discharge into surface waters. However, the BOD concentrations in the vermireactors at the end of the experiment were above the permitted limit for wastewater reuse in aquaculture, with BOD concentration in EA reactor slightly above the permitted limit (Table 3). It is important to point out that with progressive reductions in BOD concentrations of treated effluents from the vermireactors observed in the experiments (Fig 2a and Table 3), the target concentration would eventually be reached if the duration of the experiments had been extended further than 67 days.

For COD removal, the reductions were observed from all the treatments from 25th day and continued until the last day of the experiments (Fig. 2b and Table 3). The COD removal at the end of the experiment also followed the same order as was in BOD removal and was in the order of EA (59.8%) > AM (45.8%) > control (16.2%). The higher BOD and COD removal rate achieved in EA and AM reactors as compared with control reactor could be attributed to the enzymatic action in the gut of earthworms which probably helped to facilitate higher removal of organics in the wastewater as compared with the proportion removed by geo-microbial process alone (Xing *et al.,* 2005; Sinha *et al.,* 2008). The removal of BOD in the EA and AM reactors was observed to be more than COD removal. This could be attributed to the preference of earthworms for biodegradable part of wastewater (Rajpal *et al.,* 2014; Sinha *et al.,* 2008; Kumar *et al.,* 2015). All reactors produced effluents with COD concentrations within the Nigerian standards.

Table 3.Removal Rate of Effluent Characteristics

Day		12	25	46	67
BOD (%)					
	Control	1.2	30.0	45.9	44.5
	EA	14.1	48.5	76.9	79.9
	AM	8.4	37.0	65.6	69.4
COD (%)					
	Control	-	2.5	17.7	16.2
	EA	-	17.0	57.1	59.8
	AM	-	10.2	42.2	45.9
NH_3-N (%)					
	Control	75.2	48.9	50.9	29.2
	EA	77.2	86.8	90.5	92.7
	AM	76.4	85.5	85.6	86.6
NO_3-N (%)					
	Control	20.9	41.8	13.0	-
	EA	41.8	70.6	81.0	73.8
	AM	32.0	58.8	66.6	62.1
TP (%)					
	Control	27.2	37.1	26.7	31.3
	EA	37.9	65.4	57.0	48.6
	AM	30.5	44.7	40.7	35.7
K (%)					
	Control	59.6	63.3	56.2	37.0
	EA	56.2	81.1	77.4	67.0
	AM	55.9	71.7	65.6	53.2

Dissolved oxygen (DO) changes during treatment process

Dissolved oxygen is considered as one of the most important parameters in aquaculture. It is required for respiration and metabolic activities. Generally, a minimum saturation level of 5 mg/l is required in fish pond. The average concentration of DO in influent wastewater samples was 4.6 mg/l (Table 1). This was expected considering metabolic activities of fish in the pond that would have depleted the DO in the source water.

The DO is a crucial parameter in the vermifiltration process, as absence of it can affect the microbial activity and removal mechanisms such as ammonification and nitrification inside vermifilter (Singh *et al.* 2017). Changes in the concentrations of DO for the duration of the experiments are presented in Figure 3. The concentrations of DO in all the treated effluents increased rapidly from the initial value of 4.6 mg/l to 9.7, 8.9 and 8.4 mg/l in control, EA and AM and control reactors, respectively, for the first two sampling times (until the 9th day) of the experiments. There were slight reductions on the 12th day, which coincided with the period when appreciable improvements were observed in the BOD removal rates from the treated effluents. Thereafter, the DO concentrations were maintained around the values obtained on the 12th day. The DO concentrations on the last day of the experiment were in the order of EA (9.1 mg/l) > AM (8.6 mg/l) > control (7.8 mg/l). The higher DO achieved in the vermireactors as compared with DO concentration in control reactor could be due to aerobic condition in the vermifilter bed, facilitated by burrowing action of earthworms (Sinha *et al.,* 2008; Tomar and Suthar, 2011). The DO concentrations in the treated effluents at the end of the experiment thus imply that they could be directly discharged to the surface water bodies (Table 3). Moreover, the concentrations were above the minimum requirement of 6 mg/l for reuse in aquaculture.

