Effect of Mangrove Biochar Residue Amended Shrimp Pond Sediment on Nitrogen Adsorption and Leaching

Sokkeang Be 1, Soydoa Vinitnantharat 2,3 and Anawat Pinisakul 1,*

1 Chemistry for Green Society and Healthy Living Research Unit (ChGSH), Department of Chemistry, Faculty of Science, King Mongkut’s University of Technology, Bangkok 10140, Thailand; be.sokkeang@mail.kmutt.ac.th
2 Environmental Technology Program, School of Energy, Environment and Materials, King Mongkut’s University of Technology, Bangkok 10140, Thailand; soydoa.vin@mail.kmutt.ac.th
3 Environmental and Energy Management for Community and Circular Economy (EEC&C) Research Group, King Mongkut’s University of Technology, Bangkok 10140, Thailand
* Correspondence: anawat.pin@mail.kmutt.ac.th; Tel.: +66-2-470-8843; Fax: +66-2-470-8843

Abstract: Mangrove biochar residue was used for nitrogen adsorption and retention in sediment, which is beneficial for plant germination. The present study investigated the effect of contact time (5–360 min), biochar dosage (0.2–2 g L⁻¹), pH (5–6), and initial concentration (2–10 mg L⁻¹) on NH₄⁺-N and NO₃⁻-N adsorption. Three different adsorption isotherm models were used to fit the experimental data. Column leaching experiments were conducted to investigate the effect of biochar with sediment from a shrimp pond on nitrogen leaching at varying biochar dosages (0–8% w/w). The results showed that the maximum percentage of both NH₄⁺-N and NO₃⁻-N adsorption was achieved at an equilibrium contact time of 240 min, with an adsorbent dosage of 2 g L⁻¹, and pH at 5.5 and 5, respectively. The adsorption of NH₄⁺-N and NO₃⁻-N were fitted to the Freundlich model and the adsorption process followed the physisorption and ion exchange. The addition of 8% biochar reduced both cumulative water volume and nitrogen leaching from the sediment. The biochar amendment increased the relative abundance of nitrifying and denitrifying bacteria in the sediment. This result suggested that biochar amended with sediment could be useful for nitrogen loss reduction.

Keywords: adsorption isotherm; biochar; nitrogen leaching; nitrogen retention; pond sediment; shrimp farm

1. Introduction

The agricultural sector plays an important role in producing enough food to meet rising demand as the global population increases [1]. To meet the increased food demand of the growing population, fertilizers (nitrogen (N), phosphorus (P), and potassium (K)), pesticides, and other technologies have been applied to agricultural soil to aid in the development of high-value crops [2,3]. However, the application of excessive or unbalanced nutrient fertilizers to agricultural soils leads to a large quantity of nutrient loss via leaching, which is a significant source of surface, groundwater, and atmospheric pollution. Leaching of nutrients from soils may deplete soil fertility, accelerate soil acidification, create economic hardship for farmers, reduce crop yields, and affect environmental health [4–6]. Nitrogen applied to soil is typically biodegraded by microorganisms via the nitrification process under aerobic conditions or denitrification processes under anaerobic conditions [7]. During the nitrification process, about 50–70% of the nitrogen in fertilizer may be lost. Nitrogen compounds are converted into nitrate in a two-step process. In the first step, ammonia-oxidation bacteria (AOB), such as Nitrosomonas and Nitrosospira, and ammonia-oxidizing archaea (AOA) convert ammonia to nitrite. In the second step, nitrite is oxidized to nitrate by nitrite-oxidizing bacteria (NOB), such as Nitrobacter and Nitrospira [8]. Denitrification is
an essential component of nitrogen (N) cycling in soil ecosystems, because it is the main route for N-loss in soils and a significant source of greenhouse gas via reduction of nitrate into NO, N₂O, and N₂ [9]. To solve these problems, the application of an adsorbent, such as biochar, into the agriculture soil is a useful method to reduce nitrogen loss.

Biochar is a carbon-rich material derived from biomass, such as agricultural and forestry residues, by pyrolysis in a closed container with either limited or no oxygen [10,11]. The application of biochar in soil creates environmental and ecological benefits, such as reducing greenhouse gas emissions [12], acting as an environment-friendly adsorbent to reduce nutrient leaching [13], enhancing nutrient retention, and improving the soil’s chemical and physical properties [8,14]. Biochar has a high surface area and negative surface charge, increasing the cation exchange capacity (CEC) and charge density, which is the most critical factor for adsorption [15,16]. From those properties, biochar can reduce environmental pollution and increase crop yields [17]. Biochar can change the pH and electrical conductivity (EC) of soil [18], which is an important factor in characterizing various soil properties, such as nutrient concentration, CEC, organic matter, and soil texture [19]. Biochar has been shown to adsorb ammonium, nitrate, and phosphate [20]. The nitrogen and phosphate adsorption are related to biochar’s physiochemical properties, including its CEC, acidic and surface oxygen-containing functional group, surface charge, and anion exchange sites [21]. Biochar amending can promote microbial populations and microbial community structure in soil [22]. In addition, it can improve the soil’s water-holding capacity, which benefit plants’ water utilization [23]. However, biochar’s effect on nutrient leaching depends on the biochar type and application rate, pyrolysis conditions (e.g., temperature, heating rate, and residence time), soil characteristics, and environmental conditions [11,24]. Haijun et al. [6] reported that addition of 0.5% and 1% biochar by weight to coastal soil was an appropriate application rate to reduce N leaching from coastal saline soils. Meanwhile, a higher application rate of 2% to silty clay soil effectively reduced N leaching [24]. Nan et al. [5] showed that application of 2%, 4%, and 8% biochar reduced nitrogen leaching, increased water-holding capacity, enhanced microbial biomass, and changed the bacterial community structure of the soil. Thus far, the effects of adding biochar to sediment from shrimp ponds in terms of nutrient leaching and the abundance of nitrifying and denitrifying bacteria are not well-known.

Shrimp farming is among the fishery sectors that provides considerable economic benefits, and has become a priority in developing aquaculture globally [25]. Shrimp production has increased sharply in Thailand since 1972. A total of 85% of intensive culture has been used in Thailand due to it producing a high shrimp yield compared with other systems [26]. Since shrimp culture requires a high input of pelleted feed and chemicals or drugs, after the shrimp are harvested, the primary wastes are wastewater and sediment [25]. Improper management or discharge of those wastes may create environmental problems in marine, estuarine, and freshwater zones [27]. Sediment from shrimp culture is solid material that settles at the pond’s bottom and has varying physicochemical characteristics in terms of organic matter content, particle size distribution, nutrients, and pH [27]. Agricultural use of the sediment would lead to a reduction in fertilizer use due to the sediment’s high quantities of nutrients, such as total nitrogen (TN), phosphorus (TP), and total organic carbon (TOC), that are available for plant growth [28,29]. The average nutrient retention in fish and shrimp pond soil was 13% for carbon, 29% for nitrogen, and 16% for phosphorus; these are suitable amounts for agricultural use [30].

