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Development and performance assessment of an integrated vermifiltration based treatment system for the treatment of feedlot runoff

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ABSTRACT

The objective of this study was to treat feedlot runoff by developing an ecologically sustainable, affordable, and resilient treatment system having a relatively long life span. Three horizontal flow soil biofilters were utilized in this study: 1) without earthworms and plants (Biofilter (BF)), 2) with earthworms only (Vermifilter (VF)), and 3) with earthworms and plants (Macrophyte Assisted Vermifilter (MAVF)). The experiments were conducted with a hydraulic retention time of four days using *Lumbricus terestrris* earthworms and *Carex frankii* wetland plants. The average COD removal from the BF, VF, and MAVF were 23.2–30.4%, 61.4–69.1%, and 68.3–78.1%, respectively. Average TN removal efficiencies for BF, VF, and MAVF were 15.5–21.4%, 34.4–38.8%, and 39.1–44.0%, respectively. Additionally, average TP removals for BF, VF, and MAVF were 31.9–40.8%, 48.0–54.0%, and 51.1–58.3%, respectively. Comparison of results with literature indicate that the developed system can facilitate more nitrogen removal. Plant roots, along with earthworms, create an aerobic ecosystem within the treatment filter, leading to high organics oxidation and nitrification efficiency among BF, VF, and MAVF. Observational analysis indicates the system with earthworms is prone to clogging while the system with earthworms and plants was less prone to clogging. Thus, it can be concluded that if modularized, the application of MAVF systems can treat feedlot runoffs with higher removal efficiency and expanded life span.

1. Introduction

With the rise in income and more people opting for meat-based diets, more confined operations for beef cattle and other animals are becoming the new norm. The United States Department of Agriculture (USDA) estimates that, in January 2020, the total number of cattle being raised in the USA has increased to 14.7 million head, after an increase of two percent against the number of cattle being raised in January 2019 (Johansson and Parsons, 2020). The report further states that the number of animals in feedlots with a minimum capacity of 1000 heads have also gone slightly higher from the previous year's estimate. The sheltered cattle produce manure, which mixes with the drainage from the feedlots in holding ponds (Sun et al., 2017). The runoff from the feedlots is reported to have a high concentration of organics, nutrients, solids, and trace concentration of antibiotics (Othman et al., 2013). However, organics and nutrients are among major concerns as it may impact the ecosystems if directly discharged to the surface water bodies.

The treatment of feedlot runoff is much needed. The conventional treatment of feedlot runoff has majorly been done by a variety of methods including anaerobic lagoons (Huang et al., 2019; Sun et al., 2017), sequencing batch reactor (Othman et al., 2013), vegetated treatment system (VTS) (Durso et al., 2016), among others. However, most of these systems need high retention time (varying between 10 days and 25 days), frequent cleaning due to

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Abbreviations

BF	Biofilter
VF	Vermifilter
COD	Chemical oxygen demand
TN	Total nitrogen
TP	Total phosphorous
VTS	Vegetated treatment system
HLR	Hydraulic loading rate
HRT	Hydraulic rentention time
DO	Dissolved oxygen
HL	Head loss
HC	Hydraulic conductivity
PO_4^{3-}P	Phosphate phosphorus
NH_4^+-N	Ammonium N

the deposition of sludge in lagoon bed and mechanical aeration, and require significant energy (Tchobanoglous et al., 2003). The inefficiency of these systems in providing high nutrient removal is another major limitation (Tchobanoglous et al., 2003). VTS is a cost-effective alternative and requires minimal energy, but it becomes less effective when soils are saturated from runoff or high groundwater levels (Durso et al., 2016).

Consequently, there is a need for an effective alternative treatment that is not only economically feasible and also environmentally sound. Vermifiltration is a promising methodology, which is natural, sustainable, and can offer treatment with significantly lower retention time (Singh et al., 2019a,b,c,d). Vermifiltration works on the symbiotic relationship between earthworms and microbes residing within the vermifiltration system (Singh et al., 2018a,b). Despite fulfilling all requirements, the absence of denitrification and biological phosphorus removal is limiting from its application at a broader scale (Singh et al., 2017). For instance, Kumar et al. (2016) have stated that after vermifiltration in their study, total phosphorus (TP) concentration was observed to be increased to 34.5 ± 3.3 mg/L, which is ~50 fold to an influent concentration of 8.1 ± 3.3 mg/L. Similarly, Arora et al. (2016) have also observed an increase in the concentration of TP, owing to the enzymatic and microbial actions of earthworms. Similar results were found elsewhere (Kumar et al., 2014, 2015; Rajpal et al., 2014). In another instance, Singh et al. (2019a) have conducted a study using horizontal subsurface flow vermifilter and obtained average TN removals to a maximum of 21–22%, only. Yang et al. (2009) have reported an average ammonia removal of 22.6% during winters. The bypassing of this nutrient-rich vermifiltered effluent (mainly composed of nitrate and phosphate) to the aquatic ecosystem may further cause algal blooms and enhance toxicity to the aquatic living species. Considering the affordability of vermifiltration in rural contexts, improvement in the vermifilter's nutrient removal efficiency seems like a wise choice than looking out for another system.