Solids removal during treatment process

The total dissolved solids (TDS) concentrations in control reactor were consistently higher than that of the vermireactors at all sampling times (Fig 4a). The concentrations reduced from the initial value of 4.7 mg/l to 2.180, 0.003 and 0.006 mg/l in control, EA and AM reactors, respectively, which correspond to removal rate of 53.2, 99.9 and 99.9%, respectively. Several vermifiltration studies have also reported significant reductions in TDS with removal rates ranging between 80% and 97%, most especially in treatment of domestic and sewage wastewaters (Taylor *et al.,* 2003; Garkal and Jadho, 2014).

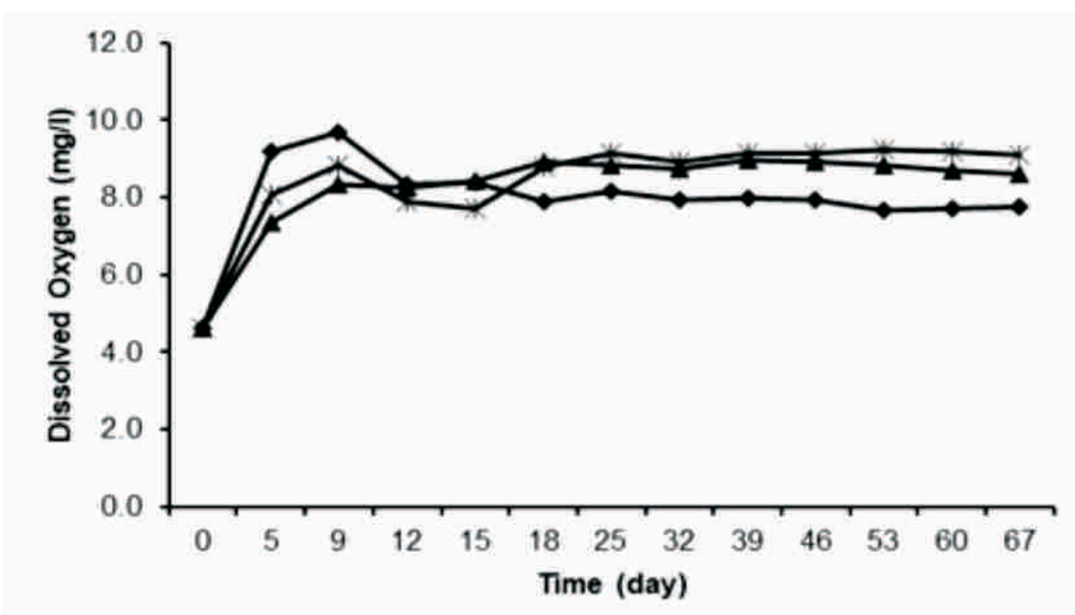


Figure 3: Variation in DO.♦ control, *EA and Am▲

a. b.