In previous studies, biochar has been made from different feedstock, such as coconut husk [8], rice husk [31], coconut shell [32], and wood [33], for soil amendment. In this study, biochar was derived from mangrove biochar residue using a traditional brick kiln, making it less costly. Biochar production from mangroves does not result in a net loss of mangrove forest, nor is it illegal in Thailand, since an equal area of mangrove is replanted once it is cut for charcoal production [34]. In addition, Malaysian mangrove wood (Rhizophora apiculate) was used to produce biochar, as it is the common tree found in swamps [35]. In India, the dense mangrove is used for biochar production as well [36].
This study’s objectives were (i) to study ammonium and nitrate ions adsorption under different contact times, biochar dosages, pH, and initial ammonium and nitrate concentrations. The adsorption isotherms were used to investigate the adsorption characteristics; (ii) to investigate the nutrient leaching by varying biochar application rates (0%, 0.5%, 1%, 2%, and 8% by weight) with sediment from shrimp ponds; and (iii) to determine the effect of biochar amendment on the abundance of nitrifying and denitrifying bacteria. To investigate nutrient leaching, laboratory column experiments were used. This study hypothesized that biochar could have the ability to adsorb nitrogen, to affect the microbial community composition in the soil, and to treat nitrogen for nitrogen leaching reduction.

2. Materials and Methods

2.1. Biochar and Sediment

The biochar used in this study was residue from mangrove biochar produced in a traditional brick kiln in which the temperature for thermal conversion ranged from 400–600 °C, in Bann Khao Yi San, Samut Songkhram Province, Amphawa District, Thailand. The biochar sample was sieved to pass a <2 mm sieve before being used as a compound fertilizer amendment in this study.

The sediment was collected from an intensive shrimp pond, following shrimp harvesting, located in Chachoengsao province, Thailand. The sediment was air-dried, homogenized, and sieved to pass a <2 mm sieve and kept in a plastic bag for all experimental uses.

2.2. Characterization of Biochar and Sediment

The parameters used to characterize the biochar and sediment were as follows: moisture contents in biochar and sediment were measured after being heated in an oven (memmert UM300 oven) at 60–65 °C for 8 h [37]. The pH of the biochar and sediment were measured with a pH meter (Metrohm 744 pH Meter) with a ratio of 1:1 (w/v) (biochar or sediment/distilled water) followed by shaking for 5 min and leaving the mixture to rest for 30 min before measurement [38]. Electrical conductivity (EC) was measured with an EC meter with a ratio of 1:5 (w/v) (biochar or sediment/distilled water) followed by shaking for 30 min and filtration with No. 5 filter paper before measurement [39]. An amount of 1 M ammonium acetate at pH 7.0 was used to determine the cation exchange capacity (CEC) [40]. Organic matter (OM) was measured using the Walkley and Black method [41], and total Kjeldahl nitrogen (TKN) followed digestion, distillation, and titration (Kjeltec™ 2100 Distillation Unit) [42]. Available K was determined by extraction with NH₄OAc 1 M at pH 7.0 and measured with inductively coupled plasma-mass spectroscopy (Perkin Elmer ICP-OES Spectrometer Optima 8000) [43]. Available P was determined using the ascorbic acid method with UV–Vis at 882 nm [44]. Ammonium-nitrogen (NH₄⁺-N) and nitrate-nitrogen (NO₃⁻-N) were determined by extraction with KCl 2 M using UV–Vis at 665 nm and extracted with K₂SO₄ 0.5 M using UV–Vis at 410 nm (Perkin Elmer Lamda 35 UV–Visible Spectrometer, Perkin Elmer Ltd., Waltham, MA, USA), respectively [45]. The biochar’s surface functional groups were characterized using a Fourier-transform infrared (FTIR) spectrometer (Thermo scientific, Nicolet 6700, Glendale, WI, USA, scanning from 4000–400 cm⁻¹). Surface morphologies (SEM) were characterized using a JSM-7610FPlus Schottky Field Emission scanning electron microscope (Akishima, Tokyo, Japan) operated at 15 kV. The N₂ adsorption desorption technique was used to measure the BET surface area following the Brunauer–Emmett–Teller method.

The point of zero charge (pHpzc) for the biochar was determined using the drift method following the protocol of Tahir et al. [46]. The pHpzc of biochar was tested in 250 mL Erlenmeyer flasks. The initial NaCl (0.01 M) pH (pHᵢ) was adjusted to 2, 4, 6, 8, 10, and 11 using 0.1 M HCl or NaOH. An amount of 0.15 g of biochar was added to 50 mL of the various pH solutions by shaking for 48 h with 180 rpm at 25 °C (Shaking Incubator Daihan Scientific IS-10R). After 48 h, the pH meter was used to measure the final pH value (pHᵢ) of the solution. The difference between pHᵢ and pHᵢ (ΔpH = pHᵢ – pHᵢ) was plotted against pHᵢ.
2.3. Batch Adsorption Experiments

NH₄Cl and NaNO₃ (AR grade) were used to make stock solution of 1000 mg L⁻¹ of NH₄⁺-N and NO₃⁻-N, respectively. The desired concentrations of NH₄⁺-N and NO₃⁻-N solution were prepared from the stock solution and all batch experiments were conducted in 250 mL of Erlenmeyer flask at 25 °C. Phenate and brucine methods were used to determine NH₄⁺-N and NO₃⁻-N concentrations at wavelengths of 640 nm and 410 nm, respectively. The removal efficiencies (%) and the amount adsorbed per unit weight of adsorbent (qₑ in mg g⁻¹) were calculated using Equations (1) and (2) below:

\[
\text{%Removal} = \frac{C_i - C_e}{C_i} \times 100, \quad (1)
\]

\[
q_e = \frac{(C_i - C_e) \times V}{m}, \quad (2)
\]

where \(C_i\) and \(C_e\) are the initial concentration and equilibrium concentration (mg L⁻¹), \(q_e\) is the adsorbed amount per adsorbent (mg g⁻¹), \(m\) is mass of the biochar (g), and \(V\) is the volume of solution (L).

2.3.1. Effect of Contact Time

The effect of contact time on NH₄⁺-N and NO₃⁻-N adsorption removal of biochar was determined using 50 mL of the initial NH₄⁺-N and NO₃⁻-N concentrations of 10 mg L⁻¹ with pH values of 6.19 and 6.54, respectively, and 2 g L⁻¹ of biochar dosage. The mixtures were shaken for 5, 10, 20, 30, 60, 90, 120, 180, 240, 300, and 360 min at 180 rpm using an incubator shaker. At each contact time, the solutions were filtered through GF/C™ for analyses of NH₄⁺-N and NO₃⁻-N concentrations.

2.3.2. Effect of Solution pH

Solution pH is a key factor that affects the adsorption process. The experiment to test the effect of solution pH was conducted with 50 mL of the initial NH₄⁺-N and NO₃⁻-N concentrations of 10 mg L⁻¹ by adjusting the pH to 5, 5.5, and 6 using 0.01 M HCl or NaOH, at the optimum contact time of 240 min and 2 g L⁻¹ of biochar dosage. The mixtures were shaken at 180 rpm using the incubator shaker and the solutions were filtered through GF/C™ for analyses of NH₄⁺-N and NO₃⁻-N concentrations.

2.3.3. Effect of Biochar Dosage

For determination of the optimum biochar dosage required to adsorb the nitrogen, biochar dosages of 0, 0.2, 0.5, 1, and 2 g L⁻¹ were used to adsorb 10 mg L⁻¹ of 50 mL NH₄⁺-N and NO₃⁻-N at pH 5.5 and 5.0, respectively. The mixtures were shaken at 180 rpm for 240 min in the incubator shaker. Next, the solutions were filtered through GF/C™ for analyses of NH₄⁺-N and NO₃⁻-N concentrations.

