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Performance of Sub-surface Horizontal Wetland Model using *Arundo donax* for Rhizofiltration of Drain water

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Abstract
Bioremediation technologies using high biomass aquatic weed species are applicable to clean-up waste water in constructed wetland for its reuse in agriculture. A rectangular sub surface horizontal model of 4'x 2'x 1' was developed for removal of pollutants such as nitrates, phosphates and heavy metals in waste water. Gravels of 1.5-3", 0.5-1" and 0.37-0.5" size were used as a media in the treatment zone in which the rhizomes of *Arundo donax* were planted. After well spreading of roots entangled with media in a bed zone, a treatment of drain water was given. Prior to the treatment, the average pollutant concentration of nickel, copper, nitrates and phosphates in drain water were 320, 340, 500, 35 ug/L respectively which were beyond the prescribed limit for irrigation. As compared with the untreated waste water, the rhizofilter model performed in reduction of the concentrations of nickel, copper, nitrate and phosphate to the extent of 55.8, 40.6, 70.0 and 42.8 per cent respectively after the treatment. As far as water flow through gravel medium is concerned, no clogging was occurred in treatment zone resulting free discharge of water through the outlet. The characters of exuberant root and good adaptability of *Arundo donax* suggested its potential in rhizofiltration of waste water. Thus, reed based treatment of waste water can be applied for treatment of drain water on field scale for irrigation purposes vis-à-vis as a preventive measure to check nitrate and phosphate related problems of weed infestation in surface water bodies.

Keywords: Rhizofiltration, nickel, copper, nitrate, phosphate, *Arundo donax*

Introduction

The entry of pollutants such as nitrates, phosphates and various heavy metals into land and water bodies occurs due to unscientific disposal of industrial effluents, discharge from human habitation, dairy, poultry farming and runoff water from agricultural fields. In the peri-urban areas, due to higher nutrient load the use of waste water has become the common practice for irrigation purposes. Besides being a source of nutrients these effluents often contain various heavy metals, depending upon the anthropogenic activities from which these are originating. It has been reported metals entry into food chain (Haan and Lubbers 1983), increased incidence of pests (Bakhsh and Hassan 2005) and weed infestation in field crops (Khankhane and Varshney, 2009) and observed to enhance the available metal status of agricultural soils by 2 to 100 times (Samra, 2007) by the continuous use of waste water as an irrigation source. Besides this the higher level of nitrates and phosphates in untreated water increases the eutrophication of water bodies. Therefore in order to alleviate the detrimental impact of untreated waste water discharge on land and water resources, appropriate measures should be adopted to remove the pollutants prior to their entry in the field and in surface water bodies. This is effectively can be achieved by extended conventional treatment technology. However, the working expenses and energy requirements of such advanced systems are high. The option is to go for phytofiltration where weedy plants are used for scavenging of different contaminants. Among various approaches of phytoremediation, rhizofiltration has wider applications wherein pollutants mainly heavy metals, nitrates and phosphates are absorbed and adsorbed by weedy plant grown in artificially constructed sub-surface wetland system. In these systems, water level is below the ground, and flow occurs through a sand or gravel bed (Davis, 1994). *Arundo donax* L. (giant reed, Poaceae) is a potentially high- yielding nonfood plant, which can be used for the production of paper pulp, energy and wooden building materials. Giant reed prefers wet conditions, but can be found in areas ranging from moist, well drained soils to areas with a water table near surface (Vollmer *et al*, 2009). The very survival of reed species in pebble covered site along roads of Jabalpur indicated that they can grow in a gravel medium for rhizofiltration of desired pollutants. Investigation was therefore carried out to assess the efficacy of *Arundo donax* grown in wetland model for up-gradation of water quality.

