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Identification of an Appropriate Grass Which can be Used for Wastewater Treatment in Constructed Wetland

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Aging and poor maintenance of wastewater treatment works affect the wastewater quality and quantity. The focus of this experimental study was to identify appropriate grass which can be used for wastewater treatment in constructed wetlands. Vetiver grass (*Chrysopogon zizanioides*), Lemon grass (*Cymbopogon flexuosus*) and elephant grass (*Pennisetum purpureum*) were planted separately and exposed to influent for a period of twenty weeks. Growth measurements were recorded weekly and the quality of the effluents from each of these grasses were assessed using standard methods to determine their treatment efficiency. The study demonstrates that different grass species can be used in constructed wetlands to treat wastewater effectively. Vetiver grass showed promising results in terms of treatment efficiency, meeting WHO standards for various water quality parameters. Further research and monitoring may be needed to confirm the long-term sustainability and performance of these grasses in wastewater treatment applications.

1. Introduction

Wastewater Treatment Works (WWTW) are designed to ensure that effluent is treated and discharged into the receiving body for reuse with less detrimental effects to the environment (Li et al., 2021). WWTW receives their effluent from various sources such as residential and industrial areas and the treated effluent must be discharged to the environment with limited effects on the surrounding ecosystems (Mosolloane et al., 2019). However, most WWTW facilities in South Africa are reported to be aging, poorly maintained, malfunctioning, and often overloaded (DWS, 2022). Recent statistics shows that 77% of WWTW in South Africa are in poor condition and warranted an urgent attention (DWS, 2022).

South Africa's wastewater treatment works have been under a public scrutiny due to their inability to treat effluent efficiently (Moloi et al., 2020). The study undertaken by Moloi et al. (2020) found that there was no noticeable difference between treated and untreated effluent in the concentration of heavy metals for both WWTW which were investigated. This is because most of WWTW in South Africa could not treat effluent efficiently.

Chapter 2 of the Constitution of South Africa (SA) of 1996 states that: "Everyone has the right to have access to sufficient food and water". However, in South Africa this right has been compromised due to the deterioration of surface water quality because of failed WWTW. This is attributed to increasing anthropogenic activities resulting from population growth and over industrialisation and as result, the accumulation of waste and pollutants has increased in water bodies (Wu et al., 2017).

Several wastewater treatment technologies such as (Activated sludge system, trickling system or biological filters, Membrane Bioreactor System) are currently in operation across South Africa, however they have been proved to no longer suitable because electricity generating problems which south Africa is facing, yet these technologies are associated with high energy consumption demand for pumping, aeration and works maintenance. (Atangana et al., 2021).

Constructed wetlands which are relatively cheaper and simple to build should be explored as an alternative way of wastewater treatment technology. Constructed wetlands (CW) are defined as engineered systems compromised of controllable operational (hydrogeochemical) and functional (biological) parameters that occur in natural wetland systems (Mader et al., 2022). Constructed wetlands have been used to treat multiple inorganic

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and organic contaminants, as well as various pathogens from sources such as agricultural (Fungi), domestic (E-coli), industrial (Heavy metals), and acid mine drainage (AMD) (Sulphuric acid) waste streams.

2. Study Area

The research was undertaken at Baviaanspoort Wastewater Treatment Works which is in the City of Tshwane Metropolitan Municipality which is the Capital City of South Africa. Baviaanspoort wastewater works is located on these coordinates: 25º 41' 26" S and 28º 21' 50" E.

Figure 1. Map showing the location of the study area. (Google map., 2024)

3. Materials and Methods

The focus of this study was to identify an appropriate grass which can be used for waste wastewater treatment in a constructed wetland. The following grasses: Vetiver grass (*Chrysopogon zizanioides*), Lemon grass (*Cymbopogon flexuosus*) and elephant grass (*Pennisetum purpurreum*) were assessed for the purposes of this study. These are drought tolerant perennial grasses which are in tropical and sub-tropical regions widely neutralised. These grasses are well adapted to grow on wide range of soil types, and capable of growing in a rainfall range of 300 - 4000mm.