2.3.4. Effect of Initial NH₄⁺-N and NO₃⁻-N Concentrations

The effect of the initial concentrations of NH₄⁺-N and NO₃⁻-N was determined by adjusting the pH of the NH₄⁺-N solution to 5.5 and the NO₃⁻-N solution to 5, at 50 mL initial concentrations of 0, 2, 4, 6, 8, and 10 mg L⁻¹, an adsorbent dosage 2 g L⁻¹, and at the optimum contact time of 240 min. The mixtures were shaken at 180 rpm using an incubator shaker and the solutions were filtered through GF/C™ for analyses of NH₄⁺-N and NO₃⁻-N concentrations.

2.3.5. Adsorption Isotherm Studies

To study the adsorption isotherm, three models—Langmuir, Freundlich, and Temkin [47]—were selected to investigate the adsorption isotherm of NH₄⁺ and NO₃⁻. The isotherm models are described by the following equations:
The Langmuir’s isotherm describes the adsorption of adsorbate onto the adsorption’s surface, which is monolayered. The Langmuir equation is shown in Equation (3) below:

\[
q_e = \frac{q_{\text{max}} K_L C_e}{1 + q_{\text{max}} K_L},
\]

(3)

The Freundlich isotherm is used to describe the adsorption characteristics for heterogeneous surfaces, which are multilayered. The Freundlich equation is shown in Equation (4) below:

\[
q_e = K_F C_e^n,
\]

(4)

The Temkin isotherm is used to determine the potential of the adsorbent and adsorbed solution (binding energies). The Temkin equation is shown in Equation (5) below:

\[
q_e = \left(\frac{RT}{b}\right) \ln A C_e,
\]

(5)

where \(K_L\) (L mg\(^{-1}\)) is the Langmuir isotherm constant, \(q_{\text{max}}\) is the maximum monolayer adsorption capacity (mg g\(^{-1}\)), \(K_F\) is the Freundlich isotherm constant (mg g\(^{-1}\)), \(n\) is the adsorption intensity, \(R\) is the universal gas constant (8.314 J mol\(^{-1}\) K\(^{-1}\)), \(T\) is the absolute temperature value (K), \(A\) is the binding constant (L g\(^{-1}\)), and \(b\) is the adsorption constant (J mol\(^{-1}\)).

2.4. Column Leaching Experiment

Column experiments were carried out to examine the effect of biochar application on N leaching from the sediment. Cylinder-shaped polyethylene terephthalate (PET) columns with heights of 20 cm and diameters of 7.5 cm were used to study nutrient leaching. A valve was inserted into the rubber stopper and a thermometer was attached to a small hole drilled into the top of the column to supply water and to investigate the temperature inside the column. The bottom of the columns were covered with 5 cm of quartz, sand, and cotton to prevent sample loss. The columns were packed with 500 g (air-dry weight) of sediment homogenized with five different application rates of 0%, 0.5%, 1%, 2%, and 8% (by weight) of biochar, and each treatment was performed in triplicate. The columns were incubated at constant room temperature for 6 weeks. The columns were flushed with 175 mL of deionized water over a period each week (175 mL/week). Leachate samples were collected from the outlet at the bottom of the columns and filtered through GF/C.

The total volume and pH of the leachate were measured. Leachate samples were stored in a refrigerator. The TKN, NH\(_4\)\(^+\)-N, NO\(_3\)\(^-\)-N, and NO\(_2\)\(^-\)-N concentrations in leachate samples were determined.

The effect of biochar on the nitrifying and denitrifying microbial community in sediment was determined by mixing 2% biochar or no biochar with 500 g sediment in cylinder-shaped columns with the sizes mentioned above. 175 mL distilled water was supplied to the sediment columns and incubated for 1 week to investigate microbial growth. After a 1-week incubation, samples were collected at the column’s surface to a depth of 2 cm and stored in the refrigerator for analysis. The DNeasy PowerSoil kit (Qiagen) was used to extract DNA in the soil. The extraction protocols followed the manufacturer’s instructions. A 16 s Barcoding kit (SQK-RAB204)-minion and MinKNOW software from Oxford Nanopore Technology were used for DNA sequencing.

2.5. Statistical Analysis

The biochar and sediment sample’s physicochemical properties were determined in triplicate, and the results were indicated as mean ± standard deviation (mean ± SD). The \(R^2\) values of the Langmuir, Freundlich, and Temkin adsorption isotherms were used to compare different models’ performances. Statistical analysis was performed using Minitab v16 (Minitab, LLC, Pennsylvania, USA, Version 16). A one-way analysis of variance
(ANOVA) was used to test for significant differences between the control and treated samples at 95% ($p \leq 0.05$). The Tukey comparison was performed to confirm which treatments were significantly different from all other treatments and the origin v19 program was used to plot the results.

3. Results

3.1. Physical and Chemical Properties of Biochar and Sediment

The physical and chemical properties of biochar and sediment are shown in Table 1.

| Properties       | Biochar   | Sediment  |
|------------------|-----------|-----------|
| Moisture (%)     | 8.51 ± 0.40 | 56.66 ± 0.82 |
| pH (1:1)         | 6.95 ± 0.07 | 7.97 ± 0.01 |
| EC (1:5) (dS m$^{-1}$) | 1.26 ± 0.01 | 1.53 ± 0.01 |
| OM (%)           | 16.55 ± 0.35 | 1.53 ± 0.02 |
| TKN (%)          | 0.58 ± 0.02 | 0.10 ± 0.01 |
| CEC (cmol kg$^{-1}$) | 17.77 ± 2.63 | 16.85 ± 1.37 |
| Available K (mg kg$^{-1}$) | 1286.51 ± 2.42 | 761.67 ± 1.27 |
| Available $p$ (mg kg$^{-1}$) | 1719.15 ± 3.66 | 39.85 ± 0.44 |
| NH$_4^+$-N (mg kg$^{-1}$) | 5.76 ± 0.34 | 40.05 ± 0.75 |
| NO$_3^-$-N (mg kg$^{-1}$) | 8.29 ± 0.16 | 9.25 ± 0.21 |

The surface area, pore volume, and average pore width of mangrove biochar are shown in Table 2. The surface area and pore volume were 11.74 m$^2$ g$^{-1}$ and 0.0065 cm$^3$ g$^{-1}$, respectively. The average pore width was 5.5 nm indicating that the pore was mesoporous [48]. However, the surface area and porosity of biochar were considerable with pyrolysis temperature and the feedstock used. As shown in Table 2, the surface area of banana pseudostem biochar (4.98 m$^2$ g$^{-1}$) produced at 300 °C was smaller than that of wheat straw biochar (155.7 m$^2$ g$^{-1}$) produced at 600 °C. The varying surface areas and pore volumes might be a result of the progressive degradation of the organic material (hemicellulose, cellulose, and lignin) during the pyrolysis process [49].

| Data                           | This Study | [48] | [50] | [51] | [52] | [52] |
|-------------------------------|------------|------|------|------|------|------|
| BET surface area (m$^2$ g$^{-1}$) | 11.74      | 4.98 | 2.46 | 155.7| 34.9 | 26.6 |
| Cumulative volume (cm$^3$ g$^{-1}$) | 0.0065      | 0.00959| 0.0029| 0.12 | 0.0158| 0.0174|
| Average pore width (nm)       | 5.5        | 10.39| 4.47 | 8.4  | 1.81 | 2.62 |

| Absorbent                  | Mangrove biochar residue | Banana pseudostem biochar | Palm bark biochar | Wheat straw biochar | Fir wood pellet biochar | Kelp seaweed biochar |
|----------------------------|--------------------------|---------------------------|------------------|---------------------|------------------------|---------------------|