Materials and methods

A sub-surface rectangular wetland model made up of stainless steel of size 4’x 2’x 1’ (Length, width and depth) was developed for the treatment of waste water. The three zones were maintained in the model including inlet, middle zone as a treatment bed and outlet zone. The 10 percent space was allocated each for the inlet and outlet zone. The gravel of 1.5-3.0” was filled into the entire inlet (0.5’x 2’ x 1’) and outlet zone (0.5’x 2’ x 1’). The treatment zone (3’x 2’x1’) was filled with media into different layers. The bottom layer was filled with gravel of larges size (1.5-3”), followed by gravel of 0.5-1” cm) followed by pea gravels (0.37-0.5”) at the surface layer. Prior to filling the gravels were washed with water followed by 0.02 per cent nitric acid. The *Arundo donax* plants were collected from the *Ukhari* road, Jabalpur. The rhizomes of Arundo donax were planted at a spacing of 15cm x 10 cm and the rows were perpendicular to the direction of flow in the bed zone. The treatment zone was kept on a stand at a height of 30 cm and its T type inlet pipe (having 10 apertures) was connected with sedimentation overhead tank no. 1 (75 lit capacity) put at a height of 120 cm followed by tank no.2 (150 cm litre) at a height of 77.5 cm (Fig 1). Prior to waste water treatment, the plants were irrigated with the tap water as and when required. The water level was maintained 2-3 cm below the surface level. After the spreading of the roots up to the bottom layer, the treatment of drain water was given. The various water quality parameters before and after treatment was measured. The heavy metals in water were analyzed by Atomic absorption spectrophotometer (Thermo Solar S4 model) and nitrates by Microkjeldhal and phosphates by UV spectrophotometer. The chlorides, water reaction (pH) and electrical conductivity were analyzed by water testing kit (APHA, 1989).

Results and discussion

Water quality of drain water:

The water quality parameters of drain water are given in Table 1. The average reaction (pH) of untreated waste water was 7.85 with no seasonal changes. Electrical conductivity (EC) was ranged from 0.56 to 0.66 $dSm^{-1}$for waste water during winter and summer respectively. The chlorides were 70 mg/l during summer which was higher than winter (55 mg/l) however found within the permissible limit of FAO. The average nitrates content in waste water during summer and winter seasons were 56 and 50 mg/l respectively which were beyond the prescribed limit. No seasonal wide variation regarding phosphorous (8-10 mg/L) was observed. The heavy metals viz. iron, manganese, copper and nickel during winter and summer were 1520, 620, 290, 220 and 2000, 800, 327, 349 ug/L respectively. However, the heavy metals concentration in waste water in both the seasons was beyond the irrigation quality standards of FAO.

Table 1: Assessment of quality of waste water in the drain along rail tract.

Parameter	Winter	Summer	Average	Permissible Limit of FAO
pH	7.9	7.8	7.85	6.5-8.4
EC (d Sm^{-1})	0.56	0.66	0.61	0.7-3.0
Chlorides (mg/L)	55	70	62.5	<140
Nitrates (mg/L)	50	56	53.0	<40
Phosphates (mg/L)	10	8	9.0	NA
Iron (ug/L)	1520	2000	1760	<1000
Manganese (ug/L)	620	800	710	<200
Copper (ug/L)	290	327	305	<200
Nickel (ug/L)	220	349	280	<200

NA=Not applicable

Table 2: Performance of Arundo donax in a wetland model.

Parameter	Average concentration		% reduction of pollutants
	Drain water (before treatment)	Drain water (after treatment)	
pH	7.91	7.85	NA
EC (d Sm^{-1})	0.65	0.62	NA
Nitrates (mg/L)	50	15	70
Phosphates (mg/L)	3.5	2.0	42.8
Ni (ug/L)	340	150	55.8
Cu (ug/L)	320	190	40.6

NA=Not applicable

Table 3: Height of Arundo donax grown in the sus-surface model.

Row-wise plant height starts from inlet zone (cm)							Mean
Row I	Row II	Row III	Row IV	Row V	Row VI	Row VII	
95.46	78.86	79.42	76.84	68.24	64.42	64.08	75.33

Fig. 1: Sub-surface horizontal wetland system including sedimentation and treatment zone.

