Livestock Research for Rural Development Volume 11, Number 1, 1999

The productive water decontamination system: A tool for protecting water resources in the tropics

J Chará, Gloria Pedraza and Natalia Conde

Aquaculture and Recycling Research Group. Centro para la Investigación en Sistemas Sostenibles de Producción Agropecuaria (CIPAV) Carrera 35A Oeste # 3-66, Cali, Colombia. E-mail: julian@cipav.org.co, gloria@cipav.org.co, natalia@cipav.org.co

Abstract

Farming activities can cause important impacts on the environments due to the discharge of wastewater into streams, rivers and lakes. Wastewater treatment systems available for farms are highly specialised, costly to implement and maintain and therefore are beyond the means of most small and medium-scale farmers in the developing world. However, agriculture wastewater treatment can be effectively undertaken through biological processes involving the activity of microorganisms such as bacteria, algae, fungi, plants and animals. This approach has been used for many years in South East Asia in the integrated aquaculture-agriculture systems developed there. The Productive Water Decontamination System developed by CIPAV in Colombia uses this approach to reduce water and soil pollution, and converts the energy, organic matter and nutrients contained in the wastewater into elements that can be used in the farm, such as biogas, fertilisers, forages and food.

The system consists of a low-cost plastic tube biodigester and aquatic plant channels complemented by fish polyculture ponds and associated crops. Wastewater passes through the biodigester and then to the aquatic plant channels and the fishpond. As wastewater passes through the system, pollutants are transformed into biogas, aquatic plant biomass, food crops, and fish. In addition, Biochemical Oxygen Demand (BOD_5) and suspended solids are reduced up to 60-70% in the biodigester and up to 97% in the complete system as compared to the untreated wastewater.With this system, water decontamination can be a profitable activity, economically and socially attractive for farmers and producers in general.

Key words: Wastewater decontamination, biological purification, integrated decontamination, biodigester, aquatic plants.

Introduction

It is universally acknowledged that water becomes a critical resource as the growing population demands more and various factors reduce its quantity and spoil its quality. Out of 4,530 km^3 annually extracted from rivers and aquifers, an estimated 65 per cent is destined for agriculture, 25 per cent for industrial uses and 8 per cent for direct human consumption. A fraction of the water used mainly in urban and industrial settings is returned to rivers in a poor condition due to contamination. Water pollution caused by point and diffuse sources limits further use of the resource, especially for direct human consumption. Non-treated municipal sewage and effluents from industry, food processing and intensive animal husbandry, are the most significant sources of contamination (Lloyd 1992). Diffuse sources can be separated into atmospheric (mainly deposition of pollutants from fossil fuel combustion) and non-atmospheric (urban and agriculture runoff). At least 300,000 million cubic metres of wastewater and organic and inorganic residues are annually discharged into water bodies, causing a 40 per cent reduction of primary productivity in rivers and oceans. Poor water quality affects human health: in developing countries, polluted waters cause severe health problems and high infant mortality (Chará 1997a).

Agricultural systems contribute importantly to water pollution, mainly with suspended and sedimentable solids, nutrients, biochemical oxygen demand (BOD_5) and pesticides. The predominant trend towards specialised production and monoculture relies heavily on imported inputs and hampers the utilisation of by-products of each process. These systems give preference to short-term financial profits and do not consider natural resource degradation (Chapman 1992). Water pollution caused by solids, nutrients and BOD (an indirect way of measuring organic matter) implies environmental degradation and a loss of resources. These are very important for developing countries since production of chemical fertilisers is costly in energetic and economic terms, and loss of soil by erosion is difficult and expensive to remedy. Integrated production systems are more efficient in the use of resources. More possibilities of recycling wastes within farming systems become available as wastes from one process become inputs for another (Preston and Murgueitio 1992).

The technological development of water decontamination systems originated in industrialised nations. Due to prevailing social and economic conditions, the light and temperature annual variation, and the fact that such systems were developed mainly by engineers, the results have often been irrelevant to needs of developing countries. Water decontamination systems have tended to be highly specialised processes, costly to build and maintain, and in recent years, based on high amounts of inputs and energy. In addition, these conventional waste treatment systems are rarely linked to waste re-use such as irrigation, fertilisation or aquaculture. Moreover, they neither generate income or employment. There is therefore a need to develop or adapt simple, low-cost and practical waste management techniques, adequate for tropical conditions and available resources (Polprasert 1989).