Previously, incorporation of macrophytes (Chen et al., 2016; Tomar and Suthar, 2011; Wang et al., 2010b) and integration of a column made of adsorbents (Singh et al., 2019a,b,c; Wang et al., 2009) have been done to enhance the nutrient removal from vermifiltration. However, incorporation of the strategies mentioned above, along with design changes for achieving an even higher nutrient removal from wastewater, has never been tried. Notably, so far, change in the design of vermifiltration targeting higher removal has rarely been attempted (Singh et al., 2019a). Therefore, the necessity to develop an integrated system and assessment of its performance can not be ignored. Besides, to date, no efforts have been given towards understanding the impact of the incorporation of macrophytes on the lifespan of vermifilters. An understanding of the clogging of vermifiltration after the incorporation of plants may enhance its applicability at the field scale.

Hence, the primary objective of the current study was to maximize the removal of nutrients along with organics from the vermifiltration of feedlot runoff. The specific objectives of this study include: a) develop and assess the performance of an integrated system targeting higher removal from feedlot runoff, b) to analyse the impact of earthworms and plants on the performance and clogging of soil biofilter and c) to track the growth of the earthworms and plants incorporated to the filters.

2. Material and methods

2.1. Wastewater

The feedlot runoff was collected from a 6000-animal capacity, open-air cattle feedlot at the USDA Meat Animal Research Center, Clay Center, Nebraska. A detailed discussion of the facility can be found elsewhere (Parker et al., 1999; Zhang et al., 2013). The collected wastewater was a mix of different feedlot components, including feeding system, watering system, cattle handling system, manure-handling system, and drainage system. The runoffs from these components were drained to holding ponds until it can be applied to crop fields as irrigation. The wastewater was collected from the holding ponds on two collection events (dated: 15th July and 17th August 2019). The collected wastewater was stored at 4 °C until use.

2.2. Filter design

The treatment system used in this study had three components: 1) influent supplying system, 2) filter, and 3) effluent collection system (Fig. 1a). Feedlot runoff was supplied to the filters using Mariotte bottles with a capacity of 18 L to minimize variation in the applied flow rate. The three identical plexiglass filters, having dimensions 100 cm as length, 20 cm as width, and 40 cm as depth, was placed at a slope of 1% (Fig. 1b). The dimensions of the bedding were chosen for the prevalence of horizontal flow within the bedding and to achieve the desired hydraulic retention time (HRT). Baffles made of plexiglass (20 cm in width) were uniformly spaced (after every 10 cm) to create vertical serpentine flow along its length (Fig. 1a&c). The bedding of the filters was composed of two 10 cm layers of garden soil (Home Depot, Kellog brand) and coarse fly ash (Nebraska Ash, Fremont, Nebraska) as top and bottom layers, respectively. The coarse fly ash is a by-product of the coal-fired electricity generating power plants, which is generally being used as a filler material or road aggregate. The top layer made of the garden soil was rich in compost and wood chips (organic content: 18%), which was added to help earthworms acclimatize and be available as a substrate for the initial few days (Singh et al., 2019d). The fly ash layer was maintained in a saturated/submerged state by the placement of an outlet to develop anoxic conditions. The effluent collection tanks receive the effluent from the outlets placed 10 cm above the bottom of the filter, causing submergence of the lower layer of the bedding.

The three identical filters were identified as biofilter (BF), vermifilter (VF) and macrophyte assisted vermifilters (MAVF). The BF was devoid of earthworms and plants, while the VF or MAVF contained earthworms or a combination of earthworms and plants, respectively. The plants incorporated into the MAVF bedding were *Carex frankii*, which was selected for its rapid growth, local availability, and tolerance to survive prolonged waterlogging (Ahn and Dee, 2011). Twenty plants were planted, at equal spacing, in two