They are perfect in controlling soil erosion on arid lands and can also serving as a mulching material. These grasses are normally associated with ecological zones prone to recurrent annual bushfires, particularly in transitions between forest belts and the savannah ecological zones (Danquah *et al*., 2018). It is therefore based on the above-mentioned reason why these grasses were selected for this study. These grasses were collected from the Agricultural Research Council (ARC) site Project in Free State. They were planted the same day with the support of an agricultural scientist and planted that same day to prevent wilting.

Clay was the soil used for the experiment, this soil was collected from the ARC site project in the Freestate and transported to the Department of Water and Sanitation at Roodeplaat where the experiment set up was done. Slashed plastic gallons were used as a planter box to support planting materials, with six stumps of each grass planted in each container. The dimensions of the containers are given in Table 1.

Table 1: Dimensions of the containers used for plantation.

Measurements	Vetiver Grass	Lemon Grass	Elephant Grass
Length(mm)	40.5	40.5	40.5
Width(mm)	23	23	23
Depth(mm)	18	18	18

3.1 Growth measurements

The grasses were watered daily with 2L of wastewater collected from Baviaanspoort Treatment Works for period of 10 weeks. The measurements pertaining to height, number of new leaves and the surface area of the leaves were recorded on a weekly basis for the period of ten weeks of the experiment. For grass height, a 30cm graduated ruler was used. This was done by affixing the ruler to the edge of the container and the reading corresponding to the tip of the grass which is being measured. This action was done for the three grasses in a zigzag manner to ensure an equal and fair distribution, and the average reading recorded.

The new leaves were observed by eye inspection and the number of new leaves observed for each stump were counted and recorded. The surface area of the leaves was determined by tracing the most developed and vertically grown leaf of each of the respective willow mediums on a graph sheet. After this, the number of square boxes covered by the sketch of the leaf on the graph sheet was counted and multiplied by $2mm^2$ (size of small grid box), and the result multiplied by two to cater for the upper surface and lower surface of the leaf. This arithmetic calculation then gives an estimate of the surface area for each leaf.

Figure 2: Shows three different grasses on each container.

3.2 Sample collection and handling

Sample analyses were conducted at the UIS analytical Services laboratory in Centurion. The samples included both raw wastewater influent from Baviaanspoort wastewater works and the effluents from the three containers. The influent was collected in a 2-litre plastic bottle with labelling of date, time and sampling point name then transported in cold ice to enable for sample noncontaminating and effective laboratory analysis (wastewater sampling and preservation protocols). Effluent samples collected from the eleventh week were prepared by mixing soil samples from each of the three containers with distilled water. The mixture was shaken vigorously and then given 30 minutes allowance allowed for the settling of the solids. The liquid was extracted and taken for analysis. This process was repeated for the next week. Effluent sample containers were labelled as VG, LG, and EG representing Vetiver grass, Lemon grass and Elephant grass respectively.

3.3 Analytical methods

Total Dissolved Solids (TDS), pH, Biochemical Oxygen Demand (BOD), Nitrogen (N), and Phosphorus (P) were the physiochemical parameters analysed. Total Dissolved Solids (TDS) and pH were measured using their respective electronic probes, and the results were recorded as displayed on an electronic screen. BOD was determined based on the BOD_5 method while P and N concentrations were measured using standard methods (APHA, 1998).

4. Results and Discussion

Plant height: Figure 2 shows that the overall plant height for lemon grass increased from 50.1mm in week one to 65.5mm in week eight and remained that way for the rest of the weeks, an indication that the lemon grass has either attained its maximum height unless other factors were preventing its growth. Vetiver grass' height increased from 33.2mm in week one to 86mm in week eight, representing an increase of almost 53,8mm. Elephant grass increased from 20.4mm in week one to 60.0mm in week eight, which represents an increase of 39.6mm. Unlike lemon and elephant grass that stopped increasing in height at week eight and nine respectively, Vetiver grass continued to grow throughout the period of the experiment. A possible reason for this could be that lemon grass and elephant grass had reached their peak heights at week nine, but Vetiver grass, which showed to be a slow grower, continued to show some growth even in week nine and ten.

