JEE Journal of Ecological Engineering

Journal of Ecological Engineering 2022, 23(5), 92–101
https://doi.org/10.12911/22998993/147000
ISSN 2299–8993, License CC-BY 4.0

Received: 2022.01.27
Accepted: 2022.02.28
Published: 2022.04.01

The Performance of Treatment Train System Incorporated with Nature-Based Materials in Capturing Nutrient for Stormwater Runoff

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ABSTRACT

Biofilters, commonly called rain gardens, are becoming increasingly popular among best-management practices (BMPs). They have recently sparked significant interest due to their ability to control stormwater quality. These systems face challenges in manipulating dissolved nitrogen and phosphorus species. This study reports the results of the removal of nitrogen and phosphorus in two modified bioretention systems. The performance of modified bioretention with coconut and durian was compared. The modified bioretention system was evaluated as a single and a series. Sequencing these systems in a series maintained the continuity of nutrient removal. Both series efficiently removed NH_3-N (97% in TC5, 95% in TD5), while the removal of NO_3-N was moderate (65% inTC5, 67% in TD5). Good removal efficiencies of TP were observed in two series (84% in TC5, 81% in TD5). However, the PO_4 removal was equalized in all series (98%). The TN and ON removal were poor and fluctuated with time and column number in TC5, the overall removal efficiencies were (69% and 43%), respectively, while in TD5 a significant fraction of TN and ON were removed (86% and 78%), respectively. As compared with coconut husk, durian peel is considered a promising material that can enhance the water quality in bioretention systems.

Keywords: additives, bioretention treatment train, coconut, durian, stormwater quality.

INTRODUCTION

Recently, the impervious areas have increased in the world. Replacing soil and vegetations with urbanization areas causes that a large portion of stormwater conveys different pollutants, such as total nitrogen (TN), ammonia-nitrogen (NH_3-N), nitrate (NO_3-N), organic nitrogen (ON), total phosphorus (TP), and phosphate (PO_4), which bypass via these areas. The release of pollutants from non-point sources like (residential areas, roads, roof, etc) affects the water quality that enters water bodies, therefore causing damage to the ecological system [Ali et al. 2021]. These nutrients should be treated before entering water bodies [Lopez-Ponnada et al. 2020]. Previous studies revealed that the conventional single and conventional bioretention systems have poor removal efficiency, as some leaching of nitrogen and phosphorus has been observed in certain cases [Li and Davis 2014; Shrestha, Hurley, and Wemple 2018]. As a result, many studies in recent years have commonly committed to improving denitrification for NO_3-N removal, including some incentive adjustments, such as setting anoxic conditions (usually creating a submerged zone) or adding electron donors (e.g., some form of organic carbon) to eliminate the NO_3-N concentrations. However, the aging of organic matter may cause nitrogen leaching over time, thus decreasing the TN removal [Chen et al. 2020; Li and Davis 2014]. The leaching of ON and NO_3-N from bioretention necessitates further research to identify cost-effective amendment materials for enhancing the bioretention system and solving environmental problems due to such solid wastes [Li and Davis 2014; Tirpak et al. 2021]. Furthermore, to maintain the continuity of nutrient removal over time, some of the studies have conducted a bioretention series (bioretention treatment train). Limited studies have been carried out to demonstrate the benefits of installing best management practices (BMPS) in a series (bioretention treatment train). Some of these studies focus on water quality. Brown, et al., [2012] installed concrete and bioretention cells in series. The result revealed that the removal efficiencies of total suspended solids (TSS), and TP were 87% and 30%, respectively, while exporting in NOx (NO_3, NO_2) and TN were observed thought that this was caused by the influx of groundwater. Another study of three field bioretention cells in series was conducted to evaluate their performance. The results showed that the stormwater that had been treated by this system could be used as a source for irrigation purposes [Doan and Davis 2017]. However, there was a lack of information in this study about the specific performance of each bioretention cell separately. A field study consists of four LID practices that combined a bioretention cell, swales, and permeable pavement in low infiltration soil and high groundwater level area. The study has not observed and compared the performance of each practice separately with four LID combinations. However, the author revealed that the contaminants were efficiently eliminated by these four LID practices [Wang et al. 2019]. Another field study examined the performance of three wetlands arranged in series. The author revealed that the decrease in pollutant concentration was more than 80%, achieved by the first wetland cell [Hathaway and Hunt 2010]. Only the first wetland cell reduced all pollutants significantly. There was no significant reduction in pollutant levels from the outlet of Wetland Cell 2 to the outlet of Wetland Cell 3. Moreover, organic nitrogen was exported in the wetland 3. However, as the wetland increases over time, it is unknown how the system function will evolve. Furthermore, succeeding BMPs in series would also provide BMP with continuous performance if the potency of the first BMP diminishes over time. Alessandra, et al., [2018] studied pollutant treatment in a treatment train. The underdrain of the permeable interlocking concrete pavement (PICP) discharged into a proprietary box filter (Filterra® biofiltration). The PICP has significantly reduced total suspended solids (TSS), total phosphorus (TP), total nitrogen (TN), and total Kjeldahl nitrogen (TKN), while the nitrate/nitrite ($NO_{2,3}$–N) concentrations increased significantly. The reducing pollutant by the second part (Filterra®) was less than 2%. The bioretention filter improved the TP removal from 41% to 75%, while the TN removal has improved from 27% to 42% when stormwater passed via Filterra® biofiltration. Emma et al., [2020] suggesting that treatment trains could be used in short storm events with modest hydraulic retention loads, as bioretention systems are better suited to shifting precipitation patterns when flow regulators are used to control the rate of water entering bioretention systems.

