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On the Effect of Hydraulic Retention Time and Loading Rates on Pollutant Removal in a Pilot Scale Wetland

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Abstract: This study examines the potential of *Coix lacryma jobi* commonly known as Job tears as a wetland plant, and the effect of short Hydraulic Retention Time (HRT) and loading rates on the treatment efficiency of a vertical flow constructed wetland. Effluents from an anaerobic lagoon system were collected and used as influents for the constructed wetlands. The influents were subjected to 3, 5 and 7 days HRT and 43.73 and 19.91 m^3/m^2/day loading rate, over a period of 6 weeks. Results from the study shows that the control cell in the system was effective in the removal of phosphorus, (PO_4), Ammonia, Ammonium, COD, TDS, DO, and TSS at the higher HRT of 7 days. Similarly, the level of treatment increased as a result of higher HRT, except for the pH which showed no significant difference. Loading rates of 19.91 m^3/m^2/day at 7 days HRT was effective in the treatment of phosphorus, PO_4, COD and TSS with removal efficiency of 89.1, 84.4, 92.0 and 61.3 % respectively. Parameters such as NH_4^+-N, NH_4, NH_3, TDS showed significant removal by the wetland system at a loading rate of 19.91 m^3/m^2/day and HRT of 7 days. *Coix lacryma jobi* as a wetland plant, at HRT of about 7days and much lower loading rates is capable of removing pollutants in wastewater.

Keywords: Constructed wetlands, loading rates, Hydraulic Retention Time.

INTRODUCTION

The population of Nigeria is increasing and the rate at which wastewater is generated is becoming uncontrollable with most people discharging untreated wastewater into the nearest watercourse. [5]

It is estimated that 80% of the total disease burden in developing countries are gotten from waterborne illness, as a result of water pollution [7]

In 1996, close to 20,000 cases of dysentery and diarrhea were recorded in 37 rural areas in Nigeria [2]. In some countries, sewerage systems are often used to convey wastewater from various domestic and industrial areas to the treatment point where the water is properly treated. The use of wastewater for various agricultural activities such as irrigation, fertigation in crop production and water usage for livestock without proper treatment has caused various challenges such as health hazards for livestock, farmers and their families and also ill balance of nutrients to the plants if not used in agronomic rate. The treatment of wastewater is the best way of protecting the environment and preventing waterborne diseases. A different method of wastewater treatment has been tried across the globe with varying degree of success [9]. Recently constructed wetlands seem to gain attention. Wetland has been recommended as one of the best facility for treating wastewater in developing countries [11]. Constructed wetlands (CWs) are wetlands created from non-wetland sites with the aim of treating wastewater or maximize the removal of its contaminants According to [3] constructed wetlands are very effective in pollutant removal. They are usually used as secondary treatment unit because the wastewater must have passed through the primary treatment process. It has been reported by [12] that the functionality of wetlands in treatment of wastewater depends on, the microbial biomass, microbial activities and decomposition potential of the plant litter. It is thought that purification of wastewater in the subsurface flow constructed wetland is a result of the interaction between the plant, microorganisms, granular medium and the pollutant. Thus a variety of complex biological, physical, and chemical mechanisms combine to improve the water quality in constructed wetlands. Operational parameters such as loading rate, hydraulic retention time, type of plant and filter material are expected to have profound effect on the removal efficiency of pollutants in the wetland system. This study attempts to assess the effect of HRT and loading rate on the efficiency of a constructed wetland system for wastewater treatment.

MATERIALS AND METHODS

The study was carried out at the Department of Agricultural and Environmental Engineering, University of Ibadan experimental site. The site was selected based on its proximity to the laboratory. According to [6] Ibadan is located in Oyo State, Nigeria with, 7° 22' N Latitude and 3 °58' E of the Greenwich meridian. The metropolitan area lies within between Latitudes 7°15' and 7° 30' North of the equator, and Longitudes 3° 45' and 4° 00' East of the Greenwich meridian. The study area is within the metropolitan area.