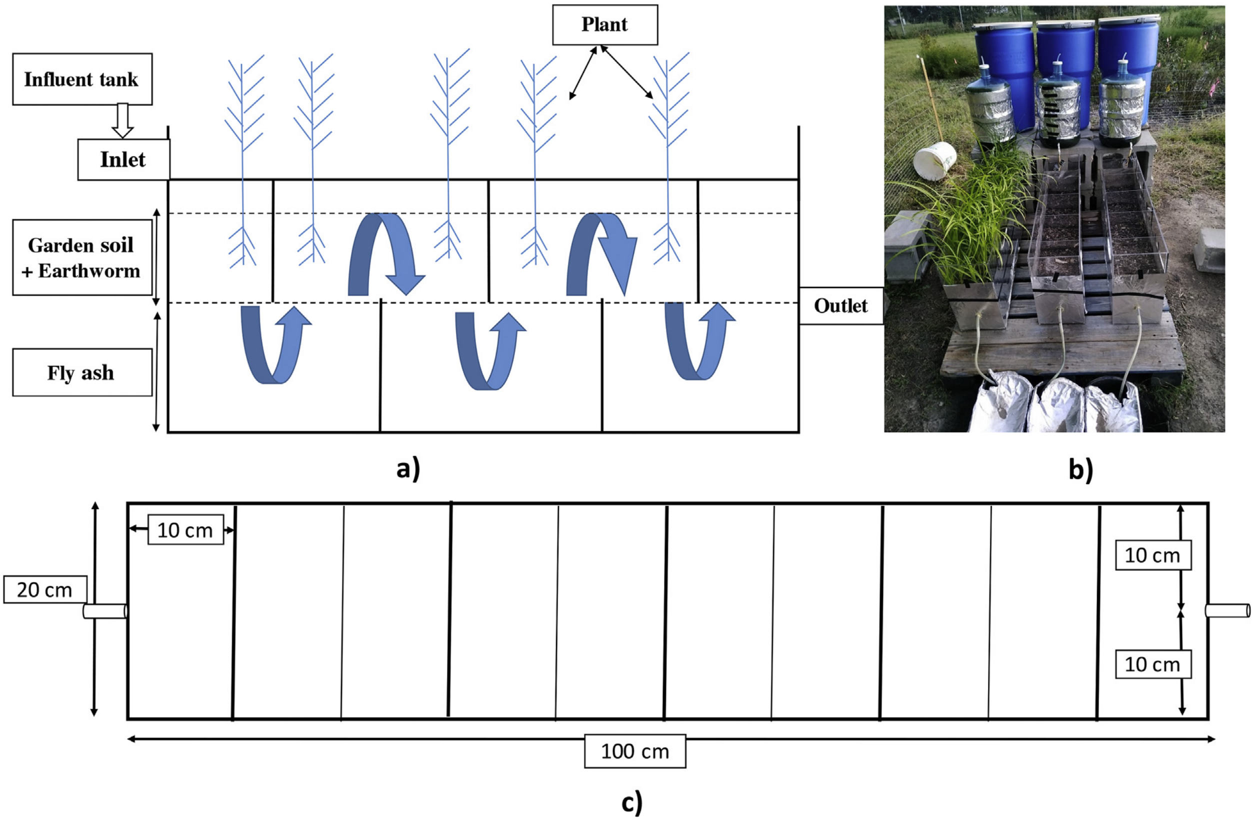

Fig. 1. Experimental setup used in this study **a)** side view schematic **b)** actual and c) top view schematic.

rows. The earthworm species used in the VF and MAVF was *Lumbricus terestrris,* which is locally available and can sustain low temperatures up to 4 °C (Crockett et al., 2001). The rate of earthworm inoculation was 10000 adult earthworms/m^3 of the active layer of vermibed (Kumar et al., 2014).

2.3. Operation of filters

The study was conducted between July 10 and September 28. The filters were placed outside to be exposed to typical climate variability for that time of year. During the acclimation phase (seven days), 2 L of tap water was sprinkled on the filter twice a day to provide moisture for microbial growth and acclimatize the earthworms (Singh et al., 2019a). After the acclimation phase, feedlot wastewater was gravity fed at the rate of 10 L/day, till the end of the experiment. The theoretical HRT was four days, resulting in a calculated hydraulic loading rate (HLR) of 0.5 m^3/m^2-day.

2.4. Analysis

The influent and effluent samples obtained from the filters were determined for chemical oxygen demand (COD), total nitrogen (TN), total phosphorus (TP), phosphate phosphorus (PO_4^{3-}-P), ammonium N (NH_4^+-N), after every four days (APHA, 2005). Dissolved oxygen (DO) and pH were measured using probes. The removal rates were calculated and the average removal rates were determined after achieving steady-state of COD removal (variation between two consecutive COD removal$\leq$5%). The biomass growth in earthworm and plant biomass was analyzed before the addition of influent and after the study was completed. The plant biomass was determined by tracking the growth and onset of new plant stems within the filter. For assessment of the impact of earthworms and plants on clogging, hydraulic conductivity (HC), and head loss (HL) of the filter was determined, according to Singh et al. (2018b). In brief, the falling head hydraulic conductivity measurement method (Elhakim, 2016) was applied, and the time took in the fall of the burette water head was noted for the calculation of HC and HL.