SEM was performed to observe the morphology of the biochar (Figure 1). The pristine biochar surface morphologies had a relatively rough and porous structure. The porosity of mangrove biochar residue is important for improving soil quality, providing habitats of microorganisms, and enhancing element removal such as NH$_4^+$-N and NO$_3^-$-N [53].
FTIR was used to investigate the properties of the functional groups in biochar. Figure 2 shows the functional groups represented in biochar. The peaks in the region of 3200–3600 cm\(^{-1}\) can be attributed to the O-H stretching vibration of hydrogen-bonded groups and water molecules. The region between 2850–3000 cm\(^{-1}\) refers to the aliphatic band C-H (alkenes). The N-H stretching (amide) vibration is found at 1550–1640 cm\(^{-1}\). The frequencies at 1400–1620 cm\(^{-1}\), 1000–1300 cm\(^{-1}\), 600–1000 cm\(^{-1}\), and 600–800 cm\(^{-1}\) for the stretching vibrations of the C=C, C-O, =C-H, and C-Cl groups, indicate the presence of aromatic, ether, alkene, and alkyl halide functional groups, respectively [54]. From FTIR analysis, it was found that functional group N-H has the possibility to adsorb NO\(_3^-\)-N and C-O has possibility to adsorb NH\(_4^+\)-N.

Figure 2. FTIR spectra of mangrove biochar residue.
The pHpzc is shown in Figure 3. This finding shows that the pHpzc value of biochar is 7.5. When the solution’s pH is lower than the pHpzc, the net surface charge of biochar is positive due to the adsorption of excess H$^+$. Thus, biochar has a strong capacity to adsorb anionic species. Meanwhile, the net surface charge on surface biochar becomes negative when the pH of the solution is higher than the pHpzc due to the desorption of H$^+$. In this situation, the surface of biochar becomes suitable for the desorption of anionic species [55].

Figure 3. The pH point of zero charge (pHpzc) of mangrove biochar residue.

3.2. Adsorption
3.2.1. Effect of Contact Time

Figure 4 shows that the achievement of close to the highest removal values of NH$_4^+$-N and NO$_3^-$-N by mangrove biochar residue is rapid in the early stages of contact time. After 5 min, NH$_4^+$-N and NO$_3^-$-N removal were 80.84% and 15.11%, respectively. The adsorption process reached equilibrium within 240 min. This might be due to the presence of a greater number of active sites on biochar for the adsorption of ammonium and nitrate ions during the initial stages. This finding can be explained in three ways. First, a physical process occurs mainly through mass transfer due to the ion concentration gradient between the solid and liquid phases [56,57]. Second, the slower phase depicts the end of physical sorption. Finally, the adsorption corresponds to chemisorption and to some extent intraparticle diffusion, continuing until saturation of the active sites [58]. Previous studies also reported similar results—namely, that ammonium and nitrate adsorption increased with an increase in contact time and after reaching equilibrium time, adsorption remained constant [53,55,59,60]. Thus, a period of 240 min was determined to be sufficient for the adsorption of ammonium and nitrate onto biochar. Based on this finding, a contact time of 240 min was selected for further experiments.
creased with increased solution pH (Figure 5). The NH4+-N removals were 88.76%, 89.59%, and 87.76% at pH values of 5, 5.5, and 6, respectively. In addition, there was significant difference between pH 5, 5.5, and 6 (p < 0.05). This finding could be due to high pH, some NH4+ can be changed to NH3 and less attraction between NH4+ on biochar because of less NH4+, ultimately reducing NH4+ sorption capacity. NH4+-N adsorbed on biochar could occur through electrostatic adsorption to negatively charged oxygen-containing surface functional groups associated with CEC [8]. The oxygen-containing functional groups, such as C-O, form complexes on the biochar surface. These functional groups provide an opportunity for cation adsorption, such as that of NH4+-N [61].

3.2.2. Effect of Solution pH

Solution pH was another key factor that affected the adsorption process of anions and cations at the solid–liquid interface. The results indicated that NH4+-N removal decreased with increased solution pH (Figure 5). The NH4+-N removals were 88.76%, 89.59%, and 87.76% at pH values of 5, 5.5, and 6, respectively. In addition, there was significant difference between pH 5, 5.5, and 6 (p < 0.05). This finding could be due to high pH, some NH4+ can be changed to NH3 and less attraction between NH4+ on biochar because of less NH4+, ultimately reducing NH4+ sorption capacity. NH4+-N adsorbed on biochar could occur through electrostatic adsorption to negatively charged oxygen-containing surface functional groups associated with CEC [8]. The oxygen-containing functional groups, such as C-O, form complexes on the biochar surface. These functional groups provide an opportunity for cation adsorption, such as that of NH4+-N [61].
3.2.3. Effect of Biochar Dosage

For ammonium and nitrate, the adsorption removal slowly because the active sites on biochar were saturated. Similar results: namely, that NO$_3^-$ adsorption by different types of biochar increased the NO$_3^-$ removal at low pH values and decreased NO$_3^-$ adsorption at high pH values [62,63]. Based on this finding, pH values of 5.5 for ammonium and 5 for nitrate were selected for further experiments.

3.2.4. Effect of Initial NH$_4^+$ and NO$_3^-$ Concentrations

Initial concentration is an important driving force in overcoming all mass transfer resistance of solutes between the aqueous and solid phases. The results (Figure 7) indicate that NH$_4^+$ and NO$_3^-$ removal increased along with increasing NH$_4^+$ and NO$_3^-$ initial concentrations. NH$_4^+$ and NO$_3^-$ removal increased from 83.14% to 86.79% and 87.49% to 92.85%, respectively. This finding can be attributed to the number of active adsorption sites on biochar that were available for NH$_4^+$ and NO$_3^-$ adsorption [63]. In addition, the adsorption removal slowed because the active sites on biochar were saturated at high initial NH$_4^+$ and NO$_3^-$ concentrations [65]. Previous studies also reported similar results: namely, that NH$_4^+$ and NO$_3^-$ removal increased along with increasing initial concentration of NH$_4^+$ and NO$_3^-$ [55,66].
3.2.5. Adsorption Isotherm

Three models of isotherms were used to fit the adsorption experiment results: the Langmuir, Freundlich, and Temkin models. The parameters and correlation coefficients ($R^2$) of the three models are listed in Table 3. After comparing the $R^2$ values of the Langmuir, Freundlich, and Temkin models, the Freundlich model was selected to describe ammonium and nitrate adsorption, as the constants ($K_f$ and $n$) were non-negative numbers with correlation coefficients $R^2$ greater than 0.99, while the Langmuir and Temkin models returned $R^2$ values smaller than 0.99. For the Freundlich isotherm, adsorption performance was better when the $n$ value was high: $n$ values between 1 and 2 indicate that conditions are favorable for adsorption, while $n$ values less than 0.5 indicate poor adsorption characteristics [67].