There is evidence in the literature that using a sequence of BMPs as a series (treatment train) could provide many benefits at the same time. These data indicate that several concerns remain unsolved, such as 1) investigating the performance of these practices using different amendment materials to avoid leaching in nutrients. 2) Choosing the ideal configuration by comparing individual and series performance in the lab scale. Conducting lab-scale tests is a cost-effective technique to determine which setup is most likely to produce the desired water quality. The validation in the field will be more useful. As a result, waste material will be studied as an alternative enhancement material to reduce the pollution caused by their dumping on the environment. An environmentally friendly approach of disposing of large amounts of coconut husk and durian peel waste, which are vastly produced in tropical countries, especially in Malaysia, may involve recycling them into different sectors. This study aimed to examine the performance of two different agricultural waste materials (coconut husk and durian peel) as additives in filter media and their impact on stormwater quality. The study compared a common waste material (coconut husk) which are widely available and commonly applied in bioretention system [Husna et al. 2014], with a new waste material (durian peel) which has not been used before in bioretention system. In addition, the performance of a bioretention system as an individual column and as a bioretention series was compared.

METHODS

Treatment train setup

Two biofilter trains (six columns) were set up in a greenhouse located at Environmental Research Laboratory (ERL) Universiti Teknologi

PETRONAS, Perak, Malaysia to compare the performance of two amendment materials, and all series multi-planted with (mixing *Cyperus alternifolius* (CA) and *Cordyline fruticosa* (CF) plant. Each biofiltration series were made up of three columns that were connected in series. The columns were semi-conical in shape, with a top-to-bottom diameter of 315–265 mm and a height of 595 mm. The two systems had the same ponding layer of 120 mm and 162.5 mm of top layer consists of (60% sand, 30%soil, 10% compost). In TC5 bottom layer of filter media consisted of 60% sand, 30 soil, 5% coconut husk, and depth 162.5 mm. In the TD5 series, the bottom layer of filter media composition of 60% sand, 30 soil, 5% durian peel. All systems have the same sand layer depth of 100 mm and gravel layer depth of 50 mm. The transition layer is used to prevent the washout of fine particles from filter media to the drainage layer. The details and materials of the two systems are shown in (Table 1). These proportions were chosen to acclimatize to tropical conditions to treat Malaysia's high rainfall intensity. All biofiltration series received synthetic stormwater influent from a water tank. Stormwater was manually controlled by a manual valve, allowing water to flow directly from the tank to column 1(C1), column 2(C2), and ultimately column 3(C3) by gravity. The experiment period was seven weeks, six weeks for plant establishment in columns, and one week for water quality analysis. (Figure 1) shows the biofiltration train details.