3. Results and discussion

3.1. Physicochemical performance

3.1.1. Dissolved oxygen (DO) and pH

After day eight, the average effluents from all the filters had 3.29 ± 0.12 mg/L lower DO than the average initial influent (Fig. 2a). The average effluent DO from the BF, VF and MAVF were 2.66 ± 0.17 mg/L, 1.89 ± 0.12 mg/L, and 1.70 ± 0.12 mg/L, respectively. The fall in DO could majorly be attributed to the utilization of influent DO for the oxidation of the organics present in the vermibed and influent. While, the observed variations in average effluent DO could be due to the higher utilization of DO in the VF and MAVF, caused by the presence of highly populated and diversified microbial communities. These microbes and enzymes are present in the gut due to earthworms (Arora et al., 2014) and plant root rhizosphere (Samal et al., 2017; Singh et al., 2019d), enhancing soil microbial communities through documented symbiotic relationships. However, in some literature, the DO of filters with earthworms and plants were found to be higher than the filters devoid of earthworms and plants (Arora and Kazmi, 2015; Samal et al., 2017; Wang et al., 2011b), which is attributed to the aeration by plants and earthworms. After the eight-day acclimation period, the effluent DO from BF, VF, and MAVF continued to decrease till 24–28 days of operation, suggesting a gradual increase in the number of microbial colonies due to earthworms and plant

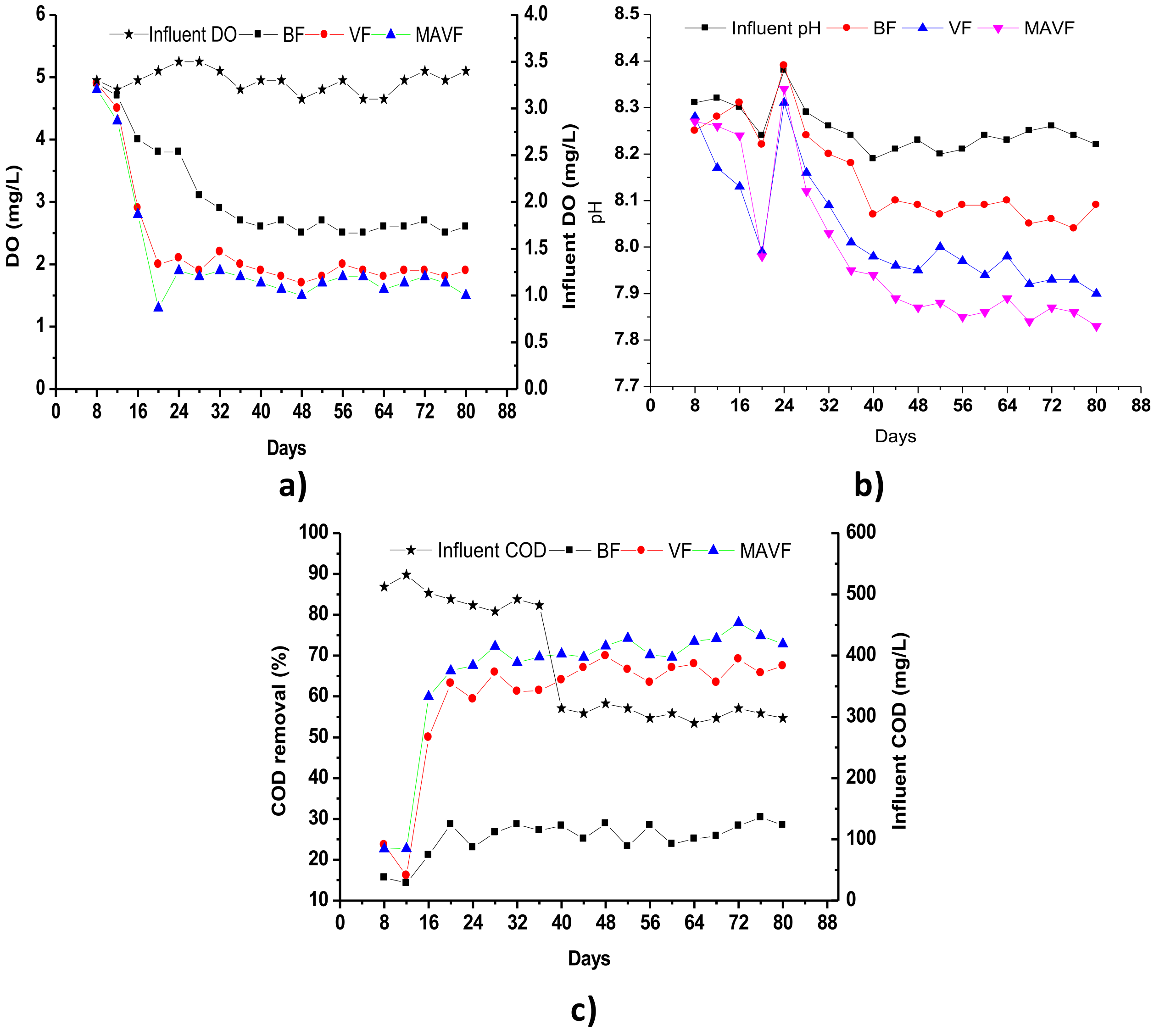

Fig. 2. Impact of plants and earthworms on **a)** DO, **b)** pH and **c)** COD removal.

activities (Jiang et al., 2016; Samal et al., 2017; Singh et al., 2019d). The gradual replacement of the air trapped in the bedding and reduction in the rate of air mixing with the upper surface of bedding, caused by saturation of bedding (Nivala et al., 2012), may also have accounted for in the above-mentioned decrease in DO. However, this study does not focus on the presence of DO in the different length of the filters.

