Wastewater treatment using artificial wetlands

Eva Maciaszek, E. Schiller, L. Fernandes and R. Miglio, Peru

PERU IS A country plagued by serious water shortage problems. Half of the total population of 22 million lives in the coastal region, which is 95 % desert. Water shortages contribute to the current situation where only 42 % of the people have access to tap water (Marmgren, 1999), and then generally only for several hours per day. Sanitation services are lacking for 56 % of the total population. Only 5 % of the sewage in Peru is treated before being released into the environment (Marmgren et al., 1999). Half of the land that could potentially be used in agriculture is unused. Because of the limited water availability 4, 300 hectares of agricultural land are irrigated with wastewater, 86 % of which have not passed through any form of treatment (Shinkai, 1999).

To change this situation, it is necessary to increase the percent of wastewater that is treated and reused. As well, it is important to introduce regulations for its reuse taking into account the health of the populations and the economic limitations of the developing countries.

The major focus of wastewater treatment in Peru is the suitability of the treated effluent to be subsequently reused in agriculture (Green, 1996). Used for irrigation, the treated wastewater provides nutrients for crops, eliminating the need for additional fertilizer, without jeopardizing the health of the population.

Bahri et al. proposes that the best approach for wastewater treatment and reuse is first to consider the final end use of the water before designing a wastewater treatment plant. This approach would provide treatment objectives that would then be applied to the particular treatment system. (Bahri, 1999)

In the study described in this paper, pilot scale vertical flow wetlands were evaluated as a potential wastewater treatment system for agricultural wastewater exiting from swine farm. The criteria used for evaluation were based on water quality requirements for irrigation.

Wetlands are a technology well suited for sustainable development in the third world. They are relatively inexpensive to construct, and their maintenance and operation is relatively straightforward.

Description of treatment system

The experimental setup was located at Universidad Nacional Agraria La Molina, an agricultural university in Lima, Peru. It was comprised of two vertical flow artificial wetlands, one with plants, *Cyperus alternifolius*, and one without plants.

Each wetland was composed of two barrels (250 L each) in series. The first barrel of the series supported descending flow and the second barrel ascending flow. Three separate flows, 20, 10 and 5 ml/s were compared in their effect on treatment. The planted and unplanted wetlands were also assessed for ability to remove wastewater constituents.

Water quality requirements for reuse of wastewater in agriculture

Guidelines are available for maximum recommended concentrations of various wastewater constituents that will allow for irrigation without adverse effects on crops, soils and humans consuming the irrigated products. Table 1 provides these values. (Green, 1996)

The World Health Organization has also published standards for wastewater reuse in agriculture with regards to micro-organisms. For irrigation of crops that will be consumed raw, a fecal concentration of less than 1000 per 100 ml is recommended. Additionally, in the case of fruit trees, treated wastewater should not be used in irrigation

Table 1. Maximum recommended concentrations of wastewater constituents for water used in irrigation, to prevent adverse effects on humans, crops and soils

Parameter	Units	Value for Sensitive Crops	Value for Resistant Crops
pH	pH units	6.0- 8.5	6.0- 8.5
Ammonia nitrogen	mg NH_4- N /L	30	35
Organic nitrogen	mg org-N /L	40	50
Nitrate nitrogen	mg NO_3-N /L	5	30
Electric conductivity	mS /cm	2	3

two weeks prior to harvesting. Furthermore, fruit that has fallen on the soil should not be collected. (Green, 1996)

Heavy metals are not expected to be present in the wastewater evaluated in the experimental set up since the wastewater originated from a swine farm.

Wastewater constituents evaluated in this study include, pH, electric conductivity (EC), ammonia nitrogen, organic nitrogen, nitrate and fecal coliforms (FC).

Evaluating treatment system performance

With regard to the standards for effluent use in irrigation, the results show that ammonia nitrogen, organic nitrogen and nitrate were removed to an acceptable level for irrigation. Fecal coliform count and electric conductivity were too high for safe reuse. (table 2) The wetland performace can be further analysed using results from a database containing information on other wetland treatment systems.