4.1 Size of new leaves

The overall Size of new leaves for lemon grass increased from 5.2mm in week one to 70.5mm in week ten, which represents an increase of 65.3mm in week ten. The overall size of new leaves for elephant grass increased from 4.0mm in week one to 70mm in week 10, representing an increase of 66mm in nine weeks. While the overall size of new leaves for Vetiver grass increased from 2.1mm in week one to 95.7mm in week 10. This therefore means that Vetiver grass proved to have high leaves growth rate as compared to the other two grasses for similar period. The comparison of the growth rate of the leaves is given by figure 3 below.

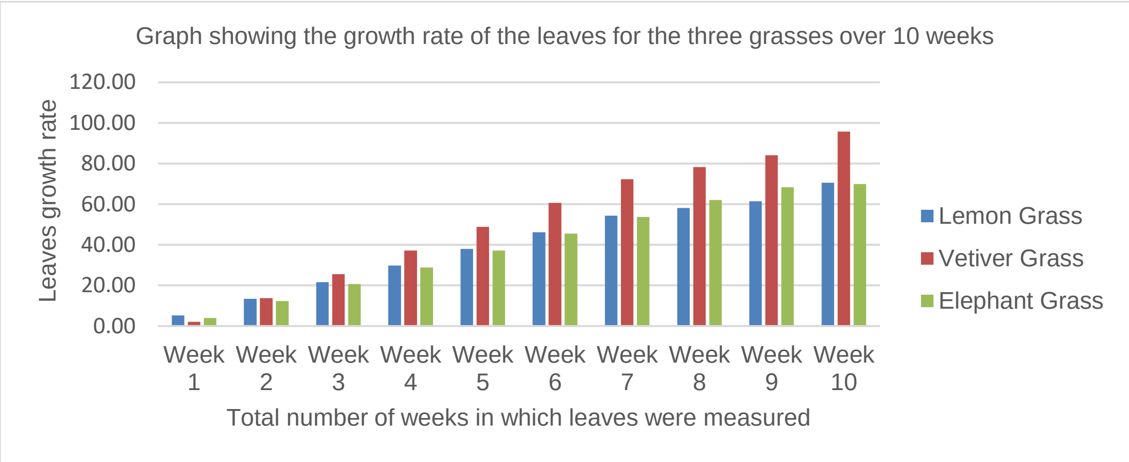

Figure 3. Shows the growth rate of the leaves for the three grasses under study over the period of 10 weeks.

4.2 Surface area

The end of week ten, proved that the grass with the maximum surface area was lemon grass with 4504mm^2 and 1006mm^2 as minimum surface area for Vetiver grass in week one.

5. Laboratory Analysis

The physicochemical parameters measured to assess the efficiency of Lemon grass, Vetiver grass, and Elephant grass in treating the wastewater are pH, Total Dissolved Solids (TDS), Nitrate, Phosphate, and Biochemical Oxygen Demand (BOD). Calculating removal efficiency of these parameters were made using removal efficiency equation (Eq. 1):

$$x = \frac{C_0 - C_t}{C_0} \times 100, \quad (1)$$

where C_0 is the initial concentration of parameter, C_t is the final concentration of parameter at time t (de la Luz-Pedro et al., 2019). The results obtained are presented in the table 2 below.

Table 2: physicochemical parameters of influent and effluents

Parameters	Influent	Lemon Grass	Vetiver Grass	Elephant Grass	WHO Guidelines
TDS (mg/l)	645	230	219	130	1000
BOD (mg/l)	121	109	30	56	50
pH units	7.5	7.7	7.9	7.6	6.5-8.5
NO3-N(mg/l)	15	2.4	1.5	2.7	50
PO4-P(mg/l)	6	1.2	0.6	0.4	2

5.1 Total dissolved solids

TDS is a measurement of inorganic salts, organic matter, and other dissolved materials in water. The toxicity of TDS is influenced by increases in salinity, changes in the ionic composition of the water, and toxicity of individual ions. The measured concentrations of influents and effluents were within the WHO guidelines of 1000 mg/l and therefore satisfactory.