Effluent pH varied between a narrow range of 7.8–8.3, while the influent pH ranged between 8.21 and 8.31, which could be attributed to the aerobic degradation of organics, ultimately generating carbonic acid. Similar changes in pH had also been observed by Hu et al. (2019) and Singh et al. (2018b). However, it could be concluded from Fig. 2b that the effluent pH from the VF and MAVF is lower than the BF, which could be due to the mixing of earthworm's crop secreted calcium with bedding materials, acting as buffering medium (Jiang et al., 2016).

3.1.2. Chemical oxygen demand (COD) removal

After achieving steady-state, COD removal from the BF, VF, and MAVF ranged between 25 and 35%, 60–70%, and 68–78%, respectively (Fig. 2c). The removal efficiencies appear to be unaffected by the changes in influent COD values. The increase in COD removal efficiencies of the VF and MAVF, comparative to the BF, became very apparent after approximately 12 days (Fig. 2c). The COD removal efficiencies for both the VF and MAVF improved to greater than 60% until the end of the study, while for the BF at or below 30% for the entire study. The improved efficiencies of the VF and MAVF are likely to be attributed to the increase in microbial biomass due to plant and earthworms activities. Similar observations were reported by other researchers (Samal et al., 2017; Singh et al., 2018a,b; Tomar and Suthar, 2011). The literature further suggests that the newly added gut microbes work in symbiosis with the indigenous microbes present in the garden soil (Jiang et al., 2016) and the root exudates from the plants present in MAVF further intensify the microbial activities by supporting their growth (Samal et al., 2017; Singh et al., 2019d). The increased aeration is also documented to assist in further enrichment of the microbial population (Arora et al., 2014). Furthermore, the average rate of COD removal from MAVF was observed to be comparatively better than the average COD removal obtained from VF. The difference could be attributed to the additional mechanisms/activities exerted by plant root exudates, enriching bacterial colonies (Lin et al., 2002; Samal et al., 2017; Singh et al., 2019d). Another important observation is that the removals from all three filters were initially low, which gradually increases with time. During the beginning of the study, COD removal from BF was approximately 15%, which increased to approximately 30% on the final day of operation. Similarly, over 72 days, COD removal from VF also increased from an initial of 17% to a final of 69%, while COD removal from MAVF was seen to increase from an initial COD removal of 23% to a final of 78%. The increase in COD removal is due to the gradual increase in the number of microbial colonies and leaching of organics from bedding material. The increase in the bacterial colonies due to the earthworms and plants has already been confirmed by several researchers (Adugna et al., 2019; Samal et al., 2017; Wang et al., 2011a).

3.1.3. *Nitrogen removal*

The feedlot runoff used in this study contained a high concentration of total nitrogen (214.0 ± 60.7 mg/L) and ammonium N (42.2 ± 18.3 mg/L). Average TN removals from BF, VF, and MAVF were obtained as 17.8%, 36.3%, and 42%, respectively. While, after achieving steady-state, the average ammonium N removal/conversion from BF, VF, and MAVF were found to be 60.8%, 76.6%, and 82.5%, respectively (Fig. 3b). The observed TN removal rates from the filters suggest the occurrence of denitrification, which could be attributed to the passing of wastewater through a series of aerobic and anoxic layers, facilitated by the baffle guided flow. ammonium N conversion could be attributed to the enhanced nitrification (Kumar et al., 2015; Samal et al., 2017; Tomar and Suthar, 2011; Xing et al., 2010) and adsorption of ammonia to the bedding (Li et al., 2014; Vymazal, 2007). Besides, the average removal of TN and ammonium N conversion in the VF was comparatively higher than the BF (Fig. 3a), which could be attributed to the intense microbial activities caused by the incorporation of earthworms (Kumar et al., 2014; Samal et al., 2017; Singh et al., 2019d; Tomar and Suthar, 2011). The highest average TN removal and ammonium N conversion from MAVF could be attributed to plant uptake of nitrogen and intense nitrification, driven by aerobic activities caused due to secretion of root exudates (Li et al., 2014; Vymazal, 2007), root aeration and expansion (Bezbaruah and Zhang, 2005; Samal et al., 2017; Tomar and Suthar, 2011). Observance of highest TN removal and ammonium N conversion from MAVF agrees with the results obtained in other studies (Li et al., 2011; Wu et al., 2013). It should also be noted that during the initial 20–28 days of operation, TN removal, and ammonium N conversion percentages from VF and MAVF gradually increased while the percentages from BF decreased (Fig. 3a&b). It could be correlated with the acclimatisation of earthworms and the growth of plants and microbial population, due to the synergistic activities of microbes from the earthworm gut and root exudates (Samal et al., 2017). The low removal rates from VF and MAVF in the initial weeks could also be attributed to the leaching/release of ammonium N from bedding material, caused by intense earthworm activities (Jiang et al., 2016).