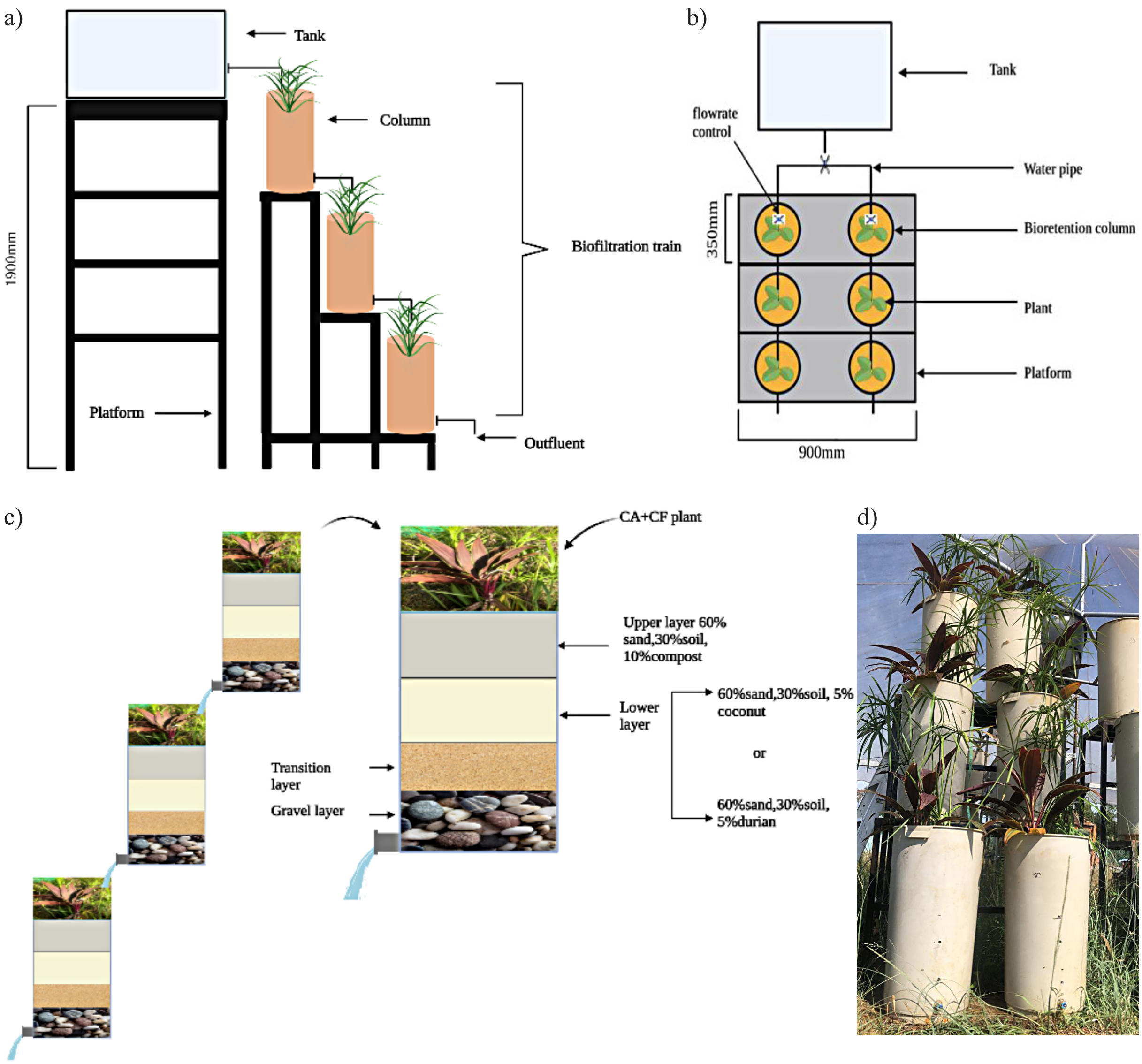

Figure 1. Bioretention series (treatment train), a) side view, b) top view, and c) the bioretention series details, d) the bioretention series (TC5 and TD5) in the reality

Table 1. Bioretention series details

Treatment train set	Characterization of filter media	Plant
TC5	Top layer 162.5 mm (60% sand, 30%soil, 10%compost) Lower layer 162.5 mm (60% sand, 30 soil, 5% coconut husk)	CF+CA
TD5	Top layer 162.5 mm (60% sand, 30%soil, 10%compost) Lower layer 162.5 mm (60% sand, 30 soil, 5% durian peel)	CF+CA

Soil media preparation

Topsoil was collected from the opposite area of Research and Development building (R&D) at Universiti Teknologi PETRONAS, Perak, Malaysia. The soil was collected and oven-dried at 105°C. particle size distribution and hydrometer test were performed by BS 1377: part 1,2 [Anon 1990a; Anon 1990b]. Artificial compost was bought from a local shop. Coconut husk and durian peel were collected from local shops (Ipoh, Malaysia). To eliminate all dust, the coconut husk and durian peel were washed three times with distilled water. Durian peel was sliced in 3-5 cm of length, cleaned, washed with distilled water, and air- dried for 2 days. Coconut husk and durian peel were oven-dried in 105°C till constant weight, after that ground using a mechanical grinder to obtain finer particles. Total organic carbon (TOC) for soil media, compost, coconut, and durian was measured using a Shimadzu Total Organic Carbon Analyser.

