Purification of Livestock Wastewater by a Constructed Wetland and Physiological Responses of Wetland Plants to Wastewater Stressors

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Abstract. A wetland containing canna, calamus, wild water chestnut and Hydrilla verticillata was constructed to measure wastewater purification efficiency and effects of livestock wastewater on the physiology of the wetland plants. The results showed that the highest removal efficiencies of the same three contaminants among all four wastewater concentration treatments were 96.42\%, 91.09\%, 79.07\% respectively. Tolerance of livestock wastewater was greatest for canna, followed by calamus, and then wild water chestnut, whereas Hydrilla verticillata was least tolerant of the livestock wastewater treatments.

Introduction

Livestock wastewater, which is high in organic matter nutrients, is a major source of pollution in rural China. Wastewater treatment processes mainly focus on biotreatment, which is expensive, instable and can generate pollutants that contaminate groundwater\textsuperscript{[1]}. Recently, constructed wetlands, which are less expensive and produce more environmentally safe end products, have become a more common wastewater treatment technique\textsuperscript{[2]} (Yan and Xu 2014). Selection of wetland plants is important to wetland system design, and plant types can include aquatic plants and floating and submerged plants, each of which has unique cleaning effects\textsuperscript{[3]}. A study on the effects of nine kinds of plants on treatment of livestock and poultry breeding wastewater found water treated through a constructed wetland containing plant beds to be better than water passed through a constructed wetlands not containing plant bed. Removal rates of Chemical Oxygen Demand(COD), Total Nitrogen(TN), Total phosphorus (TP) and NH\textsubscript{4}\textsuperscript{+}-N from livestock wastewater vary with plants, and the growth rate of plants within the wetland is positively correlated with contaminant removal efficiency\textsuperscript{[4]}.

The specific combinations of plants influence removal effects in wastewater treatment. An experiment on the effects of different plant combinations showed that a suitable aquatic plant combination may improve ammonia nitrogen and total phosphorous removal. Research on effects of combinations of wetland phytocoenosium species and plant spatial patterns within the wetlands on wastewater purification has shown that a combination of three plants improved wastewater purification over two-plant assemblages. Furthermore, an increase in submerged plant density may improve removal rate of nitrogen\textsuperscript{[5,6]}.

This experiment investigated effects of wetland plant combinations on purification of livestock wastewater. The plants used in these experiments were two emergent plants: Canna indica L(canna), Acorus calamus L.(calamus); one floating plant Trapa incisa var. Sieb.(wild water chestnut); one submerged plant: Hydrilla verticillata (L. f.) Royle (Hydrilla verticillata). The wetland plants’ stress resistance in different concentration of livestock wastewater is concerned, so as to explore feasibility of this combination to wastewater treatment based on observation of wastewater treatment effect and changes on these plants. Each of the chosen plants has been tested to have high removal efficiency of some water pollutants\textsuperscript{[7,8]}. Purification of livestock wastewater by the combined plant wetland chamber and physiological responses of wetland plants to wastewater stressors was studied.
Materials and Methods

Device Design

The experiment was carried out in a simulated wetland chamber of dimensions length 1.3m×width 1m× depth 0.8m. The chamber design included a bottom 2 cm layer of sand under an 18 cm layer of soil for planting.

Quality and Source of Raw Water

Wastewater was acquired from a livestock farm in Xichang city. Water quality index scopes for COD, TP and NH$_3$-N were 1176-2365 mg·L$^{-1}$, 22~71mg·L$^{-1}$ and 99~180mg·L$^{-1}$, respectively. Lower concentration wastewater was treated in the first and second test cycles, and the third and fourth cycles tested higher concentration sewage.

Plants Supplied and Experimental Condition

Experimental plants were acquired from natural wetlands during the first 10 days of May, and included six canna and eight calamus, which are emergent aquatic plants; five wild water chestnut, a floating plant; and ten hydrilla verticillata, a submerged plant. During tests, the light source was natural sunlight and simulated wetland water temperature was between 16.5 °C and 20.2 °C. The spatial arrangement of the experimental plants within the simulated wetland chamber is showed on Figure 1.