$n$ values of 1.75 and 1.59 were obtained for the Freundlich isotherm, showing that the process of NH$_4^+$ and NO$_3^-$ adsorption on biochar was easy (Table 3). Thus, the Freundlich isotherm proved a better fit for the experimental results than the other models, and the adsorption of ammonium and nitrate onto biochar might therefore be the multi-layer type. The Temkin model’s $b$ value is positive, which indicates that the adsorption reaction is endothermic. If the $b$ value is less than 8 kJ mol$^{-1}$, the adsorption is physical; if the $b$ value is between 8 and 16 kJ mol$^{-1}$, the adsorption process proceeds via ion exchange; while if the $b$ value is greater than 16 kJ mol$^{-1}$, the adsorption follows the chemisorption process [68]. Thus, the result indicates that the adsorption of ammonium (2.15 kJ mol$^{-1}$) and nitrate (14.06 kJ mol$^{-1}$) onto biochar follow the physisorption process and ion exchange process, respectively. Zhou et al. [66] reported that the adsorption of ammonium on Barbecue Bamboo Charcoal followed the Freundlich isotherm, a finding that is consistent with this research. In addition, Table 3 shows that constant values from the adsorption isotherm equation differed from those found in other research. This could be due to the different functional group of the adsorbent surface. The higher or lower constant values, meanwhile, could be dependent on the initial concentration.

Figure 7. Effect of initial concentration on ammonium and nitrate adsorption removal (biochar dosage 2 g L$^{-1}$, initial ammonium and nitrate concentration 2–10 mg L$^{-1}$, contact time 240 min, temperature 25 °C, ammonium initial pH 5.5, and nitrate initial pH 5).
Table 3. Values of $q_{\text{max}}$, $K_L$, $K_F$, A, b, and $R^2$ for the Langmuir, Freundlich, and Temkin isotherms of biochar.

| Model          | Constant             | Ammonium        | Nitrate        |
|----------------|----------------------|-----------------|----------------|
|                |                      | This Experiment | [39] | [66] | This Experiment | [10] | [55] | [69] |
| Langmuir       | $q_{\text{max}}$ (mg g$^{-1}$) | 7.96            | 71.94          | 20             | 7.32            | 90.74          | 28.21          | 14.46          |
|                | $K_L$ (L mg$^{-1}$)  | 0.64            | 5.895 $\times 10^{-3}$ | 0.5            | 0.14            | 0.003           | 0.13            | 0.0014          |
|                | $R^2$                | 0.9773          | 0.994          | 0.3414         | 0.986           | 0.967           | 0.99            | 0.968           |
| Freundlich     | $K_F$ (mg g$^{-1}$)  | 3.14            | 0.6604         | 12.9152        | 1.75            | 4.285           | 5.82            | 0.249           |
|                | n (g L$^{-1}$)       | 1.75            | 0.6725         | 1.18           | 1.59            | 2.553           | 2.59            | 0.503           |
|                | $R^2$                | 0.9971          | 0.985          | 0.9346         | 0.9958          | 0.935           | 0.98            | 0.917           |
| Temkin         | $A$ (L g$^{-1}$)     | 5.09 $\times 10^{-3}$ | –              | 0.0121         | 1.89            | –               | –               | –               |
|                | b (kJ mol$^{-1}$)    | 2.15            | 2.5943         | 14.08          | –               | –               | –               | –               |
|                | $R^2$                | 0.9238          | –              | 0.8474         | 0.9688          | –               | –               | –               |

| Adsorbent      | Mangrove biochar residue | Rice husks biochar | Barbecue bamboo biochar | Mangrove biochar residue | Poplar chips biochar modified with AlCl3 | Modified sugarcane bagasse biochar | Corncocks biochar |
|----------------|-------------------------|--------------------|-------------------------|-------------------------|-----------------------------------------|----------------------------------|--------------------|
| Condition      |                         |                    |                         |                         |                                         |                                  |                    |
| Temperature (°C) | 25                      | 25                 | 25                      | 25                      | 25                                      | 22                               | 30                 |
| Biochar dosage (g L$^{-1}$) | 2                      | 1                  | 0.4                     | 2                       | 0.1                                     | 2                               | 0.1                |
| Concentration (mg L$^{-1}$) | 2-10                    | 250-1400           | 2-80                    | 2-10                    | 50                                      | 1-100                            | 0-2000             |
| pH             | 5.5                     | 5.7                | 9                       | 5                       | 6                                       | 4.64                             | –                  |
| Contact time (min) | 240                    | 1200               | 2880                    | 240                     | 1440                                    | 1440                            | 1440               |
| Speed (rpm)    | 180                     | 120                | 120                     | 180                     | 120                                     | 120                             | 120                |

– Information not provided.

3.3. Nitrogen Leaching

3.3.1. Effect of Biochar on Volume Leaching

The leachate volume collected across all treatments changed from 35 mL to 167 mL (Figure 8a). The volume increased along with increasing incubation time. In the second week of the experiment’s leachate, the leaching volume was low with biochar addition, and from the third week until the end of the experiment it was stable (Figure 8a). The cumulative volume of leaching during the first leaching was significantly lower than volumes at later leaching times. Biochar addition significantly reduced the cumulative leaching volume by 4.14%, 1.19%, 0.78%, and 15.06% in 0.5%, 1%, 2%, and 8% biochar, respectively (Figure 8b). However, the cumulative leaching volume under biochar additions was not significantly different, at 0.5%, 1%, and 2% compared with the control. In addition, 8% biochar significantly reduced the cumulative volume of leachates compared with the control ($p < 0.05$) (Figure 8b). This finding indicated that the addition of biochar could increase the water-holding capacity, which is an essential economic asset for agriculture planting in the dry season. However, the increase in water-holding capacity was dependent on biochar type, pyrolysis conditions, and soil type [70].

3.3.2. Effect of Biochar on TKN, NH$_4^+$-N, NO$_3^-$-N, and NO$_2^-$-N Leaching

The temporal changes in TKN concentration and cumulation in the leachate of soil columns are shown in Figure 9a,b. The average TKN concentration in the leachate at the initial stage (week 2) of the experiment was 1260, 914, 931, 1602, and 1373 mg L$^{-1}$ in the 0%, 0.5%, 1%, 2%, and 8% biochar treatment, respectively. During the leaching process, the concentration of TKN in the leachate decreased as incubation time increased (Figure 9a). However, there was no significant difference observed between the control (0%) and 1% biochar treatment (Figure 9b). Compared with the control, the addition of 0.5% and 8% of biochar significantly reduced the cumulative TKN loss by 10.44% and 23.75%, respectively ($p < 0.05$) (Figure 9b). In addition, 2% of biochar amendment increased cumulative TKN leaching by 22.19% compared with the control ($p < 0.05$). This result was followed by the previous studies [5,71,72]. All reports indicated that the addition of biochar could reduce leaching and improve soil N retention. However, biochar’s impact on nutrient leaching...
depends on several complex processes, such as biochar application rate; chemical, physical, and biological processes; and the feedstock used in the biochar production [73].

Figure 8. Effect of mangrove biochar residue on (a) leaching volume and (b) cumulative leaching volume at different sampling times. Error bars represent SE (n = 3). Treatments include no biochar addition (control) and biochar amendment at 0.5%, 1%, 2%, and 8%.

