# Effects of treated piggery effluent from an amended constructed wetland on the growth of the Okra plant (*Abelmoschus esculentus*)

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**Abstract:** This research investigates the effects of treated piggery effluent from cassava peel-based biochar-amended constructed wetlands on the growth of the Okra plant (*Abelmoschus esculentus*). A batch-fed pilot-scale Horizontal sub-surface flow constructed wetland (HSSFCW) planted with Vertiveria zizanioides was operated with a 3-day Hydraulic Retention Time (HRT). Four different substrates comprising sharp sand SS, quarry dust QD, sharp sand amended with biochar (SS+B), and quarry dust amended with biochar (QD+B). Using standard procedures, the biochar and piggery effluent were characterized before and after treatment in the HSSFCW. The treated effluents from the four systems were applied to the Okra plant, and growth parameters of Leave area index LAI, Plant height Ph, and stem diameter QD were measured and analyzed for five consecutive weeks. The results show that substrate types have a significant effect on LAI and QD but insignificant for Ph. The highest measured LAI, Ph, and QD were 13.02, 316.7, and 12.3 mm, respectively for SS; 12, 323, and 14 mm for QD, 25, 307 and 14 mm for SS+B and 27, 325 and 17 mm for QD+B. The biochar-amended quarry dust CWs effluent is recommended as the best for the treated effluent irrigation for okra plant cultivation.

Keywords: *Abelmoschus esculentus*, amended substrates, biochar, cassava peel, constructed wetland, piggery effluents

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## 1 Introduction

The demand for water for domestic, industrial, and agricultural purposes is alarming due to the population explosion and increasing socio-economic developments. Specifically, agricultural irrigation has been the most prominent activity that consumes an enormous volume of water (D'odorico et al., 2020). Therefore, non-conventional water sources are often explored as complementary and sometimes as alternative water supply, especially for agricultural irrigation that does not require potable water (Dery et al., 2019). Consequently, non-conventional water sources are

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deployed to overcome the issues of water shortages in regions with persistent drought periods where renewable water resources are incredibly scarce. Hence, wastewaters from urban and agricultural sources have great potential for recycling and reuse as water sources, organic matter, nutrients, and soil conditioning agents (Omotade, 2019; Cheng et al., 2020).

Untreated wastewater can also have adverse effects, such as increased soil salinity, excessive leaching of nutrients and heavy metals, and human health risks from exposure to pathogens Mora et al. (2022). Generally, it has been found through various research that piggery effluent is high in solid organic components and other nutrients either in the dissolved or particulate form, which is why it is considered a high-strength waste (Cheng et al., 2021; Núñez-Espinoza et al., 2022). Indiscriminate discharge of piggery effluent into water bodies can cause the surrounding water's eutrophication due to the high content of Nitrate and Phosphorous. However, some contaminants, especially Nitrogen (N) and Phosphorus (P), are needed within appropriate quantity limits for soil enrichment for agronomic activities. Recent studies have shown that treated piggery effluent could be used for agronomic purposes to reduce the pressure on freshwater (Cheng et al., 2021).

Constructed wetlands are designed to simulate the functions of natural wastewater treatment systems. In any CW system, the substrate (planting medium) and the vegetation (macrophytes) play essential roles in the performance of the nature-mimicking system (Sandoval-Herazo et al., 2018; Kataki et al., 2021). The quality of the substrate materials directly influences the efficiency of a constructed wetland in terms of the rate and effectiveness of pollutant removal and the ability to provide suitable hydraulic conditions for the flow of treated water (Oginni and Isiorho, 2014; Kataki et al., 2021; Raphael et al., 2023). The effect of substrate type on denitrification and microbial community in CW structure was investigated by Fu et al., (2020). The best distribution of dissolved oxygen with the best removal efficiency of ammonium nitrogen and total nitrogen were observed in a system filled with sand plus activated carbon plus ceramide and sand only (97.4% and 96.2%, respectively). It was concluded that substrates with high porosities can improve the dissolved oxygen (DO) supply and nitrogen removal efficiency in CW. Various materials like biochar have been used as a low-cost adsorbent in CWs to improve the performance of the substrate due to its low cost and availability. Amendment of CWs has been found to promote the removal of Total Nitrogen (Liang et al., 2016). A suitable substrate is expected to be conducive to the root establishment and growth of phytoremediation plants in it.

Generally, information about the effect of biochar on piggery effluent treatment efficiency in horizontal subsurface flow-constructed wetlands (HSSFCWs) and its recycling in annual crop cultivation like okra is scarce. Recently, sand, ash, furnace slag, and coal fly ash were commonly used as amendment material in CWs (Liang et al., 2016; Fu et al., 2020). Deng et al. (2021) emphasized that CWs substrates determine the treatment performance of the system and describe biochar amendment in CW as a novel application in CW systems. These substrates and their amendment materials can intercept pollutants, support plant growth, and provide reactive substances and surfaces for biofilm attachment in the treatment system. Treated effluent from CWs is often recycled for landscape and irrigation purposes, which helps mitigate the adverse effect of water scarcity globally.

Gravel and sand are the commonest substrates used in CWs because they are relatively cheaper to get and have high porosity. They have also been reported to have their flaws which are mainly their inability to pollutant retention and micro-organism attachment (Wang et al., 2018). This made it necessary to study the behavior of other amendment materials to fill these gaps. Quarry dust (QD) is a by-product of the crushing process, which is the breaking down of large boulders and rip-raps into aggregate sizes that are used in concrete works. It is often referred to as the fine fraction of aggregates. It is mostly used in construction industries mostly to replace fine sand (Sundaralingam et al., 2022). Quarry dust properties depend mostly on the parent materials from which it is crushed. Generally, QD has a lesser amount of chemical composition compared to natural sand. Apart from $SiO_2$ which is usually found to be higher in natural sand, all other constituents are more in QD than they are found in natural sand (Manimaran et al., 2017). So, this will always affect the quality of effluent whenever either of them is used as substrates in CWs.

Okra plant (*Abelmoschus esculentus*) is a vegetable crop grown under subsistence farming or commercially in many parts of the world, especially in the tropics and sub-tropics. It is an herbaceous hairy annual plant of the family of Malvaceae. Its parts like leaves, flowers, buds, pods, stem and seeds are used for different purposes. Okra is a popular health food due to its fibre, vitamin C and high amounts of oxidants (Adekiya et al., 2018). The plant can be grown all-year -round but due to lack of water, it is often limited to rainfed agriculture, except in some few cases where it is grown under surface irrigation condition near river banks.

*Vertiveria zizanioides* (L) is a perennial plant belonging to poaceae family. It is grown widely globally due to its dense network of fibrous root useful in soil erosion control and phytoremediation of wastewater (David et al., 2023). It is an indigenous ubiquitous plant whose phytoremediation potential has been studied (Nguyen et al., 2023). Common growth measurements selected in Okra growth stages are those that are visibly seen to affect plant yield. Examples are plant height, plant leave area, number of branches produced, stem diameters and others (Pandey et al., 2017).