3.1.4. *Phosphorous removal*

The TP and orthophosphate removal from all three filters were found to range between 35 and 60%, against the average influent TP, and orthophosphate concentrations of 167.6 ± 49.7 mg/L and 90.0 ± 80.2 mg/L, respectively. After achieving steady-state, average TP and orthophosphate phosphorous removal efficiencies from the BF were 37.2 ± 2.4% and 47.3 ± 1.5%, respectively. TP and orthophosphate removal efficiencies from the VF were 50.6 ± 1.7% and 53.9 ± 1.7%, respectively, and the difference in removal efficiencies with the BF could be attributed to the soil grinding activities of earthworms, resulting in creation of more adsorption sites within the same bedding volume (Samal et al., 2017; Singh et al., 2017). The conversion of organic phosphorous to phosphates could be attributed to the enzymatic and microbial activities induced by earthworms (Jiang et al., 2016). After the conversion of organic phosphorous to orthophosphate, the reports suggest that the removal of orthophosphate is majorly dependent on adsorption only, due to the complexities involved in the biological phosphorus removal (Jiang et al., 2016; Samal et al., 2017). A minor fraction of removal could also be due to the uptake by earthworms for their biomass growth (Samal et al., 2017). The adsorption of orthophosphate in this study is caused by both earthworm-gut grindedgrinded garden soil and coarse fly ash, incorporated as a bedding matrix. Research has shown that the calcium ions along with the charged compounds of iron and aluminum present in the fly ash reacts with phosphate and form a series of insoluble salts that precipitate (Chen et al., 2007). However, differentiation between the phosphate adsorption due to soil and coarse fly ash was not a part of this study so it could be considered as a future research scope. If compared with the available literature, observed results indicate that the newly developed system has offered better TP removal (Values are present in section 1) (Arora et al., 2016; Kumar

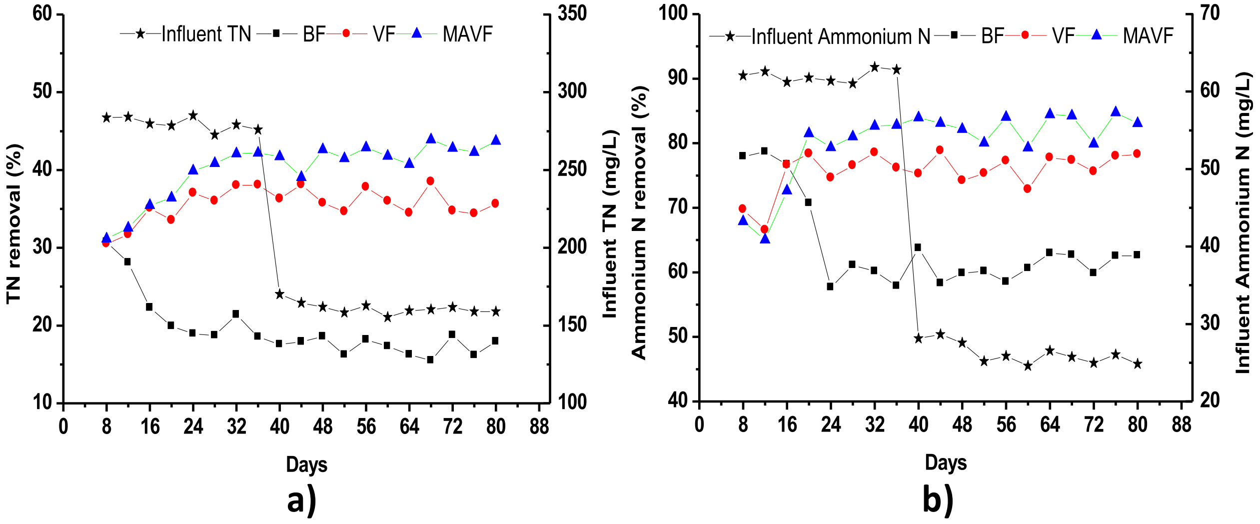

Fig. 3. Impact of earthworms and plants on **a)** TN removal and **b)** Ammonium N removal.