Figure 9. Cont.
Temporal changes in NH$_4^+$-N concentration in the leachate and cumulative NH$_4^+$-N loss from soil columns are shown in Figure 9c,d. In the second week, the average NH$_4^+$-N concentration in the experiment’s leachate decreased with biochar addition by 176.83, 157.71, 137.21, 137.5, and 88.93 mg L$^{-1}$ in the 0%, 0.5%, 1%, 2%, and 8% biochar mixtures, respectively (Figure 9c). In addition, NH$_4^+$-N concentration decreased with increasing incubation time throughout the experiment. The addition of 0.5%, 1%, and 2% of biochar increased cumulative NH$_4^+$-N leaching compared with the control by 1.44%, 6.74%, and 22.26%, respectively (Figure 9d). However, there was no significant difference between the control and 0.5% and 1% biochar-amended sediment. The column amended with 8% biochar reduced cumulative NH$_4^+$-N leachate by 45.48% ($p < 0.05$) compared with the control. This finding indicated that increasing levels of biochar decreased cumulative levels of NH$_4^+$-N leaching. This is because high levels of biochar are more effective on the active site and at removing cationic species, such as NH$_4^+$-N, from the solution due to their net negative surface charge [31]. On the other hand, the CEC value of the biochar is the most critical factor that affects NH$_4^+$-N adsorption onto biochar [24]. The CEC value of the biochar used in this study was 17.77 cmol kg$^{-1}$, which is 5.18% higher than that of sediment (16.85 cmol kg$^{-1}$). The increase in CEC value of the soil mixed with biochar was the main factor in increased NH$_4^+$-N adsorption ability, reducing NH$_4^+$-N loss in the leachate [24]. These results were linked to NH$_4^+$-N adsorption (Figure 6); a high dosage of biochar could remove or reduce NH$_4^+$-N loss.

Figure 9e,f displayed the effect of biochar on the temporal change of NO$_3^-$-N concentration and cumulation in the leaching experiments under different treatments. The results found that the leaching of NO$_3^-$-N concentration decreased with increased incubation time (Figure 9e). The addition of 0.5%, 1%, and 2% of biochar reduced cumulative NO$_3^-$-N leaching by 1.44%, 6.74%, and 22.26%, respectively (Figure 9f). However, there was no significant difference between the control and 0.5% and 1% biochar-amended sediment. The column amended with 8% biochar reduced cumulative NO$_3^-$-N loss by 45.48% ($p < 0.05$) compared with the control. This finding indicated that increasing levels of biochar decreased cumulative levels of NO$_3^-$-N leaching.
found that the leaching of NO$_3^-$-N concentration decreased with increased incubation
time during the experiment. In the second week of the experiment, the NO$_3^-$-N concen-
tration in the leachate decreased with biochar addition by 55.66 and 55.5 mg L$^{-1}$ in 2%
and 8% of biochar amendment, respectively (Figure 9e), and NO$_3^-$-N concentration was
also increased with biochar addition by 61.89 and 65.67 mg L$^{-1}$ in 0.5% and 1% of biochar
amendment, respectively (Figure 9e). However, the NO$_3^-$-N concentration in the leachates
decreased rapidly in the third week of incubation time. Compared with the control, the
addition of biochar reduced cumulative NO$_3^-$-N leaching by 13.16%, 13.94%, 22.20%, and
33.63% in the 0.5%, 1%, 2%, and 8% biochar additions, respectively ($p < 0.05$) (Figure 9f).
Some possible mechanisms underlying the reduced nitrate leaching in biochar-treated soils
could be as follows: (i) the ability of the biochar to adsorb nitrate from the soil solution;
(ii) increased soil aggregation and water retention due to biochar application [15]; and (iii)
the bonding that occurs between negatively charged nitrate and amino groups (Figure 2)
or positively charged cationic salts on the biochar surface [24].

Figure 9g,h displayed the effect of biochar on the temporal change in NO$_2^-$-N con-
centration and cumulative in the leaching experiments under different treatments. The
results found that the NO$_2^-$-N concentration in the experiment’s leachate decreased with
increasing leaching incubation time. In the second week, the NO$_2^-$-N concentration in the
experiment’s leachate decreased under 0.5% of biochar addition compared with control.
Meanwhile, the NO$_2^-$-N concentration in the leachates decreased rapidly during the third
week of incubation time and remained stable until the end of the experiment (Figure 9g).
Compared with the control, cumulative NO$_2^-$-N leaching decreased when application
rates of biochar were increased (Figure 9h). The addition of biochar at 0.5%, 1%, 2%, and 8%
reduced cumulative NO$_2^-$-N leaching by 34.70%, 12.57%, 3.3%, and 43.44%, respectively.
However, the addition of 1% and 2% biochar made no significant difference compared with
the control ($p < 0.05$). Previous studies have suggested that, when applied to soils, biochar
may not only affect soil ion exchange capacity but also provide refuge for soil microbes to
influence the binding of nutritional cations and anions [4].

3.3.3. Effect of Biochar on Nitrifying and Denitrifying Microorganisms

Figure 10a shows the relative abundance of nitrifying bacteria represented in biochar-
amended shrimp pond sediment and sediment without biochar amendment. These results
revealed that the bacterial community structure was different between sediment with
biochar and those without. The results indicated that the nitrifying microorganism genera
(AOB, AOA, and NOB) increased with biochar treatment compared with the biochar-
lacking control. This finding demonstrates that the application of biochar led to the
growth of nitrifier populations. The population of nitrifying bacteria of Nitrosomonas sp.,
Nitrosospira sp., Nitrospira sp., Nitrosococcus sp., and Nitrospina sp. was higher under biochar
addition. Bi et al. [74] and Prommer et al. [75] also reported that nitrification increased with
the combined application of rice straw biochar and wood biochar. The increase in nitrifying
bacteria due to the addition of biochar to soil affects moisture content, hydraulic properties,
and soil aeration [8]. Furthermore, the porous structure of biochar may provide the habitat
for microorganisms, and biochar can release labile C that microbial can use as an energy
source [76]. In addition, based on the results of nitrogen leaching in Figures 8 and 9, the
application of biochar can increase water-holding capacity and reduce N leaching, which
provides nutrient bioavailability for microbial growth. Thus, the relative abundance of
nitrifying bacteria was higher than in sediment without biochar amendment.
In this study, adsorption of NH$_4^+$-N and NO$_3^-$-N were tested using biochar. Adsorption was influenced by contact time, pH, biochar dosage, and initial concentration. The maximum adsorption capacities of biochar for removing NH$_4^+$-N and NO$_3^-$-N were achieved at an optimum contact time of 240 min, pH values of 5.5 and 5, and adsorbent dosage of 2 g L$^{-1}$, respectively. The experimental adsorption data were fitted to different isotherm models using the Langmuir, Freundlich, and Temkin models. The NH$_4^+$-N and NO$_3^-$-N adsorption isotherm was a better fit with the Freundlich model ($R^2 > 0.99$) compared with the Langmuir and Temkin models ($R^2 < 0.99$). This indicates that the adsorption of NH$_4^+$-N and NO$_3^-$-N onto biochar might be of the multi-layer type. The energy values in the Temkin model of the NH$_4^+$-N and NO$_3^-$-N adsorption isotherm were 2.15 kJ mol$^{-1}$ and 14.06 kJ mol$^{-1}$; thus, the results aligned with the physisorption process and ion exchange, respectively. Compared with the control, the addition of 8% biochar reduced cumulative volume leaching by 15.06%, TKN by 23.75%, NH$_4^+$-N by 43.44%. In addition, compared with the sediment without biochar, the abundance of nitrifying and denitrifying bacteria increased under biochar amendment. Overall, biochar can be used to adsorb NH$_4^+$-N and NO$_3^-$-N, and biochar amendment of sediment from a shrimp pond can reduce TKN, NH$_4^+$-N, NO$_3^-$-N, and NO$_2^-$-N leaching, maintain N retention, and affect the bacterial community structure. Thus, use of biochar amended with sediment from shrimp farms can decrease environmental problems caused by nutrient leaching and provide benefits for planting with reduced use of fertilizer. However, further research on the comparison of crop yields from different types of plants should be investigated.