This study aims to determine the effect of the application of treated piggery wastewater from cassava peel-derived biochar amended CW on the growth characteristics of the Okra plant (*Abelmoschus esculentus*) grown in plastic pot-culture experiment. The common treatment technology used for piggery effluent is a lagoon or pond waste treatment, some farms discharge the final effluent of their livestock's waste directly into the nearby streams, estuaries, and watercourses without undergoing any treatment thereby increasing the public health risk (Marazzi et al., 2020; Olawale et al., 2021; Sun et al., 2023).

## 2 Materials and methods

This study was conducted in an institution with a teaching and research farm located within a campus which specializes in animal production, specifically in piggery farming. The area is located within a tropical environment that is within the humid agroecological region The College is situated within the Institute for Agricultural Research and Training (I.A.R.&T.) within Ibadan city which lies between latitude 7°23'05.2"N and longitude 3°50'09.2"E. The climate condition of the region is tropically dominated with a yearly precipitation of between 1300-1500 mm and an average daily temperature of 37.2°C, the relative humidity is about 65% (FRIN. 2019; Aina-Oduntan et al., 2021).

### 2.1 Piggery effluent sampling and analysis

The composition of the sampled piggery effluent at the piggery pen was characterized before the setting up of the CW system. The effluent samples were taken from the pen outlet before being released into the surrounding drainage. The samples were characterized for physico-chemical parameters, like chemical oxygen demand (COD), biochemical oxygen demand (BOD), acid-alkaline balance (pH), total nitrogen (TN) and total phosphorous (TP), trace metals, and the sodium adsorption ratio (SAR). The characterization was done under standard conditions and benchmarked with the accepted methods, as well as the standardized records for water and wastewater analysis (Miner, 2006). Samples were collected manually in sterile bottles and taken to the laboratory immediately to determine their specific contamination levels. Samples are collected in 2-litre polyethylene bottles and rinsed with distilled water before being stored in an ice chest packed with ice cubes below 4◦C and transported to the laboratory within a few hours of collection. All the necessary analyses and component parameterizations were completed within 48 hours after sampling except for the BOD, which was obtained after five days. The gravimetric method was adopted to measure the total dissolved solids (TDS), while the open reflux titrimetric and dilution methods were used for the COD and BOD analyses, respectively. EDTA titrimetric method was used to determine Ca and Mg, while the Flame Photometery was used for Na analysis. The heavy metals Fe, Pb, and Zn were analyzed with Atomic Absorption Spectrometers, AAS (Agilent 200 Series) as in Sharma et al. (2022).

### 2.2 Effluent treatment system set up

The effluent used in the growing of the studied crop was obtained from a designed constructed wetland. The effluent was pre-treated in a holding tank of made from blue drum tank of 584 mm diameter, 876 mm height with a volume of 200 Liters where the dirt, food remains and suspended solid were partly removed and scooped out below the tank at intervals**.** The pre-treated effluent is removed from the holding tank for further treatment in the constructed wetland.

A batch-flow pilot-scale HSSFCW was constructed from a polyethene plastic container as shown in Figure 1. Each of the sixteen containers has a length of 450 mm, width of 190 mm and a height of 350 mm with a total volume of 30 Liters. The configuration produced four similar setups, whose treatment capability can be compared when Piggery effluent with the same pollutant load is fed into them. All cells were planted with vetiver plants transplanted at a density of 8 plants per square meter. Clean tap water was introduced into the system thrice a week for 2 weeks to establish the plants in the constructed wetland, then the piggery effluent was introduced to them.

Four cells used as control have sharp sand as their planting substrate, and the other four cells have stone dust as substrate. These were not amended with biochar. The remaining eight cells had 30% biochar incorporated into them with different substrates namely, sharp sand and quarry dust respectively (v/v, 1/3). All treatment cells had a substrate filled to a depth of 200 mm (0.2 m) from the base of the cell. The first 50 mm layer consisted of 10–16 mm size granite aggregates and filled above the drainpipe. The first layer was common to all cells. The second layer above that was of 150 mm consisted of the treatment substrates of four different substrates comprising sharp sand alone SS, quarry dust alone QD, sharp sand amended with biochar SS+B and quarry dust amended with biochar QD+B. The vetiver plants were planted in the substrates. The cells have a freeboard of 50m The Piggery effluent was collected and analyzed for various parameters before feeding it into the CWs. Piggery effluent was stored in a 60L tank and fed to the system through a watering can to control the flow. The Piggery effluent was allowed to remain within the CWs for 3 days (HRT) after which the treated water samples were collected and tested in the laboratory for post-treatment analysis for the same sets of parameters earlier tested for. Both raw and treated effluent qualities were compared.

### 2.3 Biochar production and characterization

The biochar used for the CW amendment was produced from dried cassava peels using a fabricated pyrolysis kiln made from metal sheets and fired with lots of firewood overnight at 300$^{o}$C in the absence of air. The material was charred at a moisture content of 20% and was removed from the kiln. The charred peels were then grounded into a powdery form to reduce clogging when mixed with the substrates used in the Constructed Wetland. The biochar was missed with the substrates at a ratio of 1 to 3 which was about 30% w/w (biochar to substrates). The produced biochar is shown in Figure 2.

Figure 1 A view of the constructed wetlands with the established Vetiver Plants

The biochar was characterized for physico-chemical properties like ash content using the principle of measuring residue after incineration of organic matter following the procedures as stated in the ASTM E1755–01 (Adeniyi et al., 2022), the specific surface area of biochar was estimated using Sears' method as in Obayomi et al. (2023) morphological structures of char were investigated by scanning electron microscopy (SEM) (SEM TESCAN-Vega3). Also, the micrographs were obtained at magnifications of 250×, 500×, 750×, 1000× and 1500×. The pore area ranged between 42.81 – 536 μm$^2$. Energy Dispersive X-ray Spectroscopy (EDS; AMETEX) equipped with SEM was used simultaneously to quantify the composition of elements on the biochar surface.

Figure 2 The crushed biochar from the charred cassava peels

The organic carbon was determined by the Walkley-Black procedure, N-total by the Kjeldahl method, and CEC using the percolation method with ammonium acetate as in Cong et al. (2022). The pH value of biochar was measured in 1:20 (m v$^{-1}$) DI water suspension as in Sathe et al. (2021). The suspension was stirred for 1 h and allowed to stand for 5 min before measuring by pH meter (Fisher Scientific Accumet AB250).

### 2.4 Bag culture experiments

Okra seedlings were sown in a medium size polyethylene bags filled with equal amounts of soil mixed with natural manure. The bags were irrigated with fresh water for 7 days to allow proper germination of seed before treated piggery effluent was introduced to it. For each experimental setup, 0.8L of treated piggery effluent from the CWs after the 3-day retention period was added to the growing okra seed. Each treatment had three replications. The experiment was laid out in a Randomized Complete Blocks Design (RCBD) with three replications. The different levels of irrigation water treatments on the okra plants were treated effluent from a sharp sand substrate without amendment (SS), quarry dust without amendment (QD), the sharp sand substrate with biochar amendment (SS+B), quarry dust with biochar amendment (QD+B). The set-up during the experiment during the treated effluent irrigation is shown in Figure 3.

