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Biomass Nutrient Recycling

An affordable closed-cycle process with added benefits

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The cost of conventional wastewater treatment (anaerobic filters, activated sludge, and centralized piping systems) has proved too expensive for many countries, including Brazil, Tanzania, and China. Building costs are more than $1000 per inhabitant for small scale treatment facilities that serve up to 10.000 people. Communities that can pay capital costs often find they cannot support the annual maintenance fees of more than $100 per capita. For these reasons, many international institutions, including the World Bank, have concluded that conventional approaches to managing human waste are inadequate for providing sanitation and clean water to the majority of the world's population.

The high cost of installation and maintenance is one reason more than 90% of the world's wastewater is discharged to oceans untreated. The World Organization reports that water contaminated by wastewater causes 8 of the 10 most frequent fatal diseases. To address health and cost concerns, scientists have conducted studies of plant-based biological wastewater treatment. In the 1980s, Steve Serfling developed integrated systems involving digesters and fish using wastewater in California, while K.R. Reddy, who lectures at several universities in Florida, used water hyacinths for wastewater treatment and researched applications for the macrophytes. Eneas Salati improved soil bed filtration in Sao Paulo, Brazil, by analyzing and mixing local soils to improve biochemical oxygen demand (BOD) reduction. Little of this research, however, had measured the potential success of combined wastewater purification and recycling nutrients. Researchers at Hamburger Umweltinstitut e.V., based in Hamburg, Germany, in 1990 started planning a biomass nutrient recycling project for 600 residents in a neighborhood of Silva Jardim, Rio de Janeiro, Brazil. The institute, in cooperation with the Brazilian nongovernmental organization O Instituto Ambiental, has constructed, modified, and tested biomass nutrient recycling in tropical zones of Brazil since 1991, including for example, the city of Petropolis. The research was funded by the European Commission, Henkel chemical company, Bayer do Brazil chemical company, Ciba Geigy Foundation, the City of Petropolis, Silva Jardim, and private donors.

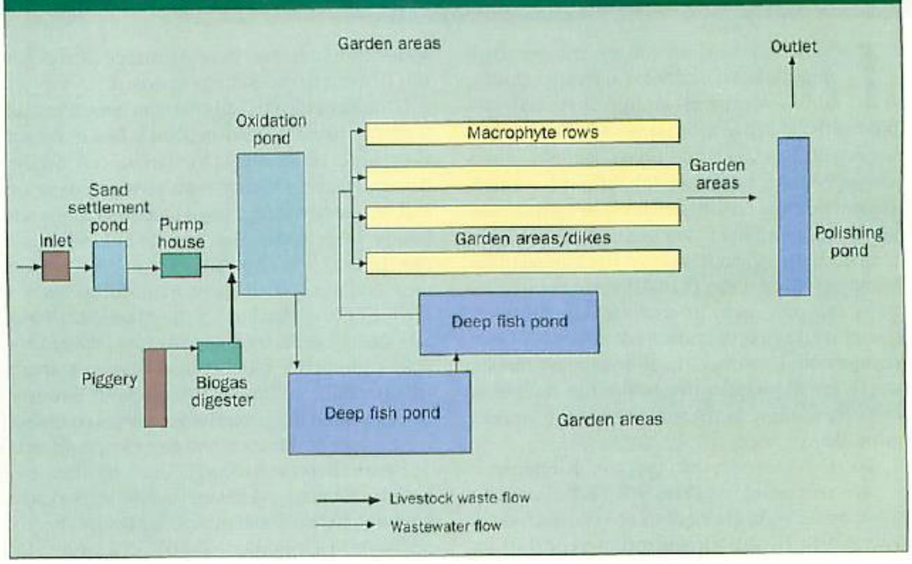
Biomass nutrient recycling is based on the efficiency of natural systems. The process purifies wastewater by reducing BOD, nutrients, and coliform and recovers nutrients for agricultural production by closing nutrient cycles, such as recycling fertilizer onsite instead of transporting it to a landfill or discharging it to natural waterways. The technology uses biomass and related biological processes such as macrophytes, soil-based plants, sludge, photosynthesis, and composting to treat wastewater and recover nutrients through naturally occurring resources – such as sunlight and soil.

In addition to water purification, the Silva Jardim project sought to determine how many ways facility land could be used beneficially (for agriculture, habitat biodiversity, flood control, and soil regeneration). With this information, researchers could evaluate the viability of converting waste nutrients into products and services.