The experimental wetland system consists of a surge tank of 3000L capacity with two distribution tanks of 500L capacity connected in series to the surge tank which was placed on a 1.5m high concrete platform to flow by gravity to the distribution tanks. Each cell was of dimension 1.2 x 0.9 x 0.4m. The constructed wetlands contain 3 cells with each connected in series. Each cell was connected to the other two cells to form a single unit. The treatment cells were filled with porous media of gravels, with different sizes viz: 2-10 mm diameter crushed granite gravel, medium size gravel of 10-25 mm and coarse gravel of 40 mm diameter. Each treatment cell was filled with gravel of particular size starting with coarse type at the inlet treatment cell while the outlet treatment cell contained the smallest diameter 2-10mm. A pump was used to convey wastewater from the wastewater pond to the surge tank which after 24hrs was allowed to flow into a distribution tank which serves as sedimentation tank. A control valve was incorporated at the baseline of the surge tank to allow drainage of sludge which could have settled as a result of sedimentation process in the surge tank.

At a level of 1.3m from the baseline in the surge tank, a pipe of length 1m was connected to link the surge tank and the first distribution tank together. A control valve for regulating the flow to the distribution tank was connected within the pipe. The second distribution tank was connected in series to the first distribution tank.

A flow meter was connected at the middle to the pipe connecting the second distribution tank to the cells. At ground level, two 90^0 elbows and T- joints were used as connectors between cells and the flow meter.

Three cells were vegetated while the other three that are not vegetated serve as control. The vegetated cells were connected in series at equidistance of 1m with two control valves connected to each of the cells. A replicate was done for the non-vegetated cells. Leakages were prevented by using yarn and gum to seal the exposed joints.

Flow rate and discharge measurement were done to determine hydraulic loading rate into the cells. The process involved filling the distribution tanks with wastewater obtained from an anaerobic lagoon

The retention time was chosen such that wastewater is contained in the cell and treated for 2days. Thus, the wastewater effluent was sampled at day 3, 5, and 7 using an opaque plastic container which has been rinsed with deionized water.

The wastewater quality was measured with Hanna HI 83200 multi-parameter photometer and the manufacturer's manual was followed with reference to standard methods for examination of water and wastewater [1] in the determination of physico-chemical properties such as Dissolved Oxygen, Chemical Oxygen Demand, Particulate Phosphorus, Soluble Reactive Phosphorus, Ammonium Nitrogen, Ammonia, and pH .

RESULTS AND DISCUSSION

Table 1 Mean (± S.D) of Influent and Effluent Parameters and Removal Efficiencies for Coix and Control Wetland at 3 days HRT (Week 1 – Week 3)

Parameters	Influent	Effluent		Removal Efficiency %	Removal Efficiency %
		Coix	Control	Coix	Control
P^H	7.3 ±0.5	6.9 ±0.2	7.5 ±0.4	-	-
Phosphorus(P)	5.8 ±2.8	1.8 ±0.2	4.5 ±2.1	69.0	22.4
Phosohorus (PO_4^{3-})	11.1 ±5.7	3.2 ±0.1	7.6 ±4.1	71.5	31.5
NH_4^+-N	51.1 ±28.8	2.6 ±1.5	17.6 ±5.0	94.9	65.6
NH_4^+	59.1 ±25.4	2.1 ±0.6	21.5 ±6.2	96.4	63.7
NH_3	63.2 ±26.0	2.3 ±0.6	24.4 ±6.5	96.4	61.4
COD	445.3 ±276.9	91.3 ±70.7	65.0 ±27.2	79.5	85.4
TDS	482.7 ±14.0	369.0 ±32.1	409.7 ±28.1	23.5	15.1
DO	0.3 ±0.2	1.0 ±0.2	1.8 ±0.6	244.4*	511.1*
TSS	542.3 ±276.3	401.0 ±187.6	439.7 ±85.0	26.1	18.9