Figure 3 The okra plant during the experiment during the treated effluent irrigation

Physical growth observations like plant height, stem diameter, leaf length, leaf width, and days to first flowering for each tagged plant were recorded weekly, with the first set of readings taken two weeks after planting (2WAT).

Plant height was measured from the ground level to the tip of the plant, plant leaf length was measured from the tip of the leaf to the leaf base where it joins the stalk, and plant leaf width was measured from their widest part end to end, by using measuring tapes and average values were calculated. The stem girths of plants were measured 10 cm above ground level using a Vernier calliper. Ultimately, the Leaf Area Index, LAI was calculated using the ground-based approach described by Schaefer et al. (2015) .

### 2.5 Data analysis

Microsoft Excel was used for all descriptive statistical analyses. The effluent characteristics and the removal efficiencies of the measured parameters were analyzed using ANOVA at $\alpha = 0.05$. The statistical tests were done using the SPSS 23.0 software package. The values of parameters monitored before and after treatment were compared under different substrate were compared, as well as the effectiveness of the biochar amendment with the substrate and its effect on growth measurement.

## 3 Results and discussions

### 3.1 Characterization of raw and treated effluent

The values of parameters of different constituents of piggery effluent and that of the removal efficiencies of different substrates used in the CW analyzed are shown in Tables 1 and 2.

**Table 1 Characterization of piggery effluent from the study area**

| S/N | Parameter* | Inflows | | | | | | | | Range | AV±SE |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | pH | 7.96 | 7.7 | 7.67 | 7.96 | 8.61 | 7.59 | 7.73 | 6.63 | 6.63 - 8.61 | 7.73±0.19 |
| 2 | TN | 0.007 | 0.013 | 0.03 | 0.007 | 0.015 | 0.017 | 0.014 | 36.3 | 0.007 - 36.3 | 4.55±4.53 |
| 3 | Ca | 111.26 | 216.56 | 204.19 | 111.26 | 145.76 | 70.44 | 30.33 | 40 | 30.33 - 216.56 | 116.2±24.6 |
| 4 | Mg | 120.88 | 191.4 | 370.31 | 120.88 | 114.28 | 228.75 | 51.67 | 34 | 34 - 216.56 | 154.02±38.36 |
| 5 | Na | 263.13 | 169.2 | 97.5 | 263.13 | 106.13 | 118.13 | 36.44 | 1.28 | 1.28 - 263.13 | 131.8±33.80 |
| 6 | SAR | 4.11 | 2.02 | 0.94 | 4.11 | 1.60 | 1.54 | 0.93 | 0.04 | 0.04 - 4.11 | 1.90±0.52 |
| 7 | TP | - | - | 283.99 | - | 180.63 | 138.27 | 10.045 | 5.21 | 5.21 - 283.99 | 121.6±42.70 |
| 8 | Zn | 1.31 | 1.84 | 6.28 | 1.31 | 0.8 | 0.95 | 0.18 | 0.16 | 0.8 - 6.28 | 3.58±1.86 |
| 9 | BOD | - | 42.4 | - | - | 24.2 | - | - | 21.2 | 21.2 - 42.4 | 29.2±4.05 |

Note: *All measurements are expressed as Mean± standard error; all measurements are in mg $L^{-1}$ except pH and SAR; † n= 8 per parameters

**Table 2 The removal efficiencies of different substrates used in the CWs**

| S/N | Parameter* | SS | QD | SS+B | QD+B |
|---|---|---|---|---|---|
| 1 | pH | 4.46±1.2 | 3.05±0.76 | 2.99±0.70 | 3.42±1.36 |
| 2 | TN | 75.6±5.5 | 80.9±6.2 | 80.2±6.8 | 73.1±9.26 |
| 3 | Ca | 92.7±1.6 | 90.6±7.1 | 84.7±5.9 | 93.9±3.50 |
| 4 | Mg | 85.1±6.5 | 83.7±7.0 | 91.8±8.3 | 83.8±5.00 |
| 5 | Na | 93.9±2.1 | 87.2±4.1 | 90.1±7.5 | 88.3±4.20 |
| 6 | SAR | 77.0±12.6 | 71.6±6.6 | 89.5±3.0 | 83.7±3.70 |
| 7 | TP | 87.6±7.4 | 90.9±6.6 | 85.8±4.7 | 82.4±6.10 |
| 8 | Zn | 75.0±5.6 | 84.9±3.3 | 81.8±12.0 | 62.7±14.70 |
| 9 | BOD | 24.8±6.1 | 32.1±5.4 | 32.1±5.4 | 38.7±6.10 |

Note: *All measurements are expressed as Mean± standard error; all measurements are in percentages (%); † n= 8 samples per parameters (SS-**sharp sand**; QD-quarry dust; SS+B **sharp sand** with biochar and QD+B-quarry dust with biochar).

The characteristic of the raw effluent falls within the values reported by Olawale et al. (2021) and those reported in the tropical environment of Brazil (Leite et al., 2019). The sources of piggery effluent were mainly from the wash water, drinking water, waste feeds and other cleaning services of the piggery pen. The pH falls within the range of 6.63-8.61 which is typical of an alkaline solution due to the mixture of the feed and urine of the pigs. The analysis of the content of the swine effluent indicates a minimal level of metals and quite low organic content. The trace of the nutrients was also minute for nitrogen but high for phosphorus which was due to the use of some phosphorus-based detergents which have been banned elsewhere but are still being used locally in the study area. This may be due to the size of the farm, which has few herds of pigs. Consequently, the swine dung flushed down the drain is not much, resulting in a low concentration of organic residues (BOD) in the effluents. From Table 2, the removal efficiency (RE) after the treatment, was quite lower in values for the amended substrates compared to other substrates except for Ca where QD+B recorded the highest value. The biochar-amended SS+B and QD+B yielded a pH RE of 2.99% and 3.42%, respectively. The removal performance recorded across the four substrates type agrees with the past findings (Udom et al., 2018; Olawale et al., 2021; Raphael et al., 2023). The effluent pH of 7.73±0.19 is already within the alkaline range, not much change is anticipated. Thus, the observation agrees with the findings of Haghshenas-Adarmanabadi et al. (2016) in which the pH of the treated effluent was close to that of the pre-treated influent.