![Figure 1. Spatial arrangement of plants within simulated wetland chamber.](image)

Note: ○1 signifies canna, ○2 calamus, ○3 wild water chestnut and ○4 hydrilla verticillata

Testing Program

Water depth maintained at 20 cm in the simulated wetland chamber by pouring 30L, 60L, 90L or 120L of livestock wastewater into the chamber, depending on the wastewater concentration being tested, and then topping up the chamber to a depth of 20cm with tap water. The water sample was collected after stir well. Water quality indexes for COD, TP and NH$_3$-N were measured beginning the day the wastewater was added. Water samples were collected from five locations within the simulated wetland chamber after uniform mixing of the water collection layer. Water quality were measured every three days until all three water quality indices fell within the regulated range of the Discharge Standard of Pollutants for Livestock and Poultry Breeding of China (GB 18596), which were 400 mg/L for COD, 80 mg/L for NH$_3$-N and 8.0 mg/L for TP For all wastewater test concentrations, water indices fell to national standards within 15 days. During each wastewater concentration test, after the first observation of an individual water quality index within the national standard range, measurement of the index was discontinued for the remaining duration of the test.

Testing Method

COD, NH$_3$-N and TP concentrations were determined according to the protocols in Standard Methods for the Examination of Water and Wastewater (National Environmental Protection Agency).respectively.
Results and Discussion

COD Purifying Effect in Different Concentrations of Livestock Wastewater

The simulated wetland chamber was effective at COD removal from all livestock wastewater concentrations (Figure. 2).

During 3-15 days of simulated wetland wastewater treatment, COD was reduced by 411-784 mg·L⁻¹, depending on the wastewater treatment concentration. For all treatment concentrations, the simulated wetland was able to reduce COD to levels below livestock wastewater discharge standards, with levels of 88.84, 149.43, 99.27 and 28.61mg·L⁻¹ for the first through fourth treatment concentrations, respectively. The highest removal efficiency was 91.09%. After three days of treatment, removal efficiency was 78.41%, 63.99%, 46.58% and 46.96% for the first through to fourth treatment concentration, respectively, and therefore highest for the lowest wastewater concentration. In constructed wetland systems, dissolved organic matter in wastewater is adsorbed and assimilated by the biological membrane of the plant root systems, and then resolved and removed through biological degradation processes. The undissolvable organic matter, on the other hand, is retained in the wetland after sedimentation and filtration. The COD removal rate was lower for high wastewater concentrations because the concentrated wastewater impairs the organic matter adsorbing capacity of the wetland plants. However, COD removal from high concentration wastewater remains efficient because of mass accumulation of undissolvable organic matter in simulated wetland matrix.

NH₃-N Purifying Effect in Different Concentrations of Livestock Wastewater

The simulated wetland reduced NH₃-N levels to within livestock wastewater discharge standards within 3 three to six days for all wastewater concentrations (Figure. 3).
NH$_3$-N was reduced by 24.2-104.5mg·L$^{-1}$ during the three to six days of treatment. For all treatment concentrations, the simulated wetland was able to reduce NH$_3$-N to levels below livestock wastewater discharge standards with end concentrations of 6.27, 2.46, 5.36 and 16.16mg·L$^{-1}$, for the first through fourth wastewater concentration treatments, respectively. The highest removal efficiency was 96.42%. After three days of treatment, removal efficiency from the first through fourth wastewater concentration treatment was 74.09%, 35.06%, 49.20% and 63.84%, respectively. Thus, the removal efficiency for the first concentration treatment was the greatest. After the first wastewater concentration treatment, removal gradually increases for the second through fourth concentration treatments. The increase in NH$_3$-N removal efficiency from the second through fourth treatment may reflect NH$_3$-N uptake and assimilation into protein and organic nitrogen by the plants [11]. During the high concentration treatments, plant growth was rapid, canna bloomed and wild water chestnut developed large amounts of fruit, all of which likely stimulated NH$_3$-N absorption.

**TP Purifying Effect in Different Concentrations of Livestock Wastewater**

Removal of TP from livestock wastewater by simulated combined plant wetlands is shown on Figure 4.