All concentration in mg/l except pH

*Indicates increase in content

Table 2 Mean (± S.D) of Influent and Effluent Parameters and Removal Efficiencies for Coix and Control Wetland at 5 days HRT (Week 1 – Week 3)

Parameters	Influent	Effluent		Removal Efficiency %	Removcal Efficiency %
		Coix	Control	Coix	Control
pH	7.3±0.5	6.8±0.1	7.7±0.2	-	-
Phosphorus(P)	5.8±2.8	1.4±0.2	3.8±1.7	76.8	34.9
Phosphorus PO_4^{3})	11.1±5.7	2.5±0.1	6.4±3.7	77.2	42.0
NH_4^+-N	51.1±28.8	1.2±0.2	11.9±5.5	97.7	76.7
NH_4^+	59.1±25.4	1.6±0.4	16.9±7.0	97.4	71.1
NH_3	63.2±26.0	1.7±0.5	18.3±7.7	97.4	71.1
COD	445.3±276.9	41.7±7.5	46.7±11.9	90.6	89.5
TDS	482.7±14.0	325.7±65.2	393.3±65.0	32.5	18.5
DO	0.3±0.2	1.5±0.3	2.0±0.7	400.0*	577.8*
TSS	542.3±276.3	315.3±153.5	385.3±96.6	41.9	28.9

All concentration in mg/l except pH

*Indicates increase in content

Table 3 Mean (± S.D) of Influent and Effluent Parameters and Removal Efficiencies for Coix and Control Wetland at 7 days HRT (Week 1 – Week 3)

Parameters	Influent	Effluent		Removal Efficiency %	Removal Efficiency %
		Coix	Control	Coix	Control
pH	7.3±0.5	6.9±0.1	7.4±0.1	5.5	-0.5
Phosphorus(P)	5.8±2.8	1.1±0.2	3.2±1.5	81.7	45.1
Phosphorus (PO_4^{3-})	11.1±5.7	2.0±0.0	4.7±2.7	82.0	57.4
NH_4^+-N	51.1±28.8	0.9±0.2	8.1±3.6	98.3	84.2
NH_4^+	59.1±25.4	1.1±0.2	10.1±4.3	98.2	82.9
NH_3	63.2±26.0	1.2±0.2	10.5±4.8	98.1	83.4
COD	445.3±276.9	32.3±8.7	30.3±9.5	92.7	93.2
TDS	482.7±14.0	290.0±67.6	361.3±148.6	39.9	25.1
DO	0.3±0.2	2.1±0.8	2.7±0.9	606.7*	811.1*
TSS	542.3±276.3	283.0±155.2	3.3±3.3	47.8	99.4

All concentration in mg/ except pH

*Indicates increase in content

Table 4 Mean (± S.D) of Influent and Effluent Parameters and Removal Efficiencies for Coix and Control Wetland at 3 days HRT (Week 4 – Week 6)

Parameters	Influent	Effluent		Removal Efficiency %	Removal Efficiency %
		Coix	Control	Coix	Control
pH	7.8±0.6	6.8±0.1	7.6±0.1	12.8	3.0
Phosphorus(P)	18.3±15.9	2.0±2.3	4.5±2.8	89.1	75.6
Phosphorus (PO_4^{3-})	38.9±32.6	6.1±7.0	13.7±8.6	84.4	64.7
NH_4^+-N	79.9±86.9	6.4±8.4	28.7±36.1	92.0	64.2
NH_4^+	97.1±105.5	7.8±10.3	35.0±44.2	92.0	64.0
NH_3	103.0±112.1	8.2±10.9	36.9±46.6	92.0	64.1
COD	700.0±581.4	112.0±147.7	178.3±235.7	84.0	74.5
TDS	1247.7±365.4	947.0±192.6	1172.0±368.7	21.9	6.1
DO	1.0±1.1	1.8±1.1	1.9±1.2	89.7*	100.0*
TSS	1550.7±432.8	600.7±422.4	544.3±262.2	61.3	64.9