The Gulf of Mexico Program (GMP) Livestock Wastewater Treatment Wetland Database (LWDB) contains data from 68 sites with total of 135 pilot and full-scale wetlands. These research results indicate that average concentration reduction efficiencies that can be expected when using constructed wetlands are: NH_4-N 48% and TN 42%. The fecal coliform reduction on average was just over 1 log unit from 160, 477 to 13, 424 coliforms/100 ml, for an average removal rate of 92%. Conductivity was reduced on average by 21%. Very little change between inlet and outlet values of pH was observed. Typically, pH inlet values were between 6.0 and 8.4 units. (Knight, 2000)

For the study carried out at UNALM, the differences in reduction rates between the three flow rates and the unplanted and planted wetlands were found to be statistically insignificant. However some trends can be observed in the results. The lack of statistical significance is more of a reflection of the small sample size of three for each of the six conditions, rather than true lack of difference in removal rate between the three different flow rates and the two wetlands. Past studies have shown that inflow flow rate and the resultant retention times do affect treatment efficiency of artificial wetlands (Tanner, 1995a,b). Variability of the wetland influent is also a major factor contributing to the resultant statistical insignificance between results obtained at the various run conditions. The results are summarized in table 2.

The wetland containing Cyperus has higher ammonia removal rates, average of 37%, than the wetland that was unplanted, average of 22%. These are below the average removal rates of the systems summarized in the LWDB. Nitrification followed by denitrification is the major removal mechanism of ammonia in wetlands. (U.S., 2000) Nitrification, converting ammonia to nitrate, is dependent on aerobic conditions and the presence of nitrifying bacteria. Subsequently, nitrate is reduced to nitrogen gas (N_2) and nitrous oxide (N_2O) in the denitrification process that occurs under anaerobic conditions. The vertical wetland design used in this study provided mostly anaerobic conditions since it was continually flooded. A small aerobic layer of a few centimeters at the surface of the soil layers can be expected to be present (Reddy). Lack of larger aerobic zone could be the limiting factor for ammonia removal in this vertical wetland design. Higher removal rates in the planted wetlands can be attributed to plant uptake of inorganic nitrogen present in soil solution and additional nitrification in the aerobic layers found around the roots of the plants (Reddy).

Main removal mechanism of organic nitrogen is through ammonification where it is converted to ammonia. Though

Table 2. Wastewater constituent average removal rates at the flowrates of 20 ml/s, 10 ml/s and 5 ml/s for the vertical flow wetlands located at UNALM

Parameter	Unplanted Wetland % removal (mg/ L)			Planted Wetland % removal (mg/L)		
	20 ml/s	10 ml/s	5 ml/s	20 ml/s	10 ml/s	5 ml/s
pH	7.71	7.80	7.67	7.44	7.51	7.33
Ammonia nitrogen	29 % (15.12)	20 % (8.25)	16 % (16.45)	53 % (19.83)	34 % (20.95)	25 % (15.23)
Organic nitrogen	51 % (26.01)	33 % (7.45)	52 % (10.96)	60 % (18.08)	18 % (0.81)	54 % (4.63)
Nitrate nitrogen	70 % (16.86)	28 % (43.06)	48 % (24.22)	91 % (7.66)	net increase	19 % (16.63)
Fecal Coliforms (NMP CF/100ml)	97 % 5.3E+08	99 % 8.0E+10	98 % 4.2E+12	83 % 4.7E+07	97 % 1.4E+11	98 % 3.7E+13
Electric conductivity (mS/cm)	0.93 % (5.26)	3.19 % (5.16)	3.49 % (5.73)	increase of 3.58 % (6.14)	2.64 % (5.68)	increase of 4.23 % (6.07)

it occurs in both aerobic and anaerobic environments, it proceeds at a significantly faster rate in the presence of dissolved oxygen. No clear trends were observed in the obtained results.

Relatively low concentrations of nitrate were entering the wetland, on average 3.21 mg NO_3/L. Similar trend is observed for nitrate and organic nitrogen reduction (table 2).

These removal rates for fecal coliforms are very close to the average removal rates reported in the LWDB. However, because the high concentrations of FC in the influent, the high removal rates still result in unacceptably high effluent values, making it unsuitable for irrigation. The observed trend is an increase in reduction with diminishing flow rate and increased retention time (table 2). At the higher flow rate, the unplanted wetland gave higher removal rates than the planted one. Flocculation and sedimentation are main mechanisms of removal. These are the same mechanisms that remove settleable and colloidal solids. (U.S., 2000) At lower flow rates the flow through the wetlands is more quiescent allowing for better settling of solids.   In this wetland design, there were no permanent open water areas, therefore solar radiation likely did not play a major role in FC reduction.