Plant selection

Two different types of plants were selected depending on resistance, type of roots, and nutrient uptake: Cyperus alternifolius (CA) and Cordyline fruticosa (CF) [Hermawan et al. 2020; Huong, Costa, and van Hoi 2020]. The plants have been kept in a greenhouse in pots for six months; afterwards they were transferred to biofilter columns. The establishment process of plants in bioretention columns has taken about six weeks.

Synthetic stormwater makeup

In order to be able to control the chemical and physical characteristics of the stormwater, synthetic stormwater was used in this study. The concentration of pollutants was used depending on real samples of stormwater collected from different land uses, such as residential, commercial, and street areas. Then, the mean of these concentrations was chosen as a baseline of the pollutant concentrations and chemicals used in stormwater makeup (Table 2). The stormwater volume that has been used in this experiment was calculated using the rational method given by MSMA. A 3-months Annual Recurrence Interval (ARI) was considered to calculate the design rainfall. A 0.018 L/s flow rate was applied for a 15-minute duration event. Runoff was controlled using a manual valve on the stormwater supplier pipe for each column. The valve was connected to the pipe terminated at the top of each column. The valve gradually opened to obtain the required flow rate, and the flow rate recorded with a measuring cylinder and stopwatch. The desired flow rate was obtained; the grade of the valve was marked and used for all experiment runs.

Table 2. Stormwater characteristics

Pollutant	Chemical source	Target concentration (mg/L)
TP	$KH_2 PO_4$	11.31333 ± 0.005
NO_3-N	KNO_3	3.633333 ± 0.05
NH_3-N	NH_4Cl	9.01 ± 0.005
ON	Urea	2.12 ± 0.02

Sampling and analysis methods

The treated stormwater samples were collected from the outlet of each column every 15 minutes. The retention time (sampling time) of each column was 45 minutes. Ten samples were collected from each series, one sample from influent of tank and nine samples of outflow. The total sampling period was 75 minutes for all series, and the total number of samples was twenty samples. The stormwater samples were taken immediately to the lab for analysis of water quality. Total nitrogen concentration was evaluated using Persulfate Digestion Method 10071 and Persulfate Digestion Method 8190 was used to determine the concentration of total phosphorus by using a Hach DR3900 Spectrophotometer (Hach, 2013) and a DRB200 reactor. Nessler method 8038 was used to test ammoniacal nitrogen, whereas method 8171 and 8048 were used to test nitrate and phosphate using the Hach DRB200 reactor. NH_3-N and NO_3-N were subtracted from TN to calculate

ON. Equations 1 and 2 were used to calculate the removal efficiency of pollutants for individual columns and the overall series.

$$CR_n = \frac{C_{n-1} - C_n}{C_{n-1}} \times 100\% \quad (1)$$

$$OR = \frac{C_{in} - C3}{C_{in}} \times 100\% \quad (2)$$

where: CR_n, OR are the mean removal efficiency of individual columns, and overall series, respectively; C_{in} the mean inflow concentration (mg/L); $C_{n,\ n-1}$, is the mean outflow concentration of individual column in (mg/L).

Statistical analysis method

All statistical analyses were performed using Minitab version 19 for all analysis. One-way ANOVA Tukey's test (α = 0.05) significant test was used to calculate the differences among the mean of influent and effluent concentrations of TN, NH_3-N, NO_3-N, ON, TP, and PO_4, for all columns. The regression and correlation of columns with outflow concentration were tested to determine if applying bioretention columns as a series influenced the stormwater quality.

Table 3. The total organic carbon content of filter media composition materials

Material	TOC %
Topsoil	1.21
Compost	5.79
Coconut	49.9
Durian	47.9

RESULTS AND DISCUSSION

Impact of different additives

The total organic carbon content of filter media composition is shown in (Table 3). The particle size distribution of three different soil compositions is shown in (Figure 2). The lower soil media layer of TD5 set with 5% durian peel (SD) consisted of higher percentage of finer particles compared with 5% coconut husk (SC) and 10% compost (10CP) layers. As a result, it is considered well grader media, compared with coconut and compost. Furthermore, the total organic carbon content of durian peel is slightly lower compared with coconut husk.