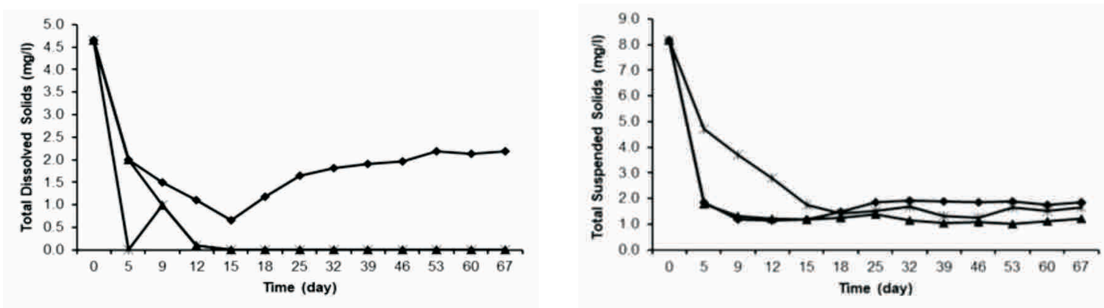


Figure 4: Variation in TDS, (a), and TSS, (b). ♦ control, *EA and Am▲

For total suspended solids (TSS) concentration, generally there were reductions from the initial values in all the reactors at all sampling times (Fig 4b). However, the removal rate was lower in the EA reactor than in other reactors until 15th day. Thereafter, there were no wide variations between the removal rates from all the reactors. On the final day of the experiment, the removal rate was in the order of AM (85.2%) > EA (80.0%) > control (77.2%). The observed removal rates are similar to removal rates, which ranged from 80%-90%, reported in other studies which employed vermifiltration in the treatment of palm oil mill effluents and pharmaceutical industry effluents (Dhadse *et al.,* 2010; Abdulmalek *et al.,* 2013).

The higher TSS and TDS removal rates in vermireactors as compared with control reactor could be attributed to the ingestion of organic and inorganic solid particles in wastewater and excretion in finer particles by earthworms (Ghatnker *et al.* 2008). These organic and inorganic particles were probably further trapped in the voids of vermifilter, causing high removal efficiency of TSS and TDS from wastewater (Sinha *et al.,* 2008).

Nutrient removal during treatment process

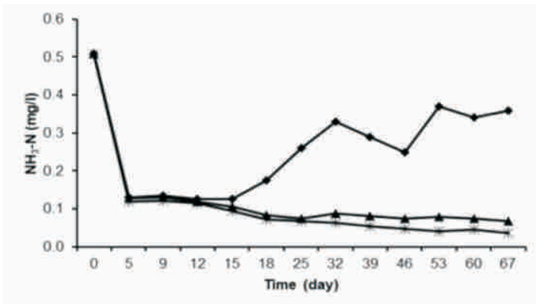
Nitrogenous compounds (ammonia, nitrite, and nitrate) are contaminants in aquaculture wastewater. They originate from fish excretion (deposition of by-product of protein metabolism), decomposition of organic matter and sometimes, agricultural runoff. Discharging aquaculture wastewater contaminated with nitrogenous compounds into surface waters can have deleterious effects on quality of the receiving water bodies.

Initial concentration of 0.509 mg/l ammonia nitrogen in the influent samples was below the permissible limit of 2.0 mg/l stipulated in Nigerian standards for safe discharge of wastewater into surface waters. However, the value was above the permitted level for wastewater reuse in aquaculture (Table 2). Ammonia nitrogen decreased appreciably in all the reactors after treatment when compared with average initial concentration in the influent samples (Fig. 5a). However, higher reductions were recorded in vermireactors (highest reduction of 92.7% and 86.6% in EA and AM reactors, respectively) than in control reactor (highest reduction of 50.9%) (Table 3).The microbial mediated nitrogen transformation (Rajpal *et al.,* 2014) and better aeration provided by burrowing activities of the earthworm (Wang *et al.* 2011) probably aided the removal of ammonia from the treated effluent from the vermireactors, which agrees with the findings of Kumar *et al*., (2015).

Ammonia nitrogen concentrations in the range of the values (> 0.1 mg/l) observed in the influent samples are known to cause various negative outcomes in fishes. While the treatment reduced the concentrations appreciable in all reactors, only effluent from EA reactor (0.037 mg/l) met the requirement for wastewater reuse in aquaculture. AM reactor's concentration of 0.068 mg/l was slightly above the limit.

Nitrates are the final product of the aerobic decomposition of organic nitrogen compounds. The average nitrate concentration found in influent samples was 0.076 mg/l, which was far below the values stipulated for discharge of wastewater into surface water bodies and reuse in aquaculture. At the initial stages (5th and 9th

a.



b.