5.2 Biochemical oxygen demand

BOD is the most important parameter in water pollution control because it indicates the actual level of biodegradable pollutants in the water. The influent sample recorded a BOD of 121mg/l. Also, the effluents from Lemon grass and Elephant grass recorded BOD levels that exceeded the WHO standard guidelines of 50mg/l. Only Vetiver grass met the required WHO guidelines. However, all the grasses achieved BOD reductions of between 9.9%% to 75%. The high BOD concentrations in the effluents can cause depletion of natural oxygen resources which may lead to the development of septic conditions in receiving waters. High levels of BOD are caused by the presence of considerable amounts of organic materials. Ngilangil et al., 2020 confirmed that higher removal of BOD showed the beneficial effect of the Vetiver grass. pH

pH plays a crucial role in wastewater treatment, by influencing various aspects of treatment efficiency and environmental impact. Vetiver, lemon, and elephant grass are natural substances that are sometimes associated with pH regulation in soil and wastewater treatment. Although the PH levels of the three showed a slight increase as compared to the original influent concentration of 7.5 yet remain within WHO limits. Regular monitoring and control of pH levels contribute to the stability of the treatment process. Sudden fluctuations in pH can disrupt biological activity and other treatment processes.

5.3 Nitrate

Nitrate is the end-product of the aerobic stabilization of organic nitrogen and may enter the environment via run offs from agricultural lands or in treated effluents from wastewater works. The influent concentration of nitrate in the raw wastewater was 15mg/l, which was well within the discharge standards of WHO at 50.0mg/l. According to (Vymazal et al,.2019), bacterial denitrification and plant uptake have the greatest nitrogen removal potentials. These bacteria attach themselves to the walls of their mediums (Metcalf and Eddy, 1991).

Nitrogen is the most critical and imperative nutrient assimilated by plants for proper growth and development, either as ammonia or nitrates and used in the production of biological macromolecules such as amino acids and nucleotide bases (Shah *et al.*, 2016). The selected plants are not so different from other plants taking up nitrogen as either ammonia or nitrates. The observed decreases in the concentration of nitrates in the effluent samples may be attributed to assimilation by the plants or could also be due to the process of denitrification in which nitrates are reduced to molecular nitrogen gas (N2) (Mustapha, 2013). However, effluent treatment with the selected grasses showed significant nitrate removal efficiency of 84%,90% and 55% for lemon grass, Vetiver grass, and elephant grass respectively. According to Ngilangil et al., 2020 it was confirmed that vetiver grass showed high removal efficiency in nitrate, biochemical oxygen. While the study by (Masinire et al., 2020) confirmed that Vetiver grass proved to be a good accumulator of heavy metals in phytoremediation due to its ability to accumulate heavy metals in its roots.

5.4 Phosphate

The influent concentration of phosphate recorded was 6mg/l, which exceeds the WHO guideline value of 2.0mg/l. All the grasses yielded some levels of reductions. Significant reduction of 93% of phosphate was observed in elephant grass (6 to 0.4 mg/l), 90% in Vetiver grass (from 6 to 0.6mg/l) and finally 80% in Lemon grass (from 6 to 1.2mg/l). These reductions could be due to the presence of polyphosphate accumulating organisms present on the filter media, uptake by roots or sedimentation mechanisms (Guidi *et al*., 2015). The study by Ngilangill et al., 2020 cited that the vetiver grass adapts to its environment, and it continues to grow, the root of the plant absorbs nutrients from the wastewater and converts these organic into inorganic substances making the wastewater cleaner after 5 weeks. This study conducted by Maharjan et al., 2017, confirmed that Vetiver grass was found to be very effective in treating polluted water with very high nitrate and phosphate levels. It was also confirmed by the study undertaken by Boonsong et al.,2008) in Chulalongkorn University which showed that Vetiver grass can reduce around 61.01-62.48% of nitrogen and 17.78-35.87% of phosphorous. Nitrate and phosphorous may have served as nutrients for the aerobic bacteria to break down contaminants into smaller pieces.

6. Conclusion

The results indicated that the effluent from Vetiver grass proved to have the most removal efficiency as compared to Lemon and Elephant grass and met the WHO guideline value for most of the parameters under study. Removal efficiency for TDS was between 64% and 80% while that for BOD was between 9.9% and 75%. Nitrate and nitrite ranges between 84% and 90% nutrients ranged between 80% and 93%. Overall, Vetiver grass had the highest removal efficiency followed by Lemon grass and then Elephant grass. Further research on a pilot scale where a similar experiment is performed on soil not exposed to any of the grass to determine the treatment performance is recommended.

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