Nitrogen species removal

The mean outflow concentrations and removal efficiencies of TN, NH_3-N, NO_3-N, and ON pollutants for all treatment columns (TC5 and TD5) were summarized in Tables 4 and 5. Mean outflow concentrations and removal efficiencies of all pollutants in each series with column numbers were

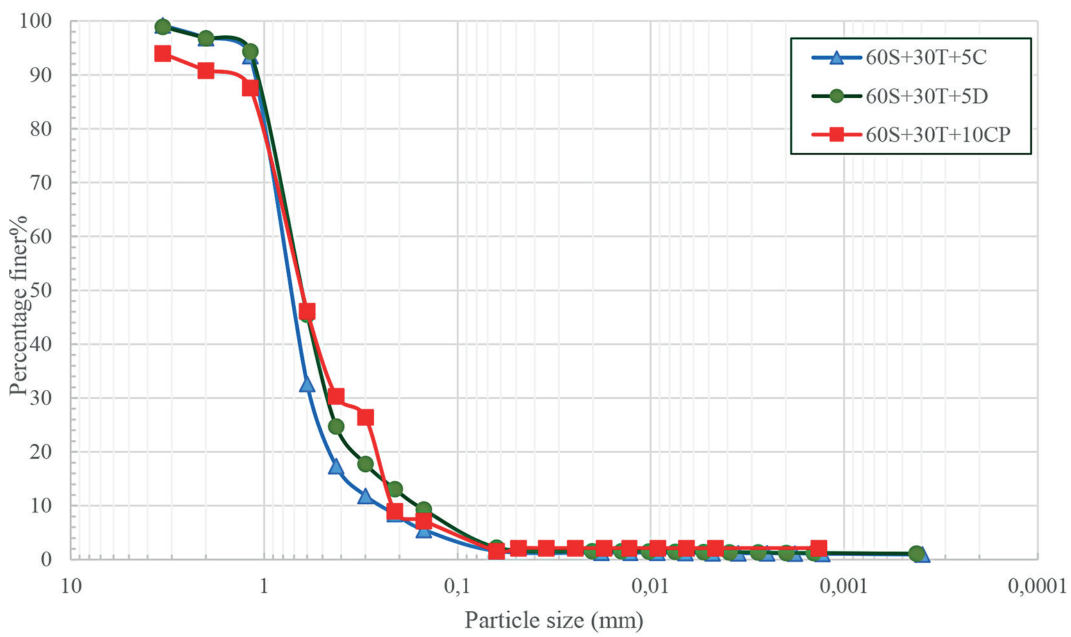

Figure 2. Particle size distribution of filter media composition

plotted in (Figure 3). The first column (C1) in two series (TC5 and TD5) significantly reduced TN, NH_3-N, NO_3-N except ON.

Regarding TN removal, a statistically significant decrease in outflow concentration was observed in C2 ($p \leq 0.05$) of two series (TC5 and TD5) (Figure 3). The TN removal in TC5 was slightly increased and fluctuated with time especially in C3 (from C2 to C3). In comparison, the mean outflow concentration in TD5 kept decreasing with time and number of column. However, C3 outflow reduction was not significantly efficient, similarly to C1 and C2 in two series ($p \geq 0.05$). The TN removal efficiency of C1 in TC5 and TD5 was (51% and 64%), respectively. In turn, the overall removal efficiency of TC5 was 69%, compared with 86% in TD5 for the overall event period. Further, there were no significant differences between the outflow concentrations of TC5 and TD5 ($p \geq 0.05$). The decrease in outflow concentration was negatively correlated with increasing column number (Table 6, r = -0.59, and r = -89), for TC5 and TD5, respectively. This finding agreed with the statement that the TN removal is better in the deeper layers of the filter media than in the surface layers. The results of TN in TD5 is consistent with the previous study [Wan, Li, and Shi 2017], This could also be due to the contribution of plant roots, since applying multi-plant species with different root structures could contribute to greater pollutant uptake [Abbasi et al. 2019], which is anticipated in the depth where roots are mostly in higher density and reproduced [Huong et al. 2020; Muerdter, Smith, and Davis 2020]. However, the efficiency of columns decrease with increasing column number in the series and this finding supports the approach of (irreducible concentration) in which the filter media cannot capture more nutrients.

The outflow concentration of NH_3-N in all columns for two series keeps decreasing with time and column number (Figure 3). Moreover, a significant decrease in C2 and C3 ($p \leq 0.05$) was observed for TC5. The series TD5 was effectively removed NH_3-N in C1, and no significant differences were observed in C2 (from C1 to C2). Although a significant reduction was observed in C3, this contributed to ammonia being removed in C1. The removal efficiency for C1 in TC5 was 76% compared with 85% in TD5. During the monitoring period, the overall reduction in two series ranged from 95% to 97% in TD5 and TC5, respectively. Moreover, no significant differences in the outflow concentration between TC5 and TD5 ($p \geq 0.05$) were detected. The NH_3-N removal increased with filter media depth and column number, the concentration in TD5 reached the irreducible concentration earlier than TC5 (Table 6, r=-0.87, and r=-0.69), respectively. In general, NH_3-N is mainly captured by soil media, plant roots uptake assimilation, nitrification [Abbasi et al. 2019; Li et al. 2019].