Nitrogen concentration is a significant yardstick for measuring the quality of domestic and agricultural effluents to be reused or recycled (Robles et al., 2020). The swine wastewater sample from this study was quite low in total Nitrogen concentration with a range from 0.007 mg $L^{-1}$ to 36.3 mg $L^{-1}$, giving a mean TN concentration of 4.55±4.53 mg $L^{-1}$ for the collected samples as shown in Table 1. The low value is due to the frequent cleaning of the pen and adequate provision of wallow/muddy puddle which is frequently drained and refilled with clean water. However, the recorded

RE (in % per cent) was high for the different substrates of the constructed wetlands with vetiver plants. The four substrate mediums performed significantly well, achieving very similar REs of about 75.6%±5.5% (SS), 80.9%±6.2% (QD), 80.2%±6.8% (SS+B), and 73.1%±9.26% (QD+B), respectively, as seen in Table 2.

Phosphorus is an essential element for plant life, but when there is too much of it in the studied wastewater, it can speed up the reduction of dissolved oxygen in water bodies (Jupp et al., 2021). This elevated value was as a result of phosphate-based detergent used in the cleaning of the pen. This however, is beyond allowable discharge limit for the study area. From the effluent analyzed, total phosphorus concentration was relatively high, ranging from 5.21 mg $L^{-1}$ to 283.99 mg $L^{-1}$, with a mean value of 121.6±42.7 mg $L^{-1}$, (Table 1). Phosphorus is an essential macronutrient that is mostly supplemented in diet fed to pigs (She et al., 2017). All four substrates' setups adequately reduced the total phosphorous contents in the piggery effluents. Based on the analysis presented in Table 2, it could be inferred that the unamended substrate with the vetiver plant achieved a slightly better removal efficiency of 87.6%±7.4% (SS) and 90.9%±6.6% (QD), respectively compared with the substrate amended with biochar whose removal efficiency are 85.8%±4.7% (SS+B) and 82.4%±6.1% (QD+B), respectively. This is due to the plant uptake of Phosphorus directly thereby removing it from the substrates compared to those that were absorbed by the biochar used in the substrate amended which is still within the treatment system and make phosphorus accumulation detectable in the system.

The concentration of Zinc from the raw samples ranged from 0.18 - 6.28 mg $L^{-1}$ at a mean value of 3.58±1.86. This is relatively low compared to the permissible limit of zinc in wastewater which varies from 300 to 600 mg $L^{-1}$. The prevention of Zn accumulation in the soil through Zn excretion in manure and its requirements as a microelement in pig feed makes its presence to be low in piggery systems globally (Shurson et al., 2022). However, for the removal efficiency of the vetiver plant and biochar amendment on the substrate, it was observed that the unamended substrate achieved removal efficiencies of 75.0%±5.6% (SS) while 84.9%±3.3% was recorded for the QD-only setup. The biochar-amended substrate achieved 81.8%±12.0% (SS+B) and 62.7%±14.7% (QD+B) removal efficiency.

The presence of metals Mg, Ca, and Na in the wastewater can affect soil sodicity, structure, and infiltration levels, and they are the block for measuring SAR. SAR is an indication of the concentration of sodium ($Na^+$) as a ratio of the combined concentration of calcium ($Ca^{2+}$) and Magnesium ($Mg^{2+}$) in effluents. Excessive concentration of SAR in the effluents can increase soil salinity, kill soil nutrients, impede plant growth, and negatively impact the soil structure (Huang et al., 2019). From Table 1, the concentrations of the metals are considerably high in the analyzed wastewater, with the concentration of $Mg^{2+}$ ranging from 34 -216.5 mg $L^{-1}$ and that of $Na^+$ ranging from 1.28-263.13 mg $L^{-1}$ and that of $Ca^{2+}$ ranging from 30.33-216.56 mg $L^{-1}$. Considering the implication of high sodium in wastewater on the soil or irrigated plants, these ranges seem to be a concern. Sometimes organic acid salt is deliberately added to the pig feed to reduce the incidence of diarrhea in weaned piglets and maintain their intestinal mucosa (Nowak et al., 2019). This often increases the footprint of Na in piggery wastewater while Ca and Mg are important parts of swine feed. From Table 2, it can be seen that all the substrates used in the HSSFCW setups have an excellent removal efficiency of these metals from the wastewater passed through them. For all the substrates, $Mg^{2+}$ recorded a removal efficiency of 85.1%±6.5% (SS), 83.7%±7.0% (QD), 91.8%±8.3% (SS+B), and 83.8%±5.0% (QD+B), respectively. For $Ca^{2+}$, the removal efficiency was calculated to be 92.7%±1.6% (SS), 90.6%±7.1% (QD), 84.7%±5.9% (SS+B) and 93.9%±3.5% (QD+B) while the removal efficiency for

Na+ for the substrates used in the HSSFCW was calculated to be 93.9%±2.1% (SS), 87.2%±4.1% (QD), 90.1%±7.5% (SS+B) and 88.3%±4.2% (QD+B), respectively. The result obtained in Table 2 indicated that all the substrates used in the HSSFCW are suitable for mitigating the toxic effects of excess metallic cations concentration from the wastewater, as all the substrates indicate an excellent removal efficiency. Consequently, the percentage improvements in the SAR for the four mediums are 77.0±12.6% (SS), 71.6±6.6% (QD), 89.5±3.0% (SS+B) and 83.7±3.7% (QD+B). Thus, the objective comparison of the treated wastewater from the four HSSFCW setups shows that the substrate amended with biochar achieved better performance for the piggery effluents treatments in terms of SAR.

The BOD removal performances are low, and not many differences were observed for all the substrates, including the biochar-amended substrates. This result is consistent with the trends in other published research findings (Haghshenas-Adarmanabadi et al., 2016; Khatamian et al., 2019; Olawale et al., 2021). This gives rise to the heavy load of organics in the effluent hence its suitability for recycling in okra cultivation.

### 3.1 Characterization of biochar for the experiment

The results on the physico-chemical properties of the biochar used in the constructed wetland substrates amendment are shown in Table 3. The micrograph from the scanning electron microscope (SEM) is shown in Figure 4. A regular network of smooth-shaped pores and cracks characterizes the surface of the biochar can be seen. This micro-morphological structure could be an advantage to the adsorption properties of the applied biochar in the CW setups. The specific surface area (SSA) value observed for the biochar was 157.4 $m^2$ $g^{-1}$. The value was lower than the 430.37 $m^2$ $g^{-1}$ obtained by authors in Deng et al. (2017) for cassava waste-based biochar produced at 750°C but very close to the value of 145.1 $m^2$ $g^{-1}$ obtained for the modified cassava waste-based biochar at 500°C reported in Luo et al. (2021).