All concentration in mg/l except pH

*Indicates increase in content

Table 5 Mean (± S.D) of Influent and Effluent Parameters and Removal Efficiencies for Coix and Control Wetland at 5 days HRT (Week 4 – Week 6)

Parameters	Influent	Effluent		Removal Efficiency %	Removal Efficiency %
		Coix	Control	Coix	Control
pH	7.8±0.6	6.9±0.2	7.4±0.1	11.9	5.1
Phosphorus(P)	18.3±15.9	1.6±1.8	4.1±2.4	91.4	77.6
Phosphorus (PO_4^{3-})	38.9±32.6	4.8±5.7	12.6±7.4	87.6	67.5
NH_4^+-N	79.9±86.9	3.1±4.0	20.0±24.6	96.1	75.0
NH_4^+	97.1±105.5	3.8±4.8	24.3±29.9	96.1	74.9
NH_3	103.0±112.1	4.0±5.1	25.8±31.7	96.1	74.9
COD	700.0±581.4	53.3±41.8	158.3±216.5	92.4	77.4
TDS	1247.7±365.4	596.7±125.9	784.3±404.7	52.2	37.1
DO	1.0±1.1	1.8±0.5	2.7±1.0	82.8*	179.3*
TSS	1550.7±432.8	364.0±254.7	349.0±189.0	76.5	77.5

All concentration in mg/l except pH

*Indicates increase in content

Table 6 Mean (± S.D) of Influent and Effluent Parameters and Removal Efficiencies for Coix and Control Wetland at 7days HRT (Week 4 – Week 6)

Parameters	**Influent**	Effluent		Removal Efficiency % Coix	**Removal Efficiency % Control**
		Coix	Control		
pH	7.8±0.6	6.7±0.1	7.1±0.2	14.0	9.4
Phosphorus(P)	18.3±15.9	0.8±0.6	3.1±1.6	95.8	82.9
Phosphorus (PO_4^{3-})	38.9±32.6	2.4±1.8	9.2±4.0	93.8	76.3
NH_4^+-N	79.9±86.9	0.6±0.7	11.5±14.1	99.2	85.6
NH_4^+	97.1±105.5	0.7±0.9	13.0±18.1	99.3	86.6
NH_3	103.0±112.1	0.8±0.9	13.8±19.2	99.3	86.6
COD	700.0±581.4	32.7±34.1	30.7±32.1	95.3	95.6
TDS	1247.7±365.4	437.7±134.8	684.3±378.0	64.9	45.2
DO	1.0±1.1	2.5±0.4	3.1±1.3	162.1*	220.7*
TSS	1550.7±432.8	267.7±134.4	259.7±79.4	82.7	83.3

All concentration in mg/l except pH

*Indicates increase in content

The effects of Hydraulic Retention Time on pollutant removal.

Table 1 - 3 shows the average concentration of pollutant in wastewater and after treatment with *coix* and control for 3, 5 & 7 days HRT respectively. The result in general shows some level of treatment in both units. However, the TDS and TSS removal rate were not effective when compared to other parameters.

The TDS removal rate of 23.5, 32.5 and 39.9% respectively in Tables 1-3 show an increasing rate of pollutant removal with increase in hydraulic retention time.

TSS influent concentration was reduced by 61.3 76.5 and 82.7% respectively at 3, 5 & 7 days HRT indicating a definite trending pollutant removal. On the contrary, the level of treatment in the control unit was not as effective as that with (Coix for Phosphorus, PO_4, TDS and TSS) for 3 days HRT with observation in week 1 to week 3. This could be attributed to deposition of dry leaves around the field.

The increase in DO confirms a higher level of treatment. There is a trend of pollutant reduction with increase in the retention time from week one to week six. (Tables 1 to 6) the pH of the water prior to treatment was slightly alkaline and changed slightly acidic after treatment with values varying from 6.8±0.1 in day 3 to 6.9±0.2 in day 5 and 6.7±0.1 in day 7.