The mean outflow concentration of NO_3-N for TC5 was slightly higher than TD5 (Figure 3). The removal efficiency of TC5 and TD5 in C1 was 51.3% and 70%, respectively. This could be attributed to the particle size distribution of the lower layer for TD5 (Figure 2) which contains a greater portion of finer particles and a suitable amount of carbon source. This result is consistent with the finding that a lower permeability layer at the bottom of bioretention column could provide denitrification conditions with carbon source though absent of saturated zone [Wan et al. 2017]. This condition increases the surface area of carbon source that is available for bacteria, increasing denitrification as a result [Peterson, Igielski, and Davis 2015]. The overall two series exhibited a moderate decrease in outflow concentrations which contributed to 65% and 68% of influent in TC5 and TD5, respectively. Moreover, no obvious effect of column number on nitrate removal of TD5 was noted, since nitrate was mainly removed by the first column (Table 6, r = 0.32), while in TC5, nitrate removal correlated with column number (Table 6, r = -0.85). A significant difference in outflow concentrations between TC5 and TD5 ($p \leq 0.05$) was observed. The moderate removal suggests that the influent concentration of NO_3-N was not high enough to make a difference, and it was very close to the irreducible concentration of filter media [Hathaway and Hunt 2010]. The general presence of plant and carbon sources in filter media could enhance denitrification in both systems [Lopez-Ponnada et al. 2020].

Regarding ON, large leaching was observed in C1 for TC5 and TD5 (Figure 3). In TC5, the leaching of C1 enhanced in C2; however, exporting ON was observed in C3. In TD5 the outflow concentration decreased in C2 and C3 (Figure 3). However, the outflow concentration of C2 (from C1 to C2) revealed statistically significant improvements ($p \leq 0.01$). The removal efficiency of C1 was (-58% and -36%) in TC5 and TD5, respectively. However, the overall efficiency was

-43% and 78% in TC5 and TD5, respectively. However, no significant differences between the overall outflow concentration of the two series ($p \geq 0.05$) were noted. Outflow concentration is negatively correlated with increasing column number (Table 6, r = -0.08, and r = -0.89), for TC5 and TD5, respectively. The leaching in TC5 is attributed to the presence of amendment materials in filter media (coconut husk) which contains higher total organic carbon than durian peel (Table 3); this could contribute to a negative effect on ON removal. Organic nitrogen could be removed by the mineralization process; it is a biological mechanism in which the complex forms of organic N break down to inorganic N. It is often a slow process; as a result, the assimilation process needs a long time. Under certain conditions the outflow concentration of ON increased, its removal fluctuated, and it is dependent on the system design and operational parameters, as well as filter media composition.

Phosphorus species removal

Tables 4 and 5 show the mean outflow concentrations and removal efficiencies of the TP and PO4 bioretention series (TC5 and TD5), respectively. TP and PO_4 of C1 in TC5 and TD5 were significantly reduced. The mean outflow concentrations for TP in TC5 were slightly lower than TD5 (Figure 3). No significant reduction in outflow concentrations has been exhibited in C2 and C3 ($p \geq 0.05$). Conversely, in TD5, a significant difference was observed in the outflow concentrations of C1 and C2 ($p \leq 0.05$). However, TP removal efficiency of C1 in TC5 and TD5 was 83% and 77%, respectively, while the overall removal efficiency for the two sets was 84% and 81%, respectively. However, there were no significant differences between the outflow concentration of TC5 and TD5 ($p \geq 0.05$). The removal was not strongly correlated with column number in two series (Table 6, r = -0.05, and r = -0.31), for TC5

Table 4. Mean treated effluent concentrations of individual columns

Pollutants	TN		NH_3-N		NO_3-N		ON		TP		PO_4	
Series	TC5	TD5	TC5	TD5	TC5	TD5	TC5	TD5	TC5	TD5	TC5	TD5
C1	7.31	5.36	2.19	1.39	1.77	1.08	3.35	2.89	1.88	2.59	0.11	0.12
C2	4.24	3.07	0.73	1.24	1.50	1.17	2.02	0.66	1.82	1.49	0.06	0.08
C3	4.51	2.14	0.23	0.49	1.26	1.18	3.02	0.47	1.85	2.14	0.08	0.07
Average	5.36	3.52	1.05	1.04	1.51	1.14	2.80	1.34	1.85	2.07	0.08	0.09

Table 5. Mean removal efficiencies of individual columns and overall bioretention series, bold letter is significant differences