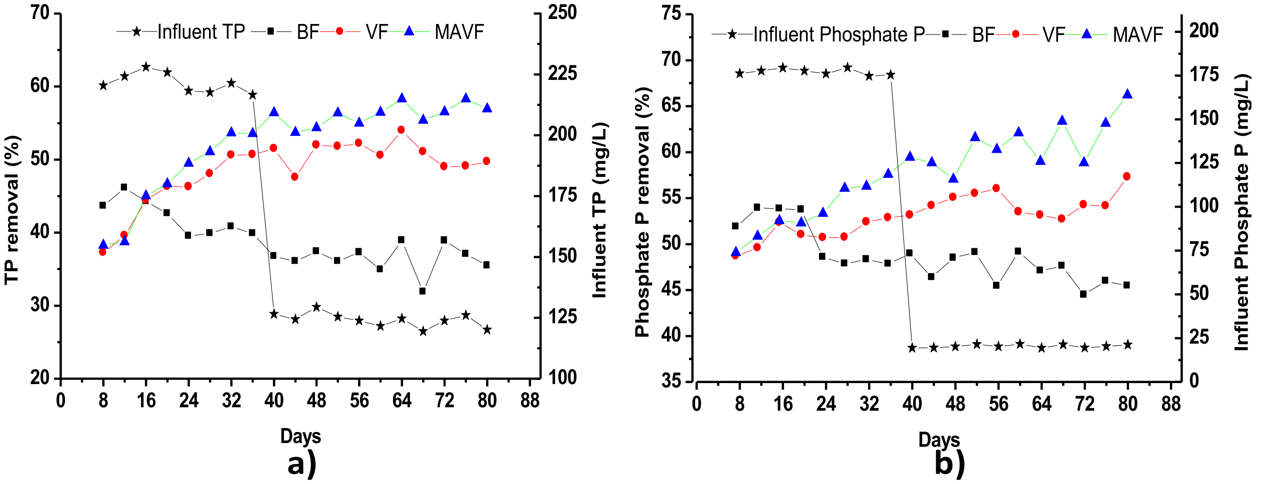

Fig. 4. Impact of earthworms and plant on **a)** TP removal and **b)** phosphate removal.

et al., 2014, 2015; Rajpal et al., 2014). Furthermore, the average removal from MAVF was even higher than the VF as average TP and orthophosphate removal from MAVF were 55.4 ± 2.0% and 60.0 ± 3.0%, respectively. These differences in removal could be due to the incorporation of plants to the vermifilter, which are reported to uptake phosphates as nutrients for their biomass growth (Chen et al., 2016; Tomar and Suthar, 2011). Apart from the above, TP removal from the BF decreased from an initial efficiency of 43.6% to the efficiency of 35.5% on the final day of analysis (Fig. 4a), while, TP removal efficiencies from VF and MAVF were seen to gradually increase till steady state when compared with the initial day (Fig. 4a). Similar results were observed for orthophosphate removal. The leaching of phosphorous contained in the bedding material, acclimatisation of earthworms, and plants, along with the increase in microbial population may have been the reason behind low removals during initial days (Arora et al., 2014).

3.2. Clogging

Fig. 5a shows that the HC of all three filters has decreased throughout the operation period. Over a period of 64 days, the HC of BF decreased from 106.7 m/day to 96.2 m/day, resulting in a total HC decrease of 10.5 m/day (Fig. 5a). During the same period, the HC reduction from VF was less than half, at 4.7 m/day. Similarly, in MAVF, HC reduction was only 4.3 m/day. Likewise, an increase of 0.97 cm, 0.41 cm, and 0.37 cm in the head loss was observed in BF, VF, and MAVF, respectively (Fig. 5b). The decrease in HC and the increase in HL values indicate some clogging had occurred. However, it was not worse, since, throughout the experimental period, no ponding was observed. It also indicates that the incorporation of earthworms or plants along with earthworms can not completely alleviate the clogging problem of soil biofilters. Similarly, in a study aimed at treating brewery wastewater by vermifiltration, Singh

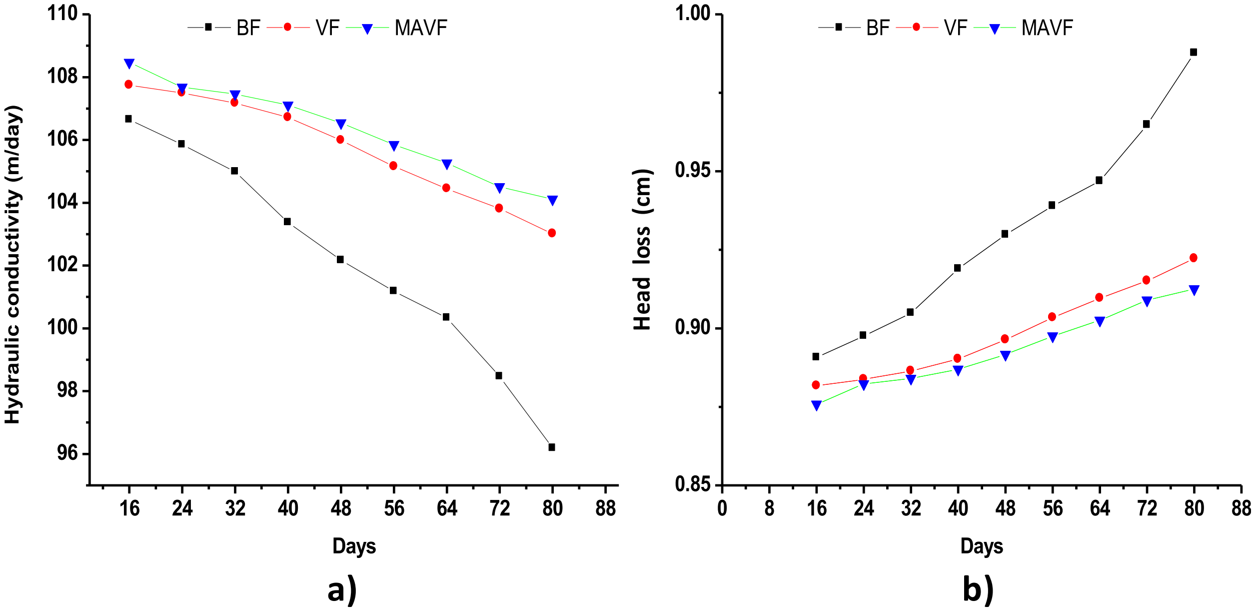

Fig. 5. Impact of earthworms and plants on **a)** hydraulic conductivity and **b)** head loss.