**Table 3 The results of the physico-chemical properties of the biochar used in the study**

| Parameter | Samples | | | Mean±SE |
|---|---|---|---|---|
| TN% | 0.098 | 0.102 | 0.103 | 0.1 ± 0.002 |
| Organic C% | 12.89 | 12.76 | 12.76 | 12.8± 0.043 |
| CEC, cmol/kg | 12.74 | 12.73 | 12.69 | 12.7± 0.014 |
| pH | 10.54 | 10.52 | 10.51 | 10.5 ± 0.010 |
| Ash% | 16.03 | 16.04 | 15.9 | 16.0± 0.037 |
| Specific SA | 157.42 | 157.81 | 157.23 | 157.5 ±0.171 |

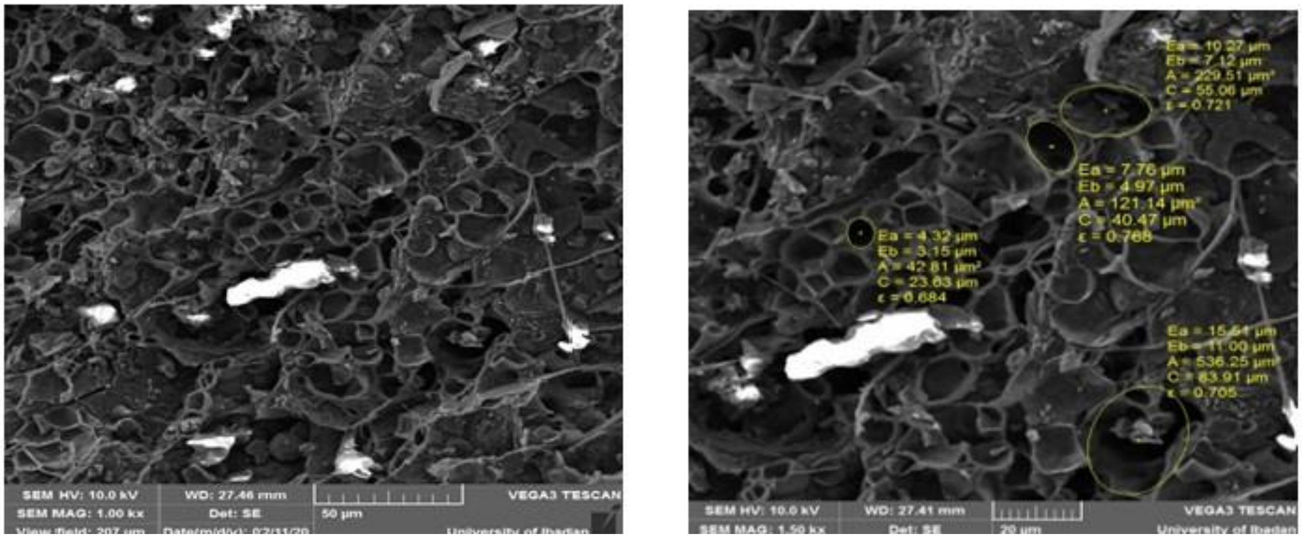
The Cation exchange capacity (CEC) obtained for the cassava- peel based biochar prepared in this study is much lower than the value of 213.23 cmol $kg^{-1}$ obtained in Deng et al. (2017). The large SAR and CEC values of the biochar in Deng et al. (2017) were attributed to the pyrolysis temperature of 750 °C , which is far higher than the average temperature of 350°C used for the biochar made from Cassava peel in this study.

The ash content of the produced biochar in the study is higher than the 5.03% reported for the same feedstock (cassava waste) produced by Deng et al. (2017) and 5.26% reported by Luo et al. (2021). The total nitrogen content for the biochar is low, but the organic carbon value obtained was at an average value of 12.7%, which is good for a carbonaceous material. These differences in the properties of the cassava peel biochar compared to those sampled from the literature are probably due to different biochar production or sample processing methods.

### 3.2 Agronomic and biometric observation of irrigated okra plant

The graphs showing the weekly progression of plant height, stem diameter and leave area index are shown in Figures 5 to 6. The readings taken for the five consecutive weeks show that the highest values for the fifth week for LAI, Ph and SD for SS constructed wetland were 13.02, 316.7, and 12.3 mm respectively. The QD CW had the LAI, Ph and SD highest values of

11.68, 323.3, and 14.3 mm respectively. The LAI, Ph and QD highest values for SS+B were 24.49, 306.7 mm and 14.0 mm. The QD+B CW had respective values of 27.30, 325.0 and 17.0 mm. All these revealed that the highest values of the considered parameter were recorded for the QD+B CW system. Earlier studies show that apart from Silicon oxide ($SiO_4$) which is more in natural sand compared to quarry dust, all other chemical constituents of quarry dust are higher than that of natural sand. This probably is responsible for a better growth parameter recorded for QD+B effluent. Ayusa et al. (2020) found amended QD to have a favourable influence on the growth of the plant they studied. The same with the study by Al-Kharabsheh et al. (2022).



(a) Micro-morphological structures (b) Microstructural details

Figure 4 The SEM analysis of produced biochar showing

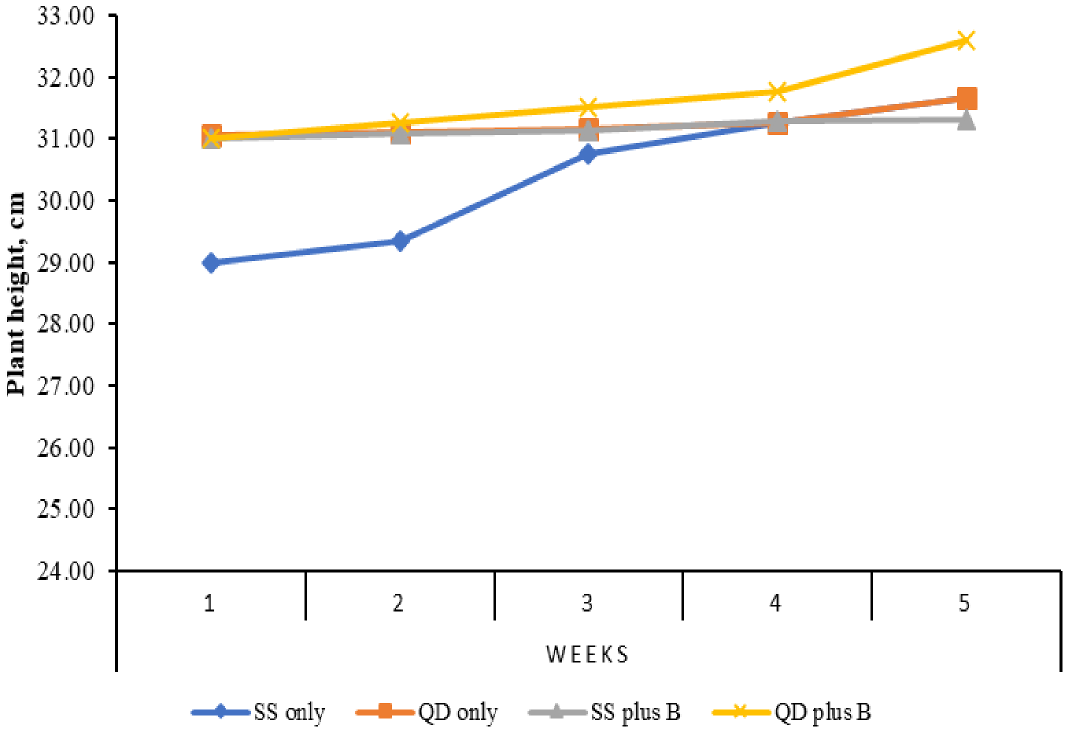


Figure 5 Graph showing the weekly progression of plant height for different substrates

