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TREATMENT EFFICACY OF SHORT ROTATION WOODY SPECIES AND THEIR ECONOMIC APPRAISAL IN VEGETATION FILTER SYSTEM

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ABSTRACT

Reclamation of domestic wastewater is one of the growing concerns of escalating urban population. In the present study, a serpentine Overland Flow System (OFS) is employed for treatment of domestic wastewater emanating from residential areas of university campus at Pantnagar (Uttarakhand), India through fast growing woody species of Eucalyptus hybrid, Populus deltoides, Salix alba and Melia azedarach. The OFS system showed good pollutant removal efficiency during the study period (Aug 2009-Aug 2011) under domestic wastewater and control trial. The Vegetation Filter System (VFS) showed good pollutant removal potential with average reductions of 77.2, 72.0, 75.4, 61.0 and 60.0% for BOD, COD, total nitrogen, total phosphorus and potassium, respectively at the end of 2nd year. The economic calculations show that the additional benefit incurred from biomass growth harvest in 5 years from 1 ha land of VFS was Rs. 46.42 lakh ($86000 USD) that can allow good margin for investment, operation and management of wastewater treatment system. Therefore, the present installation of vegetation filters is a better option for treatment of domestic wastewater generated from small communities, villages, towns and can be also helpful in fulfilling the wood requirement of villagers and local market.

Keywords: Domestic wastewater; vegetation filter; treatment efficiency; economic appraisal

INTRODUCTION

Domestic wastewater generation has superseded the industrial waste water generation in India and is the major cause of water pollution and eutrophication. Conventional domestic wastewater treatment system involves large expenditure to bring down the pollutants level to the permissible discharge limits. In the present study, an appropriate wastewater management approach is adopted, wherein twin benefits such as treatment and reuse can be achieved, and sustainable development can be promoted. Recently, land application of domestic wastewater is gaining momentum owing to the fact that it provides the most cost-effective and safe wastewater treatment and disposal method (Singh, 2011). Being rich in organic matter and nutrients, it could be used as source of nutrients for biomass production and thus can be helpful in sustaining economy. Therefore, this study investigates the fertigation potential of domestic wastewater for Vegetation Filter System (VFS), which further reduce the investment cost for nutrient recovery and wastewater treatment. VFSs provide a natural way of wastewater treatment by the combined action of environmental components like soil matrix, microorganisms and plant uptake through roots. The system can provide primary, secondary as well as tertiary treatment to wastewater through various physical, chemical and biological processes.

MATERIALS & METHODS

Present study was conducted in the experimental field of one hectare land at G. B Pant University of Agriculture and Technology, Pantnagar, Uttarakhand, India. It is located at 29° 01’ 469” N and 79° 29’ 393”E and at an altitude of 243.8 meters above the mean sea level in the south of the foothills of Himalayas Shivalik range. The annual average temperature varies from minimum 4.0^{o}C to maximum 41.8^{o}C. The study area is sub-humid and has the sub-tropical climatic zone with average annual rainfall of around 1350mm. The soil of the experimental site was of sandy loam texture with a slightly acidic (pH 6.3-6.5) and an electrical conductivity of 140-165 µS cm^{-1}. Organic matter (OM) ranged from 14.2 to 14.9 g kg^{-1}. The site had a bulk density and infiltration rates of 1.45 g cm^{-3} and 0.32 cm hr^{-1} respectively. Mixed plantation of four short rotation energy species of *Eucalyptus hybrid, Populus deltoides, Salix alba and Melia azedarach* was done in both treatment (wastewater-irrigated) and control plots in February 2009. Overland flow irrigation system was designed with serpentine furrows throughout the vegetation filter system in order to provide maximum removal of pollutant with minimum risk of contamination. Plant to plant and row to row spacing was 2 m X 2 m with a plant density of 2500 plants per hectare. In total, both treatment and control plot consist of 6 replicated rows of four species. Domestic wastewater discharged exclusively from bathrooms and kitchens of