Silva Jardim Site

The Silva Jardim facility was developed for research purposes but also was designed to provide municipal wastewater treatment service to inhabitants once the study was completed in 1995. Currently, wastewater is conveyed through sewer pipes from the neighborhood to a shallow-entrance sand-settlement pond. Wastewater flows a few meters to the pump house, where it is pushed to the adjacent oxidation pond at the highest elevation on the site (see Figure 1). Gravity pulls wastewater a few meters to two serial, deep fish ponds, where nutrient mineralization and pathogen elimination processes continue. A central distribution box splits the wastewater stream into similar flows to four macrophyte ponds , which are divided into four sections. Macrophytes take up nutrients, and their root systems filter wastewater and eliminate pathogens. Throughout each of the processes, oxidation and coliform reduction occur through exposure to sunlight and natural aeration.

Figure 1. Facility Component Modules at Silva Jardim



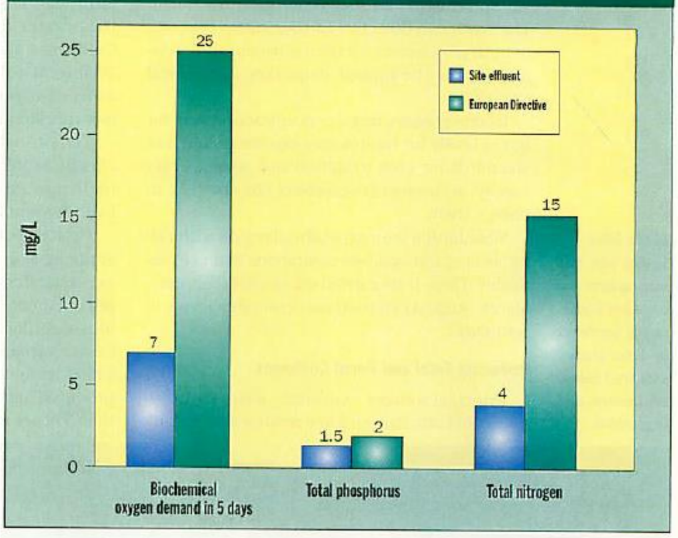
Effluent from the macrophyte ponds reaches the garden area, which is outfitted with subsoil irrigation pipes, and passes to a final polishing pond. Throughout the process, water and nutrients are absorbed into dikes on pond borders. Treated wastewater discharges to a stream that feeds a large lake, which provides drinking water for the area. Wastes form livestock are treated in an underground digester, and mineralized effluent discharged into the oxidation pond then follows the flow path described above.

Silva Jardim uses about half of the 1-ha site for wastewater purification processes. Because the treatment processes biomass nutrient recycling, the site also supports agricultural production, fertilizer recovery, and carbon dioxide absorption by plants. Water absorbed passively into dikes that contain ponds also is used for crops; aquaponic cultures and water fowl both use the pond space; and subsoil irrigation systems simultaneously provide final wastewater disposal and support agricultural production. In addition, the site provides soil regeneration (from macrophyte composting and passive irrigation), wildlife vegetation, and flood protection. Conventional facilities typically provide wastewater treatment, sometimes onsite flood control, and wildlife habitat near stabilization ponds. Alternative wastewater treatment systems are known for their high ratio of surface area per inhabitant equivalent (5 to 10 m^2/inhabitant equivalent). However, as indicated by the above described uses, when integrated land use at the facility was quantified, land-use flexibility was found to be superior to conventional facilities. From 1992 to 1995, the monitoring program at Silva Jardim indicated that biomass nutrient recycling met Brazilian and European discharge standards for wastewater treatment facilities, including reducing coliform to safe levels.

Wastewater Purification

Purification is necessary before wastewater can be used for agricultural production. Conflicting reports have been published regarding health implication of using wastewater for agricultural products destined for human consumption. To address this, the researchers examined BOD, phosphorus, nitrogen, and other substances. They found that natural processes reduced BOD by 97%; influent concentration averaged 226.3 mg/L and effluent concentration averaged 6.7 mg/L. An effluent standard of 10 mg/L BOD was set in 1986 by the Brazilian Ministry of Urbanization and Environment for irrigation water used on cereal crops (such as wheat and corn), trees, or grassland or for animal water supply. The standard set in May 1991 by the European Directive for urban wastewater treatment is 25 mg/L and 70% to 90% reduction. Average influent concentration of total phosphorous was 8.16 mg/L, reduced by 81% for an average of 1.54 mg/L in the final outlet (see Figure 2). The European Directive concerning urban wastewater treatment requires a total phosphorous discharge up to 2 mg/L or a minimum reduction of 80% for flows to areas subject to eutrophication.