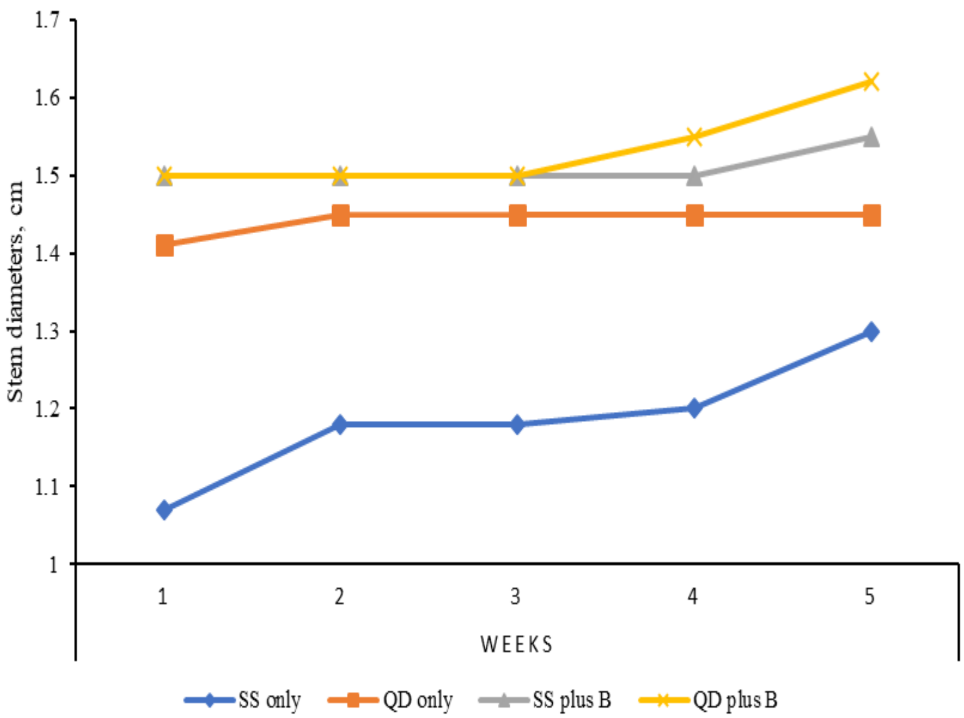


Figure 6 Graph showing the weekly progression in stem diameter for different substrates

### 3.3 Statistical analysis of the measured results

The result from the effect of treated effluent for different substrate types on the measured plant growth attributes of plant height (Ph), leave area index (LAI) and stem diameter (Sd), showed that the qualities of treated effluents from different substrate types have significant effect on both LAI and Sd (p=0.000) for both parameters, but insignificant for Ph (p=0.075).

For multiple comparisons of effects, there was a significant difference in the result for LAI for both SS+B and QD+B. This simply means biochar amendment significantly affected the measured LAI for the okra plant. There was no significant difference in the measured value of LAI for both SS and QD.

The p-value calculated for Ph under different effluent qualities for amended and unamended substrates were all greater than 0.05 (p>0.05), leading to the acceptance of $H_0$ (that is, there is no significant difference in Ph values across treatments) when treated effluent from different substrate was applied to okra plant.

**Table 4 Mean separation for different substrate effects on plant growth parameters**

| | | Subset for alpha = 0.05 | | |
|---|---|---|---|---|
| | N | 1 | 2 | 3 |
| Leave area index, LAI | 15 | QD (11.49) * | | |
| | 15 | SS (12.84) | | |
| | 15 | | SS+B (23.22) | |
| | 15 | | | QD+B (25.76) |
| Plant height, Ph | 15 | SS+B (30.35) | | |
| | 15 | SS (30.40) | | |
| | 15 | QD+B (31.76) | | |
| | 15 | QD (31.80) | | |
| Stem diameter, Sd | 15 | SS (1.11) | | |
| | 15 | | SS+B (1.40) | |
| | 15 | | QD (1.42) | |
| | 15 | | | QD+B (1.60) |

Note: The mean for groups in homogeneous subsets is displayed

The effect of treated effluent from different substrate types on stem diameter was found to be significantly different between groups of different substrate types. QD compared to SS was significantly different (p=0.000), QD compared to SS+B was insignificantly different (p=0.971), while QD and QD+B were also significantly different (p=0.029).

For the LAI, the means were separated into three groups with SS and QD being at pal in the same group, and SS+B and QD+B separated into different groups for both Tukey HSD and DMRT tests. The Ph were all categorized into a single group for both Tukey HSD and DMRT tests, while the stem diameters were also categorized into three different groups like LAI. The SS stood alone, the SS+B also separated into the third group alone. This was summarily presented in Table 4.

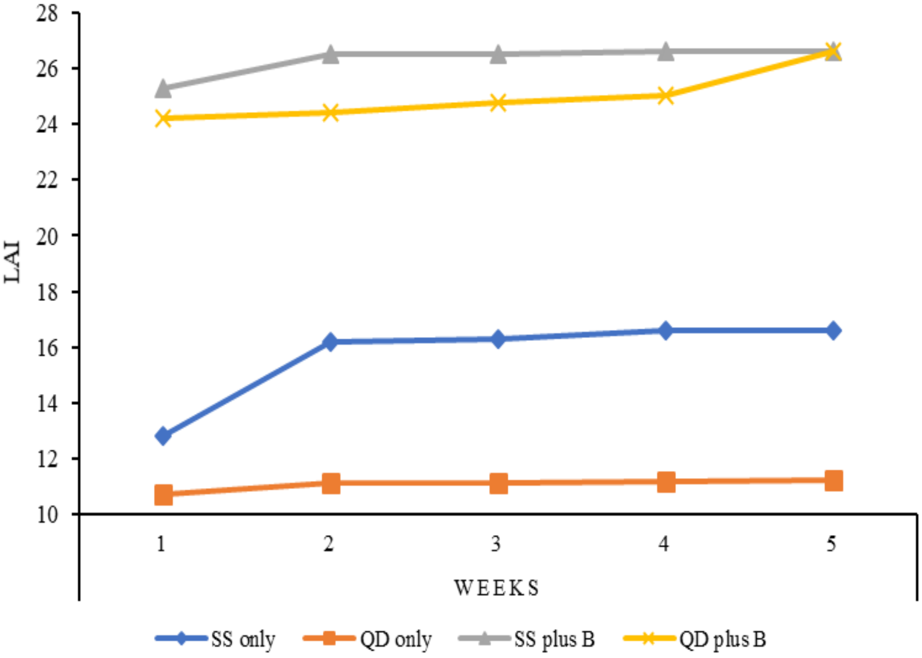


Figure 7 Graph showing the weekly progression of the leaf area index for the different substrates

From the table, the highest measured mean value for LAI was observed to be 25.76 (QD+B), Ph was 31.80 mm (SS) even though they were all at a pal and 1.60 mm (QD+B) for Sd.