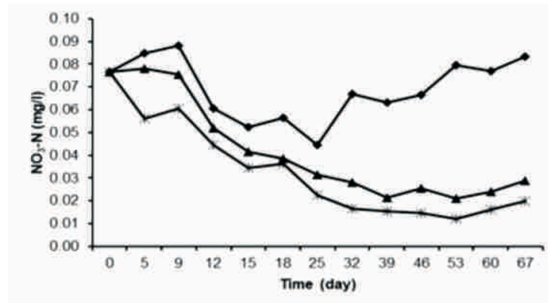


Figure 5: Variation in NH_3-N, (a) and NO_3-N, (b). ♦ control, EA

days) of the experiments, the concentration in the treated effluent showed some variations among the reactors (Fig 5b). While the concentration increased to 0.088 mg/l in effluent from control on the 9th day, the value was relatively the same in AM reactor and decreased to 0.061 mg/l in EA reactor. The results indicated that there was leaching of nitrate into the effluents from soil. The process of mineralization; nitrification and denitrification, within the garden soil used in the study could be a contributing factor for the observed phenomenon. The soil was collected very close to a poultry farm. Thereafter, progressive decreases were observed in all the reactors until after 25th, 53rd and 53rd day in control, AM reactor and EA reactors, respectively. Thereafter, the concentrations started to increase again. The reductions observed in the reactors are presented in Table 3. The results clearly showed higher removal rates in vermireactors (81.0 and 66.6% in EA and AM, respectively) than in control reactor (41%). The higher reduction rates observed in vermireactors may be attributed to earthworms' ability to incorporate nitrate into solid matrix (Rajpal *et al.,* 2014), while slight increases towards the end of the experiment could be due to inability of the soil to further accommodate nitrate.

Phosphorus and potassium are other nutrient contaminants in aquaculture wastewater that have been implicated in environmental pollution and disruption of ecosystem. For protection of the water environment, for sustainability of the resources and protection of aquatic ecosystems, the Nigerian standards stipulated that the phosphorus concentration in wastewater for discharges and reuse (aquaculture inclusive) should not exceed 3.5 mg/l. The concentration in the influent samples (12.0 mg/l) was above the permitted level. The concentration of phosphorus reduced in the effluents to 8.2, 6.2 and 7.7 mg/l in control, EA and AM reactors, respectively, on the final day of the experiment (Fig. 6a), with removal efficiencies of 31.2, 48.6 and 36.6%, respectively. The highest removal efficiencies were in the order of 65.4% (EA) > 44.6% (AM) > 37.1% (control), recorded on the 25th day of the experiments.

Some studies have reported increases in the phosphorus concentration in the effluent from vermifiltration process (Kumar *et al.,* 2015; Rajpal *et al.,* 2012; Kumar *et al.,* 2014). The high concentration of phosphorus reported in treated effluents in those studies was generally attributed to the enzymatic and microbial action of earthworm. A major contributing factor for the observed trend in some of those studies would likely be high organic load, which facilitated rapid phosphate mineralization in the system causing increased concentration of phosphorus in the effluent. High concentration of phosphorus in the effluent was also attributed to leaching of vermicast from the filter material to effluent of vermifilter (Kumar *et al.,* 2015).

Rapid formation of vermicast could have also been facilitated by high organic load. However, low strength wastewaters like aquaculture wastewater usually contain less organic load which will ultimately result in low phosphate mineralization and production of vermicasts, which ordinarily would have increased the concentration.

Phosphorus removal is also attributed to

a. b.