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residential colonies of Pantnagar was collected by obstructing the flow of drain through a check dam. Wastewater from the check dam was lifted by a 2 HP water pump for irrigating the treatment plot. However, control plot was irrigated with underground water through the shallow borewell of 30ft depth. The water flow rate was kept constant at a rate $50m^3$ per hour and was allowed to travel approximately 800m distance in the whole serpentine plot until it reaches the final outlet. The discharge at the outlet was measured through a V-notch weir installed in the end of the outlet. The domestic wastewater and control water were supplied in same frequency in the field at rate of $200m^3$ per day to each plot of treatment and control. Normally, both plots were irrigated twice a week in an interval of 3 days. However, in the outlet water flow rate of approx. $80m^3$ means 40% of the inlet water supply was received in each plot. Domestic wastewater was analyzed monthly to check the variation in the nutrient load (NPK), biochemical oxygen demand (BOD) and chemical oxygen demand (COD). Nitrogen was analyzed by Kjeldahl method. Phosphorus (P) was analyzed colorimetrically with Vanado-molybdate method. Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) were determined by Iodometric method and reflux method respectively for analyzing the organic load in wastewater. Potassium (K) was analyzed using a digital flame photometer.

RESULTS & DISCUSSION

Meteorological Data

Average temperatures during the study period varied between 19.9–41.8°C in summer, 8.8–34.4°C in autumn, 4.0–25.1°C in winter and 10.3–40.8°C in early spring. Precipitation was marked by unusual meteorological phenomena at the site, with droughts in April 2010 and April 2011 and excessive rainfall in August 2010. During the entire study, precipitation levels varied around 4.4–70.6 mm in summer, 0.4–325.6 mm in autumn, 0–20.6 mm in winter and 0.2–18 mm in early spring.

Table 1: Typical composition of untreated domestic wastewater (Tchobanoglous *et al.*, 2003)

Contaminants	Unit	Concentration		
		Low strength	Medium strength	High strength
Solids, total (TS)	mg l^{-1}	390	720	1230
Dissolved, total (TDS)	mg l^{-1}	270	500	860
Suspended solids, total (TSS)	mg l^{-1}	120	210	400
Biochemical Oxygen Demand (BOD_5)	mg l^{-1}	110	190	350
Chemical Oxygen Demand (COD)	mg l^{-1}	250	430	800
Nitrogen (total as N)	mg l^{-1}	20	40	70
Nitrates	mg l^{-1}	0	0	0
Phosphorus (total as P)	mg l^{-1}	4	7	12
Total coliform	No./100ml	10^6-10^8	10^7-10^9	10^7-10^{10}
Faecal coliform	No./100ml	10^3-10^5	10^4-10^6	10^5-10^8

Wastewater Characteristics

The wastewater used in the present study can be categorized as low strength wastewater (Table 1) as per the classification of Tchobanoglous *et al.* (2003). The pH, electrical conductivity, total nitrogen, phosphate, sodium, potassium, Biochemical Oxygen Demand, Chemical Oxygen Demand, dissolved solids and suspended solids of domestic and control (borewell) water applied in VFS showed that the average concentration of each of the above water quality parameters of domestic wastewater were much higher than that of the control water as it contains a wide variety of dissolved and suspended impurities (Table2). Through water use and subsequent discharge, the quality of water deteriorates due to addition of variety of organic and inorganic constituents of anthropogenic and natural origin.

Table 2: Physico-chemical characteristics of wastewater and control (borewell) water used in the present study

Parameters	Wastewater	Control
pH	8.3±0.01	7.8±0.1
Electrical Conductivity (µS cm^{-1})	527±0.2	243±4.5
Dissolved Oxygen (mg L^{-1})	1.2±0.01	3.3±0.2
Nitrogen (total as N mg L^{-1})	30.7±0.05	1.9±0.4
Phosphorus (total as P mg L^{-1})	6.4±1.7	1.2±0.2
Potassium (mg L^{-1})	2.9±0.03	1.01±0.04
Sodium (mg L^{-1})	7.3±0.32	5.1±0.01
Biochemical Oxygen Demand 5days, 20^0C (mg L^{-1})	66±9.5	3.3±0.4
Chemical Oxygen Demand (mg L^{-1})	226±16.5	6.1±0.2
Solids, total (mg L^{-1})	429±4.2	279±37
Dissolved, total (mg L^{-1})	205±5.4	134±14
Suspended solids, total (mg L^{-1})	224±1.5	145±10.1