## 4 Conclusion

Given the low cost of installing a CW and the volume of water it can treat per time, CW is still the simplest means of treating pre-treated piggery effluent. Amendment of CWs is a viable option that can enhance the performance of CWs. It is highly recommended to use Quarry dust substrate amended with biochar to enhance the quality of effluent to be drained out of it for recycling in crop irrigation. Treated piggery effluent from cassava-peel derived biochar amended CW can produce effluent that can be used in Okra plant irrigation. The effect of the effluent is proper growth which will eventually lead to good yield especially when the effluent is taken from biochar amended quarry dust substrate. Biochar has shown great potential as an amendment to improve soil quality and promote plant growth, as well as to adsorb pollutants from water. In this study, the results show that the application of plants and biochar together with the quarry dust as alternative filter material can significantly enhance the treatment efficiency of HSSF CWs. The current study indicated that amendment of filter substrates with biochar could significantly increase the efficiency of *Vertiveria zizanioides* roots to take up nutrients. The biochar-amended quarry dust CWs effluent stood out amongst all effluents in terms of measured plant parameters and therefore recommended as the best in quality for the treated effluent irrigation for okra plant cultivation. In future studies, the effect of the hydraulic retention time (HRT) on the quality of the treated effluent on growth quality measurements can be considered.

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## References

Adekiya, A. O., C. M. Aboyeji, O. Dunsin, O. V. Adebiyi, and O. T. Oyinlola. 2018. Effect of Urea Fertilizer and Maize Cob Ash on Soil Chemical Properties, Growth, Yield, and Mineral Composition of Okra, (L.). *Journal of Horticultural Research*, *26*(1): 67-76.

Adeniyi, A. G., C. A. Adeyanju, E. C. Emenike, S. K. Otoikhian, S. Ogunniyi, K. O. Iwuozor, and A. A. Raji. 2022. Thermal energy recovery and valorisation of Delonix regia stem for biochar production. *Environmental Challenges*, 9(1):100630.

Aina-Oduntan, O. A., Q. A. Onilude, J. A. George-Onaho, A. I. Woghiren, and O. R. Jeminiwa. 2021. Spatial Distribution of Insect Diversity in Selected Locations within Forestry Research Institute of Nigeria, Ibadan, Nigeria. Journal of Applied Sciences and Environmental Management, 25(7): 1249-1255.

Al-Kharabsheh, B. N., M. Moafak-Arbili, A. Majdi, J. Ahmad, A. F. Deifalla, A. Hakamy, and H. Majed- Alqawasmeh. 2022. Feasibility study on concrete made with substitution of quarry dust: a review. *Sustainability*, 14(22): 15304.

Ayusa, J. K., J. B. Mukundi, and A. O. Adimo. 2020. Comparative growth and dry matter accumulation in selected tree species in response to quarry dust media amendments. *Journal of Horticulture and Forestry*, 12(4): 122-129.

Cheng, D., H. H. Ngo, W. Guo, S. W. Chang, D. D. Nguyen, Y. Liu, Q. Wei, and D. Wei. 2020. A critical review on antibiotics and hormones in swine wastewater: Water pollution problems and control approaches. *Journal of Hazardous Materials*, 387(1): 121682.

Cheng, F., L. Wu, H. Zhong, C. Liu, W. Qiao, and C. Wei. 2021. Evaluation of electrocoagulation process for high-strength swine wastewater pretreatment. *Separation and Purification Technology*, 272 (1):118900.

Cong, X., S. Zhou, T. Wang, G. Pang, and Z. Xu. 2022. Effects of biochar application and irrigation on soil preferential flow and winter wheat productivity. *Polish Journal of Environmental Studies*, 31(1): 625-635.

David, A., A. Fărcaș, and S. A. Socaci. 2023. An overview of the chemical composition and bioactivities of Vetiveria zizanioides (L.) Nash essential oil. *Trends in Food Science and Technology*, 140(1): 104153.

Deng, H., D. Feng, J. He, F. Li, H. Yu, and C. Ge. 2017. Influence of biochar amendments to soil on the mobility of atrazine using sorption-desorption and soil thin-layer chromatography. *Ecological Engineering*, 99(1): 381-390.

Deng, S., J. Chen, and J. Chang. 2021. Application of biochar as an innovative substrate in constructed wetlands/biofilters for wastewater treatment: Performance and ecological benefits. *Journal of Cleaner Production*, 293(14): 126156.

Dery, J. L., C. M. Rock, R. R. Goldstein, C. Onumajuru, N. Brassill, S. Zozaya, and M. R. Suri. 2019. Understanding grower perceptions and attitudes on the use of nontraditional water sources, including reclaimed or recycled water, in the semi-arid Southwest United States. *Environmental Research*, 170(2): 500-509.

D’Odorico, P., D. D. Chiarelli, L. Rosa, A. Bini, D. Zilberman, and M. C. Rulli. 2020. The global value of water in agriculture. *Proceedings of the National Academy of Sciences*, 117(36): 21985-21993.

FRIN. 2019. *Forestry Research Institute of Nigeria, Metrological Station Report on Ibadan Nigeria. FRIN Publishing.*

Fu, G., J. Wu, J. Han, L. Zhao, G. Chan, and K. Leong. 2020. Effects of substrate type on denitrification efficiency and microbial community structure in constructed wetlands. *Bioresource Technology*, 307(jul): 123222.

Haghshenas-Adarmanabadi, A., M. Heidarpour, and S. Tarkesh-Esfahani. 2016. Evaluation of horizontal–vertical subsurface hybrid constructed wetlands for tertiary treatment of conventional treatment facilities effluents in developing countries. *Water, Air, and Soil Pollution*, 227(28): 1-18.

Huang, M., Z. Zhang, Y. Zhai, P. Lu, and C. Zhu. 2019. Effect of straw biochar on soil properties and wheat production under saline water irrigation. *Agronomy*, 9(8): 457.

Jupp, A. R., S. Beijer, G. C. Narain, W. Schipper, and J. C. Slootweg. 2021. Phosphorus recovery and recycling–

closing the loop. *Chemical Society Reviews*, 50(1): 87-101.

Kataki, S., S. Chatterjee, M. G. Vairale, S. K. Dwivedi, and D. K. Gupta. 2021. Constructed wetland, an eco-technology for wastewater treatment: A review on types of wastewater treated and components of the technology (macrophyte, biofilm and substrate). *Journal of Environmental Management*, 283 (1): 111986.

Khatamian, M., B. Divband, and R. Shahi. 2019. Ultrasound-assisted co-precipitation synthesis of $Fe_3O_4$/bentonite nanocomposite: Performance for nitrate, BOD and COD water treatment. *Journal of Water Process Engineering*, 31(1): 100870.