Pollutants	TN		NH_3-N		NO_3-N		ON		TP		PO_4	
Series and	TC5	TD5	TC5	TD5	TC5	TD5	TC5	TD5	TC5	TD5	TC5	TD5
Inf to C1 (CR1)	**51**	**64**	**76**	**85**	**51**	**70**	-58	-36	**83**	**77**	**97**	**97**
C1 to C2(CR2)	**42**	**43**	**67**	11	15	-8	40	**77**	3	**43**	**42**	29
C2 to C3(CR3)	-6	30	**68**	**60**	16	-1	-49	29	-2	-44	-26	22
OR	69	86	97	95	65	67	-42	78	84	81	98	98

Bold numbers represent a statistically significant differences

Table 6. Statistical analysis of outflow concentration in bioretention series

Pollutant	TC			TD5		
	R-sq.	R- Equation	r	R-sq.	R- Equation	r
TN	0.5	$1.667 C^2 – 8.067C + 13.71$	-0.58	0.84	$0.6833C^2 – 4.339 C + 9.011$	-0.89
NH_3-N	0.81	$0.4861 C^2 – 2.926 C + 4.633$	-0.87	0.56	$0.917 + 0.776 C – 0.3061 C^2$	-0.69
NO_3-N	0.72	$2.067 – 0.1444 C - 0.0333 C^2$	-0.85	0.13	$0.9111 + 0.2056 C – 0.0389 C^2$	0.32
ON	0.12	$7.022 – 4.841 C + 1.169 C^2$	-0.08	0.91	$7.183 – 5.321 C + 1.028 C^2$	-0.89
TP	0.11	$2.042 – 0.2083 C + 0.0483 C^2$	-0.05	0.58	$5.464 – 3.753 C + 0.8817 C^2$	-0.31
PO_4	0.73	$0.2200 – 0.1417 C + 0.03167 C^2$	-0.54	0.51	$0.1689 – 0.05778C + 0.00778 C^2$	-0.71