**Author Contributions:** Conceptualization, S.B., A.P. and S.V.; methodology, S.B.; software, S.B.; validation, A.P. and S.V.; formal analysis, A.P. and S.V.; resources, A.P. and S.V.; data curation, S.B., A.P. and S.V.; writing—original draft preparation S.B.; writing—review and editing, A.P., S.V.
and S.B.; supervision, A.P. and S.V. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research was funded by the Petchra Pra Jom Kla Master’s Degree Scholarship, grant No. 1281/2562 from King Mongkut’s University of Technology Thonburi (KMUTT), Thailand.

**Institutional Review Board Statement:** Not applicable.

**Informed Consent Statement:** Not applicable.

**Data Availability Statement:** Not applicable.

**Conflicts of Interest:** The authors declare no conflict of interest.

**References**

1. Pawlak, K.; Kołodziejczak, M. The Role of Agriculture in Ensuring Food Security in Developing Countries: Considerations in the Context of the Problem of Sustainable Food Production. *Sustainability* **2020**, *12*, 5488. [CrossRef]

2. Popp, J.; Péter, K.; Nagy, J. Pesticide productivity and food security. A review. *Agron. Sustain. Dev.* **2013**, *33*, 243–255. [CrossRef]

3. Campos, E.V.R.; De Oliveira, J.L.; Fraceto, L.F. Applications of Controlled Release Systems for Fungicides, Herbicides, Acaricides, Nutrients, and Plant Growth Hormones: A Review. *Adv. Sci. Eng. Med.* **2014**, *6*, 373–387. [CrossRef]

4. Yao, Y.; Gao, B.; Zhang, M.; Inyang, M.; Zimmerman, A.R. Effect of biochar amendment on sorption and leaching of nitrate, ammonium, and phosphate in a sandy soil. *Chemosphere* **2012**, *89*, 1467–1471. [CrossRef]

5. Xu, N.; Tan, G.; Wang, H.; Gai, X. Effect of biochar additions to soil on nitrogen leaching, microbial biomass and bacterial community structure. * Eur. J. Soil Biol.* **2016**, *74*, 1–8. [CrossRef]

6. Sun, H.; Lu, H.; Chu, L.; Shao, H.; Shi, W. Biochar applied with appropriate rates can reduce N leaching, keep N retention and not increase NH3 volatilization in a saline soil. *Sci. Total Environ.* **2017**, *575*, 820–825. [CrossRef]

7. Thakur, I.S.; Medhi, K. Nitrification and denitrification processes for mitigation of nitrous oxide from waste water treatment plants for biovalorization: Challenges and opportunities. *Bioresources. Technol.* **2019**, *282*, 502–513. [CrossRef]

8. Plaimart, J.; Acharya, K.; Mrozik, W.; Davenport, R.J.; Vinitnantharat, S.; Werner, D. Coconut husk biochar amendment enhances nutrient retention by suppressing nitrification in agricultural soil following anaerobic digestive application. *Environ. Pollut.* **2021**, *268*, 115684. [CrossRef]

9. Liu, Y.; Zhu, J.; Ye, C.; Zhu, P.; Ba, Q.; Pang, J.; Shu, L. Effects of biochar application on the abundance and community composition of denitrifying bacteria in a reclaimed soil from coal mining subsidence area. *Sci. Total Environ.* **2018**, *625*, 1218–1224. [CrossRef]

10. Yin, Q.; Ren, H.; Wang, R.; Zhao, Z. Evaluation of nitrate and phosphate adsorption on Al-modified biochar: Influence of Al content. *Sci. Total Environ.* **2018**, *631–632*, 895–903. [CrossRef]

11. Vígašová, E.; Galamboš, D.; Diviš, D.; Danková, Z.; Daňo, M.; Krivosudský, L.; Lengauer, C.L.; Matík, M.; Briančin, J.; Soja, G. Engineered biochar as a tool for nitrogen pollutants removal: Preparation, characterization and sorption study. *Desalination Water Treat.* **2020**, *191*, 318–331. [CrossRef]

12. Hu, L.; Li, S.; Li, K.; Huang, H.; Wan, W.; Huang, Q.; Li, Q.; Li, Y.; Deng, H.; He, T. Effects of Two Types of Straw Biochar on the Mineralization of Soil Organic Carbon in Farmland. *Sustainability* **2020**, *12*, 10586. [CrossRef]

13. Yin, Q.; Wang, R.; Zhao, Z. Application of Mg-Al-modified biochar for simultaneous removal of ammonium, nitrate, and phosphate from eutrophic water. *J. Clean. Prod.* **2018**, *176*, 230–240. [CrossRef]

14. Kameyama, K.; Miyamoto, T.; Ivata, Y.; Shiono, T. Influences of feedstock and pyrolysis temperature on the nitrate adsorption of biochar. *Soil Sci. Plant Nutr.* **2016**, *62*, 180–184. [CrossRef]

15. Pratiwi, E.P.A.; Hillary, A.K.; Fukuda, T.; Shinogi, Y. The effects of rice husk char on ammonium, nitrate and phosphate retention and leaching in loamy soil. *Geoderma* **2016**, *277*, 61–68. [CrossRef]

16. Ding, Y.; Liu, Y.-X.; Wu, W.-X.; Shi, D.-Z.; Yang, M.; Zhong, Z.-K. Evaluation of Biochar Effects on Nitrogen Retention and Leaching in Multi-Layered Soil Columns. *Water Air Soil Pollut.* **2010**, *213*, 47–55. [CrossRef]

17. Wang, Z.; Guo, H.; Shen, F.; Yang, G.; Zhang, Y.; Zeng, Y.; Wang, L.; Xiao, H.; Deng, S. Biochar produced from oak sawdust by Lanthanum (La)-involved pyrolysis for adsorption of ammonium (NH4\(^+\)), nitrate (NO\(_3^-\)), and phosphate (PO\(_4^{3-}\)). *Chemosphere* **2015**, *119*, 646–653. [CrossRef]

18. Yuan, H.; Lu, T.; Wang, Y.; Chen, Y.; Lei, T. Sewage sludge biochar: Nutrient composition and its effect on the leaching of soil nutrients. *Geoderma* **2016**, *267*, 17–23. [CrossRef]

19. Husson, O.; Brunet, A.; Babre, D.; Charpentier, H.; Durand, M.; Sarthou, J.-P. Conservation Agriculture systems alter the electrical characteristics (Eh, pH and EC) of four soil types in France. *Soil Tillage Res.* **2018**, *176*, 57–68. [CrossRef]

20. Hollister, C.C.; Bisogni, J.J.; Lehmann, J. Ammonium, Nitrate, and Phosphate Sorption to and Solute Leaching from Biochars Prepared from Corn Stover (*Zea mays* L.) and Oak Wood (*Quercus* spp.). *J. Environ. Qual.* **2013**, *42*, 137–144. [CrossRef] [PubMed]

21. Zhou, L.; Xu, D.; Li, Y.; Pan, Q.; Wang, J.; Xue, L.; Howard, A. Phosphorus and Nitrogen Adsorption Capacities of Biochars Derived from Feedstocks at Different Pyrolysis Temperatures. *Water* **2019**, *11*, 1559. [CrossRef]

22. Gui, S.; Whalen, J.K.; Thomas, B.; Sachdeva, V.; Deng, H. Physico-chemical properties and microbial responses in biochar-amended soils: Mechanisms and future directions. *Agric. Ecosyst. Environ.* **2015**, *206*, 46–59. [CrossRef]
53. Viglašová, E.; Galamboš, M.; Danková, Z.; Krivosudský, L.; Lengauer, C.L.; Hoed-Nowotny, R.; Soja, G.; Rompel, A.; Matík, M.; Briančin, J. Production characterization and adsorption studies of bamboo-based biochar/montmorillonite composite for nitrate removal. Waste Manag. 2018, 79, 385–394. [CrossRef]