Figure 2. Silva Jardim Site Effluent Compared to European Union Standards



The biomass nutrient recycling process at Silva Jardim reduced total nitrogen from a concentration of 20.7 mg/L to 4.1 mg/L, an 80% reduction. This meets the standard (10 mg/L) set by the state testing agency FEEMA for discharging wastewater to natural waters and the European Directive requirement (15 mg/L or a 70% to 80% reduction for discharge to areas subject to eutrophication) for urban wastewater treatment. The European Directive further states that one or both parameters for total nitrogen and phosphorous may be applied, depending on the local situation.

Incoming heavy metal concentrations were far below levels for wastewater discharge and met standards for crop irrigation and animal water supply, so project researchers did not seek to reduce them.

Silva Jardim is an agricultural region with cattle farming and fruit tree plantations that use pesticides. Three tests carried out in 1994 (February, March, August) showed no detectable levels of pesticides.

Reducing Total and Fecal Coliforms

Principal sources of drinking water contamination in Latin America are wastewater leaking from centralized pipes, open wastewater drains contaminating drinking water wells and groundwater, and wastewater outlets to rivers. This contamination and odor can be readily detected by walking the streets in Rio de Janeiro and examining the appearance of rivers. Researchers found that the Silva Jardim facility reduced coliform counts to safe levels. Incoming concentrations of fecal coliform as high as 1.6 billion most probable number (MPN)/100mL were recorded. Average inlet and outlet concentrations were approximately 170 million MPN/100mL and 2000 MPN/100 mL, respectively. The Brazilian Ministry of Urbanization and Environment standard for water used to irrigate cereals, trees, grassland, or for animal water supply is 4000 MPN/100 mL. European law does not address coliform in wastewater discharges, but European Union Guidelines allow a maximum concentration of 2000 fecal coliform per 100 mL for swimming waters. On average, the Silva Jardim facility also met this standard.

The site, which was turned over to the municipality in 1995, is operated by a private operator that receives some technical support from O Instituto Ambiental.

Capital costs, excluding modifications for scientific research, were less than $50.000, or $90 per inhabitant-equivalent, compared to $1000 per inhabitant equivalent for conventional facilities meeting similar standards. Net operating costs (expenses less revenues) are $3000 to $7000 annually, depending on types of crops produced and operator competence. This is less than $13 per inhabitant-equivalent. These costs vary substantially according to local situations, but in any case, are lower by orders of magnitude than costs associated with conventional facilities, especially when pipes are factored into the accounting.

Product Testing

Pigs, ducks, fish vegetables, and fruit produced on the Silva Jardim site were tested for pathogen contamination. Parasitology tests of pigs raised onsite showed no contamination. Meat was certified by government testing authorities as suitable for human consumption. No test result differences were found between pigs raised onsite and control pigs bought at the market. Parasites were found in feces or intestines of both kinds of pigs but were not considered to affect meat quality. Analysis of ducks raised onsite showed that all animals were considered “in good condition” or “in optimal condition for human consumption”. Although parasites were found in the intestines of some fish, they were declared fit for human consumption by the government testing laboratory. No parasites found in the intestines were transmittable to humans.

Principal safety measures were developed to minimize farmer/operator chances of contamination, including using gloves and boots, harvesting fish without entering ponds, and getting regular health checks at the local clinic (selective pathogen and general health examination).

Test results indicated that produce without direct soil contact (for example, cane and different bean varieties) were free from parasites. However, fruits or legumes in contact with soil or meant to be eaten raw were not approved for human consumption. These plants should not be grown until operational schemes, such as composting processes, have been optimized.

However, if these fruits or legumes were cooked or disinfected to kill pathogens, they may be suitable for animal feed. Human consumption would be feasible only after tests of cooked vegetables confirmed suitability.

Latin America communities with populations of 10.000 to 200.000, which house a large percentage of the continent's population, border on lands that could be used in the same way as the Silva Jardim facility.

This facility model is unsuitable for areas in large cities where high density architecture requires other wastewater solutions. However, experience since the Silva Jardim project indicates components of the system can be adapted to suburban and urban areas that have space available for landscaping.

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