Fig. 2: Spreading of roots of Arundo donax in gravel medium of treatment bed.

Fig. 3: Change in color of water before and after treatment of waste water.

Performance of wetland model:

The wetland model was consisted of sedimentation and treatment zone for sedimentation and treatment of waste water respectively (Fig. 1). In respect of water flow through gravel medium, no clogging was occurred in treatment zone resulting free discharge of purified water through the outlet. This could be due putting over the pea gravel on the layer of 0.5-1" leaving no scope for infiltration in the present studies as opposed to the reports of putting pea gravels over the 1.5-3" gravel layer infiltrates the bigger pores of 1.5-3" gravels which contributes to clogging (Taylor *et al*, 2007). Moreover, if the gravels below the 0.37" such as sand or soil if filled in surface layers gets mixed in the pore spaces of gravels in the layer below contributes to clogging. It was observed that the plant population increased from 35 plants at the time of planting to the 150 plants at the time of treatment with waste water. The average height of the *Arundo* plant was 75.33 cm. Except the border rows of row number 1 and row number 7 and height of row no 3 which was at par with row number 4, the variation in plant height was observed (Table 3). The average plant height was found in following decreasing order in the direction starts from inlet towards the outlet zone: Row 2 $<$ Row 4 $<$ row 5$<$ row 6. This may be due to the more accumulation of nutrients available to the plants in these rows than the lesser nutrients available at the rows nearer to the outlet zone. After maturity of plant, the roots penetrated downward through the gravel medium were resulted in a complete root zone filter ready for treatment (Fig 2).

After the treatment, lower concentrations of nitrate were observed in filtered water (15 mg/l) as compared to its higher content in untreated water (50 mg/l). The reduction of nitrogen in the treated water to the extent of 70 per cent was due to removal of nitrate content by reed plant in sub surface wetland partly through absorption and uptake by plant. Besides this the root zone of plant offered an oxidized microenvironment facilitating percolation of nitrate through oxygen poor zone in sub-surface medium where nitrate was removed by denitrification. These results are well supported by the findings of Juwarkar *et al* (1985) regarding efficient removal of nitrogen by similar reed plant such as *Phragmites carca*. Gersberg *et al* (1986) also reported nitrogen removal by aquatic plants in the constructed wetland. The lower concentration of phosphorous (2.0 mg/l) was observed in the treated water as compared to the untreated water (3.5 mg/l). The lower nutrient efficacy of phosphorus may be due to non use of soil or lateritic material in the bed zone. In respect of chlorides, iron and manganese no change in their concentration was observed during treatment. As far as metal removal is concerned, the plant grown in filter bed resulted decrease in the concentration of nickel and copper from 340 to 150 and 320 to 190 ug/L respectively which were within the prescribed limit of irrigation (Pescod, 1992). The reduction of nickel and copper to the extent of 55.8 and 40.6 percent respectively was due to the ability of reed plant for removal of heavy metal through their absorption and accumulation. This is confirmed by the findings of Deng *et al*, 2004 that *Arundo* accumulated higher nickel concentration in the wetland. The drastic change in a color of the filtered water sample was observed as compared to the yellowish color before treatment (Fig 3). This may be due to withholding of the suspended particles by well spread entangling root system of tested plant which resulted in reduction of the color, which is confirmed by the reports of Joseph *et al* (2001) that change in color of waste water occurs because of functioning of reed root as a filter bed.

Conclusion

It is clear from the studies that the untreated waste water carries higher pollutant concentration indicated above the prescribed limit for irrigation purposes. Looking to the scarcity of water during dry period in peri-urban areas the use of waste water in agriculture after its proper treatment is the option. In this respect, having ability to grow successfully in a gravel medium and phyto-filtration potential for pollutants, locally available *Aundo donax* can be utilized for treatment of waste water in constructed sub-surface wetland for irrigation purposes and as a preventive measure for reduction of aquatic weed infestation in surface water bodies.

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