C represents the column number of bioretention series

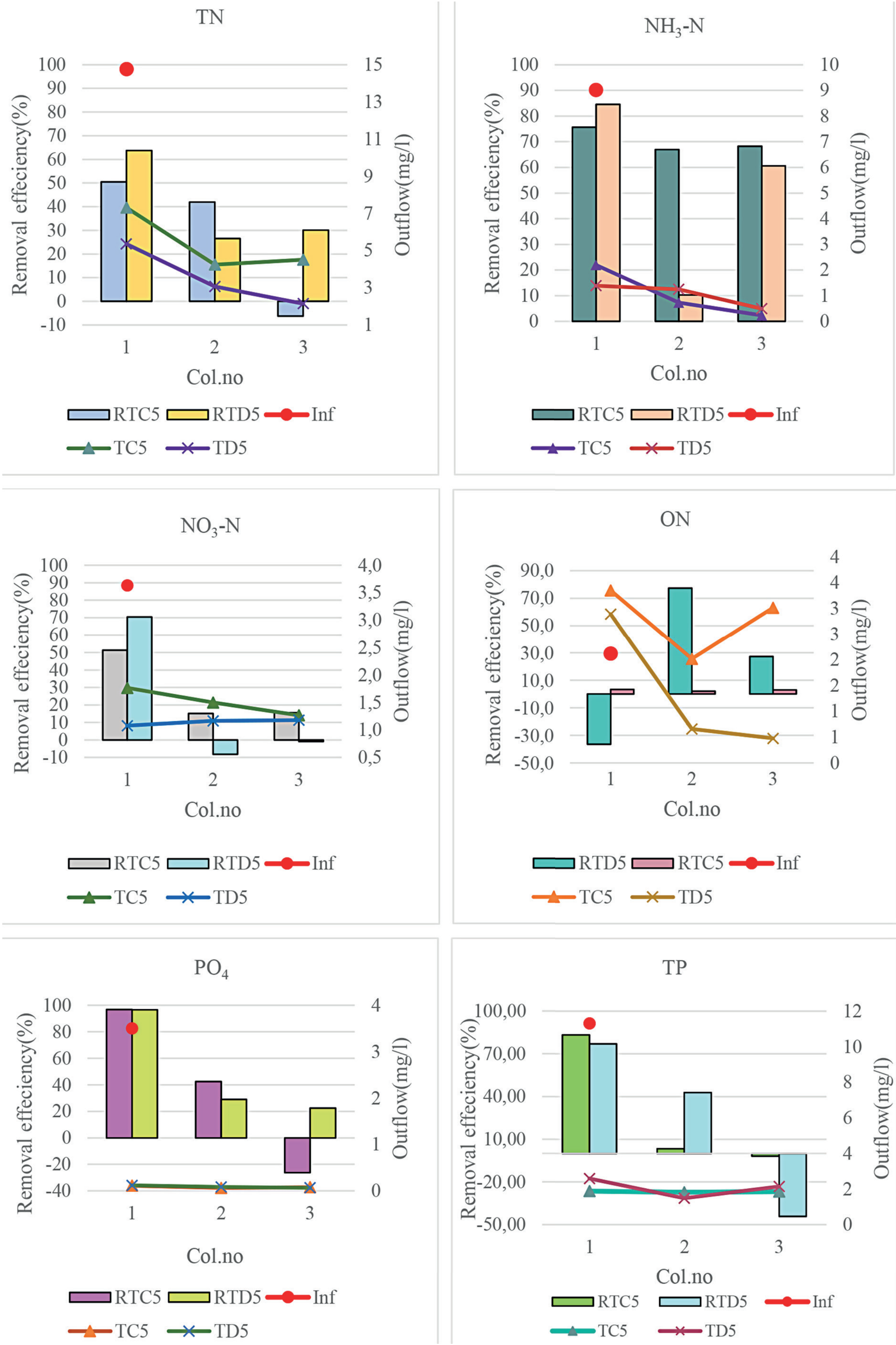

Figure 3. Mean outflow concentrations and removal efficiencies in TC5 and TD5 series; RTC5 and RTD5 represent removal efficiency of TC5, and TD5, respectively, TC5 and TD5 represent the outflow concentration of TC5 and TD5

and TD5, respectively. TP is removed by sedimentation and filtration process via filter media particles [Marvin, Passeport, and Drake 2020]. The two series showed similar performance in capturing PO_4 (Figure 3). Significant outflow reduction was observed in C2 of TC5 ($p \leq 0.05$) since this set reached the irreducible concentration before TD5. TD5 was moderately correlated with column number, (Table 6, r = -0.71), while TC5 was poorly correlated (Table 6, r = -0.54). In general, the removal efficiency of C1 was 97% for the two series, while the overall removal was 98% in each of TC5 and TD5. The removal efficiency of the two series was almost the same, since the two amendments materials were excellent performing in phosphate removal.

CONCLUSIONS

In this study, conventional bioretention systems were enhanced using two different amendment materials (durian peel and coconut husk) in the lower filter media layer and installing bioretention columns in subsequent series in two sets. The removal effectiveness declined with increasing column number, indicating that the capacity of filter media reached is the lower concentration (irreducible concentration) at which no further removal can be achieved. In general, TD5 reached the irreducible concentration before TC5 and had much lower outflow concentrations, especially in nitrogen (TN, NH_3-N, NO_3-N, and ON) except in TP, which were slightly higher than TC5. It was observed that the mean outflow concentration of (TN, ON, TP, PO_4) in TC5 was slightly increased and fluctuated with time, especially in C3 (from C2 to C3). In comparison, the mean outflow concentration in the TD5 series kept decreasing with time and column number. The lower N species concentrations in the durian amendment series (TD5) have been most likely due to provide of saturated conditions, in the lower portion of filter media which facilitated denitrification. Applying bioretention series (at least two columns) could enhance stormwater quality under free-flow conditions as well as if the influent concentrations are much higher than the irreducible concentration of used media. The effectiveness of bioretention decreases in the last column (C3) and did not affect phosphorus removal, since phosphorus is captured by filter particles and the influent concentration for this column is very low. However, applying bioretention series is more efficient on nitrogen removal, although some leaching is observed in TC5 (outflow C2 lower than outflow C3), especially in TN and ON. In general, although the effectiveness is not significant between all columns, especially C3, and for continuity removing nutrients, it is necessary to arrange the bioretention columns in series; this could provide greater nutrient removal if the effectiveness of the C1 and C2 is reduced over time. Applying bioretention series is necessary in some cases to ensure achieving outflow concentration close to the target of good water quality. Applying durian peel in the lower layer of bioretention series showed a higher degree of stability of nutrient removal than coconut husk. To avoid cost and labor wasting, more investigations should be undertaken on lab size treatment train for testing different rainfall intensities and concentrations on the performance of bioretention series, as well as long-term scenarios.

Acknowledgments

This research was funded by the Fundamental Research Grant Scheme (FRGS) under the Ministry of Higher Education Malaysia reference code FRGS/1/2019/TK01/UTP/03/2, and Yayasan Universiti Teknologi PETRONAS (YUTP) cost centre 015LC0-151.

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