54. Naik, D.K.; Monika, K.; Prabhakar, S.; Parthasarathy, R.; Satyavathi, B. Pyrolysis of sorghum bagasse biomass into bio-char and bio-oil products. J. Therm. Anal. Calorim. 2017, 127, 1277–1289. [CrossRef]

55. Hafshejani, L.D.; Hooshmand, A.; Naseri, A.A.; Mohammad, A.S.; Abbasi, F.; Bhatnagar, A. Removal of nitrate from aqueous solution by modified sugarcane bagasse biochar. Ecol. Eng. 2016, 95, 101–111. [CrossRef]

56. Halim, A.A.; Latifi, M.T.; Ilhmin, A. Ammonia removal from aqueous solution using organic acid modified activated carbon. World Appl. Sci. J. 2013, 24, 1–6. [CrossRef]

57. Zhu, K.; Fu, H.; Zhang, J.; Lv, X.; Tang, J.; Xu, X. Studies on removal of NH4+-N from aqueous solution by using the activated carbons derived from rice husk. Biomass Bioenergy 2012, 43, 18–25. [CrossRef]

58. Kuci´c, D.; Cosi´c, I.; Vukovi´c, M.; Briski, F. Sorption kinetic studies of ammonium from aqueous solution on different inorganic and organic media. Acta Chim. Slov. 2013, 60, 109–119.

59. Kizito, S.; Wu, S.; Kirui, W.K.; Lei, M.; Lu, Q.; Bah, H.; Dong, R. Evaluation of slow pyrolyzed wood and rice husks biochar for adsorption of ammonium nitrogen from piggy manure anaerobic digestate slurry. Sci. Total Environ. 2015, 505, 102–112. [CrossRef]

60. Vu, T.M.; Trinh, V.T.; Doan, D.P.; Van, H.T.; Nguyen, T.V.; Vigneswaran, S.; Ngo, H.H. Removing ammonium from water using modified corncob-biochar. Sci. Total Environ. 2017, 579, 612–619. [CrossRef] [PubMed]

61. Liu, Z.; Zhang, F.-S. Removal of lead from biochars prepared from hydrothermal liquefaction of biomass. J. Hazard. Mater. 2009, 167, 933–939. [CrossRef] [PubMed]

62. Chintala, R.; Mollinedo, J.; Schumacher, T.E.; Papiernik, S.K.; Malo, D.D.; Clay, D.E.; Kumar, S.; Gulbrandson, D.W. Nitrate sorption and desorption in biochars from fast pyrolysis. Microporous Mesoporous Mater. 2013, 179, 250–257. [CrossRef]

63. Olgun, A.; Atar, N.; Wang, S. Batch and column studies of phosphate and nitrate adsorption on waste solids containing boron impurity. Chem. Eng. J. 2013, 222, 108–119. [CrossRef]

64. Hafshejani, L.D.; Nasab, S.B.; Gholami, R.M.; Moradzadeh, M.; Izadpanah, Z.; Hafshejani, S.B.; Bhatnagar, A. Removal of zinc and lead from aqueous solution by nanostructured cedar leaf ash as biosorbent. J. Mol. Liq. 2015, 211, 448–456. [CrossRef]

65. Ahmadi, S.; Igwegbe, C.A. Adsorptive removal of phenol and aniline by modified bentonite: Adsorption isotherm and kinetics study. Appl. Water Sci. 2018, 8, 1–8. [CrossRef]

66. Zhou, Z.; Yuan, J.; Hu, M. Adsorption of ammonium from aqueous solutions on environmentally friendly barbecue bamboo charcoal: Characteristics and kinetic and thermodynamic studies. Environ. Prog. Sustain. Energy 2014, 34, 655–662. [CrossRef]

67. Panda, H.; Tiadi, N.; Mohanty, M.; Mohanty, C. Studies on adsorption behavior of an industrial waste for removal of chromium from aqueous solution. S. Afr. J. Chem. Eng. 2013, 22, 132–138. [CrossRef]

68. Inam, E.; Etim, U.; Akpabio, E.; Umoren, S. Process optimization for the application of carbon from plantain peels in dye abstraction. J. Taibah Univ. Sci. 2017, 11, 173–185. [CrossRef]

69. Zhao, H.; Xue, Y.; Long, L.; Hu, X. Adsorption of nitrate onto biochar derived from agricultural residuals. Water Sci. Technol. 2018, 77, 548–554. [CrossRef] [PubMed]

70. Verheijen, F.G.; Zhuravel, A.; Silva, F.; Amaro, A.; Ben-Hur, M.; Keizer, J.J. The influence of biochar particle size and concentration on bulk density and maximum water holding capacity of sandy vs sandy loam soil in a column experiment. Geoderma 2019, 347, 194–202. [CrossRef]

71. Li, Y.; Cheng, J.; Lee, X.; Chen, Y.; Gao, W.; Pan, W.; Tang, Y. Effects of biochar-based fertilizers on nutrient leaching in a tobacco-planting soil. Acta Geochim. 2018, 37, 1–7. [CrossRef]

72. Zhao, X.; Yan, X.; Wang, S.; Xing, G.; Zhou, Y. Effects of the addition of rice-straw-based biochar on leaching and retention of fertilizer N in highly fertilized cropland soils. Soil Sci. Plant. Nutr. 2013, 59, 771–782. [CrossRef]

73. Laird, D.; Fleming, P.; Wang, B.; Horton, R.; Karlen, D. Biochar impact on nutrient leaching from a Midwestern agricultural soil. Geoderma 2010, 158, 436–442. [CrossRef]

74. Bi, Q.-F.; Chen, Q.-H.; Yang, X.-R.; Li, H.; Zheng, B.-X.; Zhou, W.-W.; Liu, X.-X.; Dai, P.-B.; Li, K.-J.; Lin, X.-Y. Effects of combined application of nitrogen fertilizer and biochar on the nitrification and ammonia oxidizers in an anaerobic vegetable soil. AMB Express 2017, 7, 198. [CrossRef]

75. Prommer, J.; Wanek, W.; Hofhansl, F.; Trojan, D.; Offre, P.; Uriach, T.; Schleper, C.; Sassmann, S.; Kitzler, B.; Soja, G.; et al. Biochar Decelerates Soil Organic Nitrogen Cycling but Stimulates Soil Nitrification in a Temperate Arable Field Trial. PLoS ONE 2014, 9, e86388. [CrossRef]

76. Luo, S.; He, B.; Song, D.; Li, T.; Wu, Y.; Yang, L. Response of Bacterial Community Structure to Different Biochar Addition Dosages in Karst Yellow Soil Planted with Ryegrass and Daylily. Sustainability 2020, 12, 2124. [CrossRef]

77. Tian, J.; Wang, J.; Dippold, M.; Gao, Y.; Blagodatskaya, E.; Kuz' yakov, Y. Biochar affects soil organic matter cycling and microbial functions but does not alter microbial community structure in a paddock soil. Sci. Total Environ. 2016, 556, 89–97. [CrossRef]

78. Anderson, C.R.; Condron, L.M.; Clough, T.; Fiers, M.; Stewart, A.; Hill, R.A.; Sherlock, R.R. Biochar induced soil microbial community change: Implications for biogeochemical cycling of carbon, nitrogen and phosphorus. Pedobiologia 2011, 54, 309–320. [CrossRef]