Organic waste treatment and recycling can be more effectively carried out through biological processes involving the activity of microorganisms such as bacteria, algae, fungi, plants and animals. By-products of these processes include biogas, compost, fertiliser and protein biomass (Etnier and Guterstam 1997; Pedraza and Chará 1997). This approach is applied in the Productive Decontamination System developed by CIPAV, Colombia which uses elements such as the biodigester, aquatic plants and fish ponds to recycle the wastes generated in other production subsystems and to convert them into valuable products. In 1995, In 1995, the "Banco de Occidente" (Colombia) awarded CIPAV with the "Planeta Azul" (Blue Planet) National Ecology Prize, due to its work with the Productive Water Decontamination System and its participatory research process. The systems have now been introduced in various tropical countries.

Components of the productive decontamination system

Biodigesters

Biodigesters are airtight containers in which wastewater and faeces are fermented by bacteria. As a product of this process, a gas mixture of methane and carbon dioxide is obtained as well as an effluent with 60 per cent of the original BOD. Although the composition of biogas varies depending on the raw materials, the organic load applied, and the time and temperature, it is approximately equivalent to the following: methane (CH_4) 55-65 per cent, carbon dioxide (CO_2) 35-45 per cent, nitrogen (N_2) 0-3 per cent, hydrogen (H_2) 0-1 per cent and hydrogen sulphide (H_2S) 0-1 per cent (Chan 1993).

Because of its high calorific value (approximately 9,000 kcal/m^3), methane is the most desirable among the gases produced (Polprasert 1989). In rural areas, the most tangible benefit of biodigesters is the production of biogas, which replaces firewood, coal or electricity and can be easily obtained in the farm. Contrary to what happens with fossil fuels, biodigestion generates no pollution during production or combustion. As an additional benefit of the process the organic matter in wastes is reduced in 40 to 60 per cent without losing nutrient availability. Digestion increases the availability of nitrogen in organic wastes to above its usual range of 30 to 60 per cent. Phosphate and potash contents are not decreased. Anaerobic digestion also helps to inactivate some pathogenic bacteria, viruses, protozoa and helminth ova in wastes. However, biodigester effluents must be used with caution as a fertiliser for vegetables since some pathogens might persist after washing.

The digestion process involves the following steps: polymer liquefaction or partitioning; formation of acids; and formation of methane (Polprasert 1989). Extra-cellular hydrolytic enzymes produced by hydrolytic bacteria accomplish the first process. Acetogenic bacteria form acids, liberating CO_2 and H_2 in the process. Obligate anaerobic methanogenic bacteria release methane. Growth of these bacteria, which use acetic acid, methanol, carbon dioxide and hydrogen to produce methane, is generally slower than that of the bacteria involved in steps 1 and 2.

Different materials can be used to build biodigesters as long as they are completely waterproof. Some digesters are rigid as they are made of cement or a metallic bell on top of a cement base. Although these materials are durable they are too expensive for some farmers and the construction process is rather difficult. In contrast, plastic continuous-flow biodigesters (Botero and Preston 1986; Bui Xuan An et al 1997) have a low cost and their installation is easy. This design has proved efficient in gas production and the decontamination of pig unit wastewater (Table 1). A 9 m^3 biodigester can produce enough biogas to supply one burner for an average of 6.3 hours each day and to treat 600 to 800 litres of wastewater per day with good BOD_5 and solid removal rates (CIPAV 1998).

Table 1. Average decontamination in two plastic biodigesters in the municipality of Dagua (Valle del Cauca) Colombia. Average of 4 samples/biodigester (Pedraza et al 1996).

SITE	**BOD_5 mg/litre**	**Suspended solids mg/litre**	**Sedimentable solids* ml/litre**	**Nitrate mg NO_3/litre**
Biodigester inlet	6,462	18,935	538	0.9
Biodigester outlet	570.8	8,311	243	0.69
Removal, %	91	56	55	24

**Measured in an Ïmhoff cone after settling time of 10 minutes (Greenberg et al 1992)*

Low cost biodigesters have various advantages for rural families: workload is reduced because there is no need to gather and prepare firewood; discomfort from smoke disappears (an important benefit for women); pressure on natural resources (wood) is lowered; water and soil pollution is diminished; families gain access to low-cost energy; and facilities are easy to install and maintain.