Treatment efficiency of VFS

The influent and effluent concentrations in plot-I (wastewater irrigated) and percent removal statistics (i.e., mean value and standard deviation) of BOD, COD, TN, TP and K for two successive years are presented in Table 3. Out of the major nutrients present in wastewater, concentration of nitrogen was found to be highest (30.7 mg l^{-1}) followed by phosphorus (6.4 mg l^{-1}) and potassium (2.9 mg l^{-1}). Average influent concentrations in the first year operation were 57.4±12.4 mg l^{-1} BOD, 220±33 mg l^{-1} COD, 64±4.2 mg l^{-1} Total N, 7.8±1.4 mg l^{-1} Total P and 5.6±2.7 mg l^{-1} K. The first year results reflect the treatment performance of the vegetation filter system from August 2009-August 2010. Similarly, the second year operation commenced in autumn 2010, slowly started up in the following spring and achieved full operational status by the summer of 2011. For second year, influent BOD, COD, Total N, Total P and K concentration were 63.3±5.8 mg l^{-1}, 197±15.7 mg l^{-1}, 27.1±7.1 mg l^{-1}, 4.1±1.1 mg l^{-1} and 5.7±2.4 mg l^{-1}, respectively. The treatment corresponded with removal efficiencies of 63.3, 58.1, 49.2, 38.4 and 27.8%, respectively in Ist year and 77.2, 72.4, 75.4, 60.9 and 60.2% in IInd year, respectively. While removal of COD and N occurred predominantly into the atmosphere by degradation and denitrification processes, P was mainly removed by precipitation.

Table 3: Statistics of overall influent and effluent concentrations and removal efficiencies of VFS irrigated with wastewater in two successive years

	Ist Year (Aug 09-Aug 10)			IInd Year (Aug 10-Aug 11)		
	Influent conc. (mg/L)	**Effluent conc. (mg/L)**	**Removal efficiency (%)**	**Influent conc. (mg/L)**	**Effluent conc. (mg/L)**	**Removal efficiency (%)**
BOD (mg/L)						
Mean	57.5	26.1	54.84	63.1	21.5	66.3
S.D	12.4	8.02	6.8	5.8	6.6	7.2
COD (mg/L)						
Mean	220	114.4	48.1	197	76	62
S.D	33	19.7	5.7	15.7	27	4.2
TN (mg/L)						
Mean	64	16.9	49.2	27.1	8.4	70.4
S.D	4.2	5.3	13.3	7.1	4	18.8
Total P (mg/L)						
Mean	7.8	4.8	38.4	4.1	1.7	56.1
S.D	1.4	1.4	11.2	1.1	0.6	13.4
K (mg/L)						
Mean	5.6	4.7	17.8	5.7	2.8	50.1
S.D	2.7	2.5	15	2.4	1.6	11.4

The greater removal efficiency among the various constituents was for BOD followed by Total N in both Ist and IInd year. However, reductions were recorded to be least during December and January mainly due to dormant stages of trees which are deciduous in nature (Pandey *et al.*, 2011). Removal of BOD from wastewater in soil is generally a result of filtration and microbiological activity in the soil profile. Irrigation activities give altered saturated and drained conditions creating possibilities for anaerobic and anoxic (denitrification) degradation of the organic material and nitrogen. For potassium, the average concentration in wastewater was 5.61 mg l^{-1} in Ist year and 5.7 mg l^{-1} in next year which were reduced to 4.05 mg l^{-1} and 2.12 mg l^{-1} at the outlet of the filter thus attaining the annual reduction of 27.86% and 60.1%, respectively. The mean removal efficiency of VFS was 58.1 and 72.4% for COD and 38.4 and 60.9% for Total P in two successive years, respectively. On the contrary to BOD and COD, nutrients (NPK) showed significant variations during the operation period (Aug 09-Aug 11), as shown by the relatively high standard deviation values of removal efficiency (Table 3). These variations occur because the bacteria and the plants responsible for nitrogen removal are less efficient in low temperatures.