Treatment efficiency in the range 60 - 98% were observed with increase in HRT from 3 to 7days, for particulate phosphorus, PO_4, NH_4^+-N, NH_4^+, and COD between week one to week three. Coix removal rate for phosphorus was 69% on day 3 and due to further treatment increased to 76.8% on day 5, and 81.7% on day 7. This is attributed to phosphorus being partially removed by sedimentation and by reacting with porous media minerals. Also, PO_4 is mainly removed by plant uptake and adsorption onto the porous media [8]. The high removal rate of NH_4^+-N and NH_4^+ could be that nitrogen removal requires longer retention time for it to be much effective. Particulate phosphorus, PO_4, NH_4^+-N, NH_4^+, NH_3 and COD was as effectively removed in week 4, 5 and 6 in coix unit as compared to week 1 to week 3. The values observed for NH_4^+ – N and NH_3 are similar to that reported by [4].

DO recorded an increase of 244, 400, and 606% for 3, 5 and 7 days HRT respectively. This shows that the treatment process is effective with increase in HRT. Similar trend was observed in weeks 4 - 6 (Tables 4 – 6). This is in-line with the findings of [10] where it was reported that *Phragnitis karka* plant in wetland treated water/effluent's with DO level increasing by 139 % and reached 3.1 mg/l. The increase DO level indicates the existence of aerobic conditions in the root zone bed.

Effect of loading rate on level of Pollutant Reduction.

Tables 1 - 3 shows the treatment efficiency on 43.73 m/day loading rate while tables 4 to 6 shows the treatment efficiency on 19.91 m/day loading rate.

Treatment were effective for particulate phosphorus, PO_4, NH_4^+-N, NH_4^+, NH_3, COD with 69, 71.5 , 94.9, 96.4 & 79.5% removal respectively, while 244.4 % increase was observed in DO respectively. Poor treatment was observed in TDS and TSS with 23.5 % and 26.1 % reduction. Considering control unit in the same table, NH_4^+-N, NH^+_4, NH_3, COD and DO only experienced adequate treatment while parameters such as particulate phosphorus, PO_4, TDS and TSS had less than 40 % removal.

Treatment performance in week two as shown in Table 5 indicates that TDS and TSS were not effectively treated using Coix (32.5 % and 41.9 %).

Relating the two loading rates together in Tables 4 to 6, 19.91 m/day loading rate at 7 days HRT was effective in the treatment of particulate phosphorus, PO_4, COD and TSS with removal efficiency of 89.1, 84.4, 92.0 and 61.3% respectively. However, parameters such as NH_4^+-N, NH_4^+, NH_3, TDS and DO are better treated using 18.24 m/day loading rate at 7 days HRT as shown in Tables 4 – 6. On the contrary, DO and TSS treatment in control unit was achieved at 43.73 m/day loading rate as presented in Table 6.

In conclusion the results from the study revealed that constructed wetland system was able to treat the wastewater generated from the institution anaerobic lagoon at Obafemi Awolowo Hall of residence.

The system was highly effective in the removal of physical and chemical parameters. However, no appreciable difference was noticed in the pH values of both the influent and effluent result.

Removal efficiency were as high as 89.1% for phosphorus, 92.6% for NH_4^+-N and 84% for COD. Low removal efficiency were recorded for TDS and TSS especially at day three HRT with 43.73 m/day loading rate with 23.5 % and 26.1 % respectively and TDS removal of 19.91 m/day loading rate 21.9 %.

The maximum COD removal efficiency was 95.3% at 19.91 m^3/day loading rate and 7days HRT.

The *Coix lacryma-jobi* and control of HFCW unit showed significant differences in the ability to reduce PO_4, COD, DO and TDS at 18.24 m/day loading rate for 3, 5 and 7 days HRT.

These results suggest that it is possible to use *Coix lacryma-jobi* as a treatment medium for wastewater to produce a high quality effluent.

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