As was previously mentioned, installation of the system is easy and can be carried out without specialised skills. Tubular polyethylene used for low-cost biodigesters is produced in most countries. Other materials and fittings are commonly available in local markets (Bui Xuan et al 1997). Polyethylene tube diameter ranges from 0.8 to 1.25 m (2.4 m diameter tube is suitable for bigger farms). Daily maintenance of the biodigester is limited to supplying the wash-water from pigpens and stables. If well protected from animals and solar radiation, the plastic lasts an average of five years, although it has been known to last up to nine years. The size of the biodigester must be adjusted to the amount of wastewater produced daily. In general terms, a 3

m^3 biodigester is enough for three to six pigs producing between 150 and 300 litres of residual water each day.

Aquatic plants

Aquatic plants are the next important step in water purification. They grow very well in organic-loaded water (including biodigester effluent) and create an appropriate environment for microorganisms that decompose organic matter and make minerals available for plants. The high productivity of these widely distributed plants and their spontaneous proliferation on slow water bodies, cause difficulties for navigation, irrigation and the production of rice and fish (Majid 1986).

Although the problem is global, it is more pronounced in tropical and subtropical waters, which allow the lavish growth of these species. However, if considered as a crop, aquatic plants have various advantages since they are highly productive, require no ploughing, fertilisers or seeds. They can be successfully used as food, feed, soil additives, fuel or in wastewater treatment. Generally, they are more productive than conventional terrestrial crops, and since they grow in wastewater, do not compete with these for water, land or nutrients. Fresh weight, dry weight and protein production recorded for some aquatic plant species in Colombia and Cuba are given in Table 2.

Table 2. Aquatic plant production in ponds fertilised with wastewater (Chará 1995; Domínguez et al 1995)

	Duckweed	**Azolla**	**Water hyacinth**	**Salvinia**
Yield (tonnes/ha/year)				
Fresh matter	521	569	2190	691
Dry matter	16.9	34.2	131	27.6
Crude protein	6.1	9.6	13.4	6.08

Nutritive value

Aquatic plants have been traditionally used as animal feed in many tropical and subtropical countries, especially in Asia. It is currently accepted that these plants can be used to feed different farm animals, including fish, which consume them in natural environments. The dry matter content of these plants is between 5 and 15 per cent compared to 10 to 30 per cent reported for different terrestrial species. Their chemical composition is highly affected by the aquatic environment in which they grow. Raw protein content is equivalent to 10 - 36 per cent of the dry weight, higher (especially for *Lemna* sp.) than that recorded for terrestrial plants (Nguyen Duc Anh and Preston 1997). At least 80 per cent of the nitrogen in water hyacinth (*Eichhornia crassipes*), *Pistia striatotes* and hydrilla (*Hydrilla verticillata*) is in the form of protein. Mineral content is between 8 and 60 per cent of the dry weight, although sediments stuck to roots contribute a proportion. Although they are richer in iron, calcium and sodium, the amounts of phosphorus, magnesium, sulphur, manganese, copper and zinc are similar to those recorded for terrestrial species.

It must be noted that some aquatic plants have higher concentrations of carotenes and xantophylls than terrestrial species and that high concentrations of toxic substances in the water can cause high concentrations in the plants as well.

Table 3. Proximal analysis of water hyacinth *(Eichhornia crassipes*) and duckweed (*Lemna* sp) cultivated in wastewater in the Cauca Valley, Colombia (Pedraza et al 1996)

	Water hyacinth	**Duckweed**
Dry matter (%)	15	3.3
As % in dry matter		
Crude protein	10.2	36

Ether extract	15.5	4.5
Crude fibre	11.8	10.7
Ash	13.6	8.46

Use as organic fertiliser

Aquatic plants are good sources of organic fertiliser since many have considerable levels of nitrogen, phosphorus and potassium. Besides their nutrient contribution, they improve soil structure and increase water retention capacity, which is very important in sandy, lateritic and heavy clay soils, widely distributed in tropical countries. If the aquatic plants are directly placed on top of the soil, irrigation and weed control requirements of crops are reduced. Water plants can also be transformed into organic fertilisers through composting or vermi-compost production (Chará 1997b). Given their high water content, the production sites of crops, compost or vermi-compost should be close to water channels to avoid transportation costs (CIPAV 1998).

Use in wastewater decontamination

Contrary to common opinion, aquatic plants themselves do not perform much water treatment, in terms of reduction in biochemical oxygen demand (BOD_5). Their function is to provide an environment for species that do improve water quality. In this respect, their role is similar to that of activated sludge and slow filtering systems which, by facilitating physical sedimentation and bacterial metabolic activity, are the main removal mechanisms in conventional techniques (Polprasert 1989).

Table 4. Functions of aquatic plants (Stowell et al 1980)

Plant parts	Function
Roots and/or stems	Provide surface for bacterial growth in water column Are media