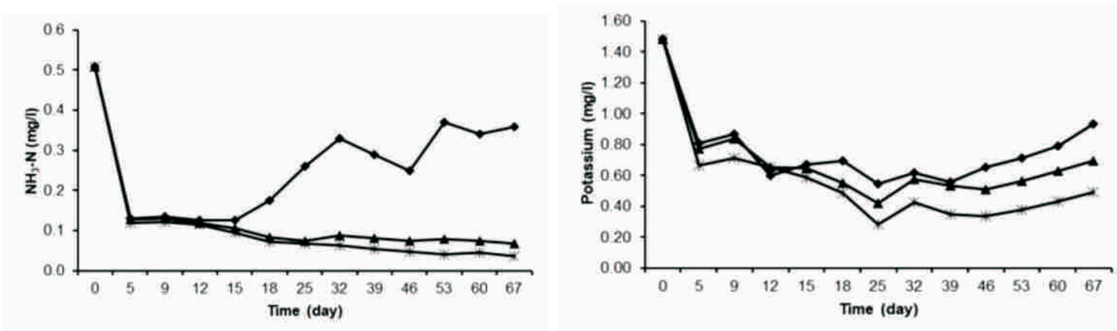


Figure 6: Variation in total phosphorus, (a), and potassium, (b). ♦ control, *EA and Am▲

sorption capacity of vermifilter bed material, surface area and size. Sorption capacity of vermifilter is improved through production of more compact, granular, porous, and blocky aggregates with reduction in number of flocks. through feeding and casting activities of earthworms. Such aggregate structure in the vermifilter offers improved adsorption and degradation of pollutants in the cast biofilms as well as enhanced wastewater treatment capability during wastewater treatment (Samal *et al.,* 2017). This may likely be the reason for the enhanced removal of phosphorus in the vermireactors. The filter materials used in this study were garden soil, sand and gravel of different sizes. Wang *et al.,* (2013) also reported 82.3% removal of phosphorus in a vermifiltration system while treating synthetic domestic sewage using soil, cobblestone, detritus and silver sand as bed material. None of the treated effluents met the requirement for discharges to surface waters and wastewater reuse in aquaculture. Only EA reactor produced effluent concentration (4.1 mg/l) close to permitted limit on the 25th day (Fig. 6a).

Potassium concentration in the influent samples was very low and within the stipulated limits for discharges and reuse in aquaculture (Table 1 and Table 2). Potassium concentration decreased in all reactors as compared with the influent concentration (Fig 6b). While reduction was generally observed in the reactors, the concentration increased slightly after the 46th day in all the reactors. The highest reductions were in the order of 81.1% (EA) > 71.7% (AM) > 63.3% (control).

Vermicomposting, from which the concept of vermifiltration was developed, is regarded as an efficient process for recovering higher potassium from organic waste, because of decomposition of organic matter coupled with enzymatic activity in worm's gut (Suthar and Singh 2008; Suthar 2007). The microorganisms present in the worm's gut are responsible for converting insoluble potassium into the soluble form (Kaviraj and Sharma, 2003). This reason should have facilitated higher recovery of potassium in the treated effluents. However, the decrease in potassium levels recorded in this study could be attributed to low production of vermicasts as a result of decrease in level of insoluble potassium in aquaculture influent. This should have formed a major part of the conversion process of insoluble potassium to soluble forms of potassium.

Conclusion

The enhanced capability of vermireactor to treat aquaculture wastewater has been demonstrated in this study. The two earthworm species employed were found to improve the organics removal, solids removal, nutrient removal and general performance of the vermireactors as compared with control reactor. The results of the present study suggest that vermifiltration system could be a reliable and affordable alternative to conventional approaches employed for treatment of aquaculture wastewater particularly in developing countries like Nigeria, where investment and maintenance costs are the major factors responsible for low adoption of wastewater treatment technologies. In addition, bio-transformation of organic matters in aquaculture wastewater into useful resources has potential economic, biological and ecological benefits. Ultimately, the system could be integrated into aquaculture management practice to supply earthworms for feed supplement. Treated wastewater could also be recycled into the ponds thereby promoting environmentally sustainable aquaculture production systems.

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