![Figure 4. Simulated combined plant wetland TP removal from different concentrations of livestock wastewater.](image)

TP was reduced by 3.16-21.55mg·L$^{-1}$ during the three to fifteen days of treatment. For all treatment concentrations, the simulated wetland was able to reduce TP to levels below livestock wastewater discharge standards with end concentrations of 0.93, 1.51, 2.82 and 7.63 mg·L$^{-1}$, for the first through fourth wastewater concentration treatments, respectively. The highest removal efficiency was 79.07%. After three days, removal efficiency for the first through fourth wastewater treatment concentrations was 41.93%, 54.71%, 21.07% and 43.45%, respectively. Plant assimilation and absorption of inorganic phosphorus into organic phosphates such as ATP, DNA and RNA likely drove the elevated TP removal efficiency during the first three days of the first and second wastewater treatments [12]. The decreased efficiency of the third wastewater concentration treatment may have been caused by phosphorus saturation of the plant root systems [13]. At the beginning of the fourth wastewater concentration treatment, large amount of phosphorus was removed from the wastewater, likely due to plant growth and fruiting and production of new plant sprouts. However, from the fourth to seventh day of the fourth wastewater treatment, wastewater TP concentration increased, likely due to phosphorus dissolution into the water from withering plants [14].

**Plant Growing Conditions**

Plants were transplanted into the simulated wetland chamber during the last ten days of May. Experiments with livestock wastewater began at the beginning of the June. The average height of canna and calamus were 65cm and 54cm, respectively when transplanted into the simulated wetland. At the end of experiments, the height of canna and calamus reached 137cm and 149cm, respectively. During the third and fourth wastewater concentration tests, the wild water chestnut and Hydrilla
verticillata, entered their wither stage, with leaves turning yellow and withering, and fruit production beginning for wild water chestnuts. The leaves of few calamus plants withered, while canna plants grow best of all four varieties.

The condition of all four plant varieties during the four wastewater concentration treatments was evaluated throughout experimentation (table 1).

Table 1. Plant growth during the experimental period.

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Note: withering extent:—signifies no withering; A1 signifies slight withering and onset of limpness; A2 signifies most leaves withering; A3 signifies serious withering.
Condition of stem and leaves:—signifies growing normally, B1 signifies withering and yellowing of top leaves, B2 signifies withering and yellowing of the whole plant, B3 signifies serious withering and yellowing, / no recording.

Because the treatment duration varied with each concentration test, plant condition data collected from day 1 to day 4 of treatment was used to compare growth condition of the four plant varieties under treatments. The rank of plant varieties in terms of decreasing total importance value S is: the first and second wastewater concentrations: canna (40) = calamus (40) = wild water chestnut (40) = Hydrilla verticillata (40); for the third wastewater concentration treatment: canna (40) = calamus (40) = wild water chestnut (40) > Hydrilla verticillata (35); for the fourth waste water concentration: canna (40) > calamus (30) > wild water chestnut (5) = Hydrilla verticillata (5). Which shows that with increasing wastewater concentration, canna growth improved, but the other three plant varieties withered and lost water. In order of decreasing growth performance the plant varieties ranked: canna > calamus > wild water chestnut > Hydrilla verticillata.

Conclusions

(1) The rank of water quality indexes from highest to lowest wetland removal efficiency was: NH$_3$-N > COD > TP. Removal efficiency was lowest for TP. Removal efficiencies for NH$_3$-N, COD and TP after three days of wetland treatment were 35.06%–4.09%, 46.58%–78.41% and 21.07%–54.71%, respectively, with the highest removal efficiencies for the same three indexes were 96.42%, 91.09% and 79.07%, respectively.

(2) All four plant varieties included in the simulated wetland of grew normally in low concentration livestock wastewater treatments, but wild water chestnut and Hydrilla verticillata had withered, dried up or dead leaves and stems in high concentration livestock wastewater treatments.

(3) Adaptations and resistance to stressors vary among plants. In order in decreasing tolerance to the stress of livestock wastewater, the tested plant varieties here were: canna > calamus > wild water chestnut > Hydrilla verticillata.
References