Table 1
Growth of inoculated earthworms and plants.

Filter	Number of earthworms		Earthworm biomass (g)		Shoot height (cm)		Number of plant stem	
	Initial	Final	Initial	Final	Initial	Final	Initial	Final
BF	–	–	–	–	–	–	–	–
VF	200	214	128.6	141.2	–	–	–	–
MAVF	200	206	128.6	130.4	12.2	61	54	183

* = number of stems present in all bunches of plants planted across the plan area of bedding.

– = not applicable to these reactors (as BF was devoid of plants and earthworms and VF was devoid of plants).

et al. (2018b) concluded that the incorporation of earthworms in soil biofilters could only delay the clogging of the filters. However, to the best of our knowledge, analysis of the combined impact of earthworms and plants has never been reported. Fig. 5a&b indicate that BF clogs early than the VF and MAVF, which could be attributed to the continuous deposition of solids from feedlot runoff over its bed surface and also within the pores (Caselles-Osorio and Garcia, 2007; Singh et al., 2019b). The deposited solids over the bed further form a biological mat over the bedding, in turn, restricting/minimizing the rate of percolation of wastewater through the filter (Nivala et al., 2012). Apart from solids, the microbes present in the filters also contribute to the occurrence of clogging (Li et al., 2011; Singh et al., 2018b). The activities of earthworms decreased the rate of clogging, due to their activities ingestion, tunneling, burrowing, and root expansion (Arora et al., 2014; Hua et al., 2014; Singh et al., 2019d; Wang et al., 2009). Increased aeration due to earthworms cause degradation of solids trapped in the pores (Li et al., 2011) and solids deposited above the surface and within the pores along with the microbial colonies restricting capillary action are devoured (Singh et al., 2018b; Wang et al., 2010a). Throughout the experimental period, MAVF was always seen to have slightly higher HC and HL than the VF, indicating that the combination of earthworms and plants can further delay the clogging of the bedding and increase the lifespan. The delay in clogging could be attributed to the growth of plant roots, developing cracks, and fissures within the bedding (Samal et al., 2017; Singh et al., 2019d). The oxidation caused by roots also helps in degrading the organic solids trapped within the bedding (Garce et al., 2016).

3.3. *Earthworm and plant biomass*

The growth in earthworm biomass and numbers are presented in Table 1 which indicates that the VF had a higher number of earthworms than the MAVF. The comparatively lower number of earthworms and biomass growth from MAVF could be attributed to the filter volume occupied by plant roots (Samal et al., 2017; Zhao et al., 2014). While dismantling the VF and MAVF, many earthworms were found in the layer made of coarse fly ash, which could be due to the limitation of the filter volume for earthworm movement.

Shoot length and number of new stems of plant *Carex frankii* grew to ~4 folds to the initial shoot length and the initial number of stems. The root length and root structure of *Carex frankii* also grew with time. The root length below bedding reached the bottom. The increase in plant biomass suggests that this choice of the plant was suitable for MAVF and it could further be applied for the treatment of feedlot runoff.

4. Conclusions and future prospects

The comparison of COD, TN, and TP removal reveals that the incorporation of plants to a VF or incorporation of plants and earthworms together to a BF improves the removal potential. Plants and earthworms together play a vital role in treating feedlot runoff fed to the system. The MAVF offers the highest average removal among the tested filter types, and the VF offers better removal performance than BF. Results of change in the hydraulic conductivity and head loss of the filters show that the incorporation of plants helps to extend the life span of the VF. However, future experiments targeting the characterization of the clogging material and extent of impact are necessary. Based on high nutrients and organic removal ability and high life span, the newly developed integrated MAVF can be recommended for the treatment of feedlot runoff. The application of the developed technology in other wastewater types along with the analysis of the nutrient removal due to the incorporation of fly ash could be considered as a future research scope.

CRediT authorship contribution statement

Rajneesh Singh: Writing - original draft, Conceptualization, Visualization, Writing - review & editing. **Matteo D'Alessio:** Writing - review & editing. **Yulie Meneses:** Writing - review & editing. **Shannon L. Bartelt-Hunt:** Writing - review & editing. **Bryan Woodbury:** Writing - review & editing. **Chittaranjan Ray:** Writing - review & editing, Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jclepro.2020.123355.

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