The pH of the wastewater at all stages was within the desired limits of treated wastewater destined for reuse. In the vertical flow artificial wetland the pH was between 6.73 and 7.91. On average, the unplanted wetland had lower pH values than the planted one. As observed in the LWDB, the inlet and outlet values did not vary much.

The EC, a measure of wastewater salt concentration, was high coming into the treatment system, average of 5.70 mS/cm. It did not vary much as the wastewater passed through the wetlands. For the unplanted and planted wetlands, the effluent average EC values were 5.56 and   5.79 mS/cm respectively. These values are too high for wastewater reuse in irrigation. As supported by the results in the LWDB, treatment wetlands have little effect on the salt content of the wastewater (Knight, 2000). Irrigation techniques exist that can reduce the effects of wastewater with high salt concentration, on the crops. Additionally, salt sensitivity varies with crop types; therefore crops that are more salt resistant would be a better candidate for irrigation with treated wastewater with high salt content then those that are less resistant. (Ayers, 1987)

Possible improvements to design that could lead to increase of treatment efficiency

The size of the wetland limited the flow rates and subsequently the retention times that could be used for the wetlands. Various studies have shown improved removal rates with increased retention times (Tanner, 1995a,b)

For nitrogen reduction, an aerobic environment preceding anaerobic one is essential. Several techniques have been investigated for increasing dissolved oxygen levels in treatment systems. These include recycling (Laber, 1997), using air tubes (Green, 1997), and reciprocation (Behrends, 1996).

Reciprocation involves alternate draining and filling of adjoining subsurface flow wetlands in tandem. As a wetland is drained, biofilms surrounding the substrate are rapidly oxygenated. With subsequent filling of the wetland, anaerobic wastewater comes in contact with the oxygenated biofilm, coupling aerobic and anaerobic environments. Significant increase in nitrogen removal has been observed using this technique in a number of studies. (Behrneds, 1996, Green, 1997)   As well, the alternative draining and flooding leads to better distribution of nutrient laden wastewater. (Behrends, 1996) Introducing this technique to the existent experimental system at UNALM would necessitate the use of pumps increasing the cost and complexity of operating the treatment system. Another alternative would be to build the second wetland of a series at a lower level then the first, allowing for flow by gravity. Valves allowing for filling and draining of wetlands could be controlled manually. With relatively small volumes, more time could be allowed between filling and draining making manual control a viable alternative.

In a study by Laber et al. recycling was used to attain high nitrogen removal rates. A vertical flow wetland was operated without soil saturation and was fed intermittently, four times a day. Part of the nitrified effluent was pumped back to the preceding settling tank, which provided anaerobic conditions and necessary carbon for subsequent denitirfication. (Laber, 1997) This technique again would require the implementation of pumps raising the costs and complexity of system operation.

Improved nitrogen removal rates have also been observed when air pipes are used in intermittently filled vertical flow wetlands, ventilating the lower media layers (Green, 1997).

Removal of fecal coliforms is dependent on surface area available for adsorption and filtration. This implies that increasing the size of the wetland would lead to increase in fecal coliform removal rates. Another way of increasing treatment area is to increase the number of wetlands in series. This was shown to be effective at reaching high removal rates for pathogenic organisms (Gerba, 1999).

Conclusion

Two vertical flow systems were evaluated in treatment of livestock wastewater. Treatment efficiency of the system was evaluated based on the intended reuse application, which was irrigation. The performance of the wetland was also compared to the Livestock Wastewater Treatment Database removal rates. The planted wetland showed higher removal efficiency than the unplanted wetland. In both cases however, treatment levels were not sufficient to meet irrigation water quality standards. Several changes that could be made to the treatment system to improve wastewater constituent removal rates were described.

Modifications to the described system could provide an efficient, simple and low cost treatment system that could benefit Peru in helping to alieviate the problem of water shortages.

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EVA MACIASZEK, Peru