Leite, L. D. S., M. T. Hoffmann, and L. A. Daniel. 2019. Microalgae cultivation for municipal and piggery wastewater treatment in Brazil. *Journal of Water Process Engineering*, 31(1): 100821.

Liang, Y., Z. Hui, G. Bañuelos, B. Yan, and X. Cheng. 2016. Constructed wetlands for saline wastewater treatment: a review. *Ecological Engineering*, 98(1): 275–285.

Luo, J., X. Li, C. Ge, K. Müller, H. Yu, H. Deng, and H. Wang. 2021. Preparation of ammonium-modified cassava waste-derived biochar and its evaluation for synergistic adsorption of ternary antibiotics from aqueous solution. *Journal of Environmental Management*, 298(1): 113530.

Manimaran, A., M. Somasundaram, and P. T. Ravichandran. 2017. Experimental study on partial replacement of coarse aggregate by bamboo and fine aggregate by quarry dust in concrete. *International Journal of Civil Engineering and Technology*, 8(8): 1019-1027.

Marazzi, F., M. Bellucci, R. Fornaroli, A. Bani, E. Ficara, and V. Mezzanotte. 2020. Lab-scale testing of operation parameters for algae-based treatment of piggery wastewater. *Journal of Chemical Technology and Biotechnology*, 95(4): 967-974.

Miner, G. 2006. Standard methods for the examination of water and wastewater. *American Water Works Association Journal*, 98(1): 130.

Mora, A., J. A. Torres-Martínez, M. V. Capparelli, A. Zabala, and J. Mahlknecht. 2022. Effects of wastewater irrigation on groundwater quality: An overview. *Current Opinion in Environmental Science and Health*, 25(1): 100322.

Nguyen, M. K., N. T. Q. Hung, C. M. Nguyen, C. Lin, T. A. Nguyen, and H. L. Nguyen. 2023. Application of vetiver grass (Vetiveria zizanioides L.) for organic matter removal from contaminated surface water. Bioresource Technology Reports, 22(1): 101431.

Nowak, P., M. Kasprowicz-Potocka, A. Zaworska, W. Nowak, B. Stefańska, A. Sip, and A. Frankiewicz, 2019. The effect of combined feed additives on growing pigs' performance and digestive tract parameters. *Annals of Animal Science*, 19(3): 807-819.

Núñez-Espinoza, J. F., F. E. Martínez-Castañeda, F. Ávila-Pérez, and M. C. Rendón-Rendón. 2022. A structural approach to some contradictions in worldwide swine production and health research. *Sustainability*, 14(8): 4748.

Obayomi, O., C. B. Taggart, S. Zeng, K. Sefcik, B. Willis, J. P. Muir, E. Kan, and J. A. Brady. 2023. Dairy manure-derived biochar in soil enhances nutrient metabolism and soil fertility, altering the soil prokaryote community. *Agronomy*, 13(6): 1512.

Olawale, O., D. O. Raphael, C. O. Akinbile, and K. Ishuwa. 2021. Comparison of heavy metal and nutrients removal in Canna indica and Oryza sativa L. based constructed wetlands for piggery effluent treatment in north-central Nigeria. *International Journal of Phytoremediation*, 23(13): 1382-1390.

Oginni, F. A., and S. A. Isiorho. 2014. Evaluation of a constructed wetland for removal of some physicochemical and microbiological contaminants from wastewater in a residential tertiary institution in Nigeria. *CIGR Journal*, 16(3): 1-9.

Omotade, I. F. 2019. Growth and yield performance of hot pepper using aquaculture wastewater. *CIGR Journal*, 21(2): 18-25.

Pandey, R., V. Paul, M. Das, M. Meena, and R. C. Meena. 2017. Plant growth analysis. In *Manual of ICAR Sponsored Training Programme on "Physiological Techniques to Analyze the Impact of Climate Change on Crop Plants"*, 103-107. ICAR publishing India

Raphael, O. D., C. O. Akinbile, O. M. Abioye, D. A. Olasehinde, M. Ogunremi, and O. M. Bolarin. 2023. Heavy metals and nutrients removal in *a* batch-fed greywater treatment system planted with *Canna indica* and *Oryza sativa L*.. *Journal of Environmental Science and Health*, 58(8): 1-9.

Robles, Á., D. Aguado, R. Barat, L. Borrás, A. Bouzas,J.B. Giménez, and A. Seco. 2020. New frontiers from removal to recycling of nitrogen and phosphorus from wastewater in the Circular Economy. *Bioresource Technology*, 300(1):122673.

Sandoval-Herazo, L. C., A. Alvarado-Lassman, J. L. Marín-Muñiz, J. M. Méndez-Contreras, and S. A. Zamora-Castro. 2018. Effects of the use of ornamental plants and different substrates in the removal of wastewater pollutants through microcosms of constructed wetlands. *Sustainability*, 10(5):

1594.

Sathe, P. S., R. V. Adivarekar, and A. B. Pandit. 2021. Valorization of peanut shell biochar for soil amendment. *Journal of Plant Nutrition*, 45(4): 503-521.

Schaefer, M. T., E. Farmer, M. Soto-Berelov, W. Woodgate, and S. Jones. 2015. Overview of ground-based techniques for estimating LAI. *AusCover Good Practice Guidelines: A technical handbook supporting calibration and validation activities of remotely sensed data product*, 88-118.

Sharma, S., I. M. Kaur, and A. K. Nagpal. 2022. Spatiotemporal assessment of potentially toxic elements in sediments and roadside soil samples and associated ecological risk in Ropar wetland and its environs. *Environmental Monitoring and Assessment*, 194(9): 635.

She, Y., D. Li, and S. Zhang. 2017. Methodological aspects of determining phosphorus digestibility in swine: A review. *Animal Nutrition*, 3(2): 97-102.

Shurson, G. C., P. E. Urriola, and Y. T. Hung. 2022. Too much of a good thing: rethinking feed formulation and feeding practices for zinc in swine diets to achieve one health and environmental sustainability. *Animals*, 12(23): 3374.

Sun, L., D. Tang, X. Tai, J. Wang, M. Long, T. Xian, H. Jia, R. Wu, Y. Ma, and Y. Jiang. 2023. Effect of composted pig manure, biochar, and their combination on antibiotic resistome dissipation in swine wastewater-treated soil. *Environmental Pollution*, 323(1):121323.

Sundaralingam, K., A. Peiris, A. Anburuvel, and N. Sathiparan 2022. Quarry dust as river sand replacement in cement masonry blocks: Effect on mechanical and durability characteristics. *Materialia*, 21(1): 101324.

Udom, I. J., C. C. Mbajiorgu, and E. O. Oboho. 2018. Development and evaluation of a constructed pilot-scale horizontal subsurface flow wetland treating piggery wastewater. *Ain Shams Engineering Journal*, 9(4): 3179-3185.

Wang, H. X., J. L. Xu, L. X. Sheng, and X. J. Liu. 2018. A review of research on substrate materials for constructed wetlands. *Materials Science Forum*, 913(1):*917–929*.