Economics of VFS

There are many potential economic opportunities for biomass from short rotation woody crops planted for pollutant removal. The benefits of present study were estimated assuming one ha plot under wastewater irrigation at a plant density of 2500 trees per ha. This approach is cleaner, cheaper, and offer both environmental as well as economic benefits to the society. However, the intangible benefits of carbon sequestration, ground water table recharge etc are not estimated in present study. Only tangible benefits i.e. harvestable biomass after five year of study has been taken into account.

Table 4: Economic appraisal of Vegetation Filter System for on-site treatment of domestic wastewater

Expenditure	A (`. in Lakh)	S.No	Returns	B (`. in Lakhs)
Land Lease (1ha plot)/ year @ 0.25/year	1.25	1.	Cost of 1 tree after 5 years	Rs. 3000
Per head Labour Cost/day	`. 150/day		Cost of 2000 (80% survival rate) trees	60.00
4 Labours (1ha plot)	`.600 /day			
Labour cost per year	2.19			
Labour cost (5 Years)	10.95			
Average Sapling Cost	`. 15/sapling			
Cost for 2500 saplings	0.38			
Miscellaneous Cost/year	` 0.25/year			
Miscellaneous Cost @ 4 year	1.00			
Total A	13.58		Total B	60.00
				Net Benefit `= 46.42 Lakh

**Net benefit after 5 years = Total B - Total A*

Poplars and willows from phytoremediation systems are environmental acceptable sources of biomass for bioenergy as well as wood products (Licht, 1992). Due to availability of nutrients in the wastewater, it can be cheaply applied on short rotation crops as a substitute to conventional fertilizers (Pertu, 1994). Consequently, the costs for conventional N and P treatment would be considerably reduced. All the tree species used in the experiment i.e. *Eucalyptus hybrid, Populus deltoides, Salix alba* and *Melia azedarach* had very high commercial value in the local market of the region. The average cost of trees after 5 year rotation period has been used in the study to estimate the monetary gains from the field as harvestable biomass. The high growth of trees in wastewater plot has been deliberately ignored to find the minimum average benefit from the plantation. Total 2000 trees biomass was considered keeping the survival rates of the species into consideration. The average wood biomass per tree after 5-6 years is about 0.25 to 0.35 MT and presently the prices vary from `. 2500 to Rs. 5500 per MT though the highest has gone upto Rs. 7000/MT (NABARD, 2008) thus makes average cost of tree to be 3500/tree. The average cost of trees after 5 years was `. 2500-3000/tree as per the rates given by Forest Corporation of Uttarakhand for the year 2008-2009 and the survey done in the commercial market (Pandey and Srivastava, 2010).

The total expenditure and returns for the total trees is given in Table 4. The total cost of the harvestable biomass after 5 years was estimated to be approx. `. 60 lakh (`. 3000 per tree) considering >80% survival rate of plants. However, the expenditure was calculated to be approx. 13.58 lakh which include manpower cost, sapling cost, irrigation, site preparation and miscellaneous. Since, the site used for plantation was initially a barren land therefore the cost of land has not been taken into consideration. The estimates of miscellaneous cost includes the land preparation, weed removal, pest control and irrigation channel management etc. The total expenditure was then reduced from the total monetary returns and the net monetary benefit from the plantation is found to be approx. `. 46.42 lakh ($ 86000 USD). However, the intangible benefits *viz.* soil conservation; soil nutrient recovery, soil and biomass carbon sequestration etc are not considered in the net benefits during the entire study period.

The results obtained in this study clearly show that the treatment of polluted wastewater in vegetation filters is an attractive concept from the environmental and economic points of view. In vegetation filters, plant nutrients are recycled and utilized in an efficient way for the production of renewable energy in the form of biomass, instead of being wasted or causing eutrophication. Thus, the concept is an attractive option for both farmers (lower biomass production costs) and sewage treatment plant operators (lower water treatment costs). The concept could also provide significant benefits for the community at large, especially in regions facing problems with nutrient-polluted surface and groundwater. It is ideal technology for small communities due to its low cost of construction, operation, and maintenance, especially in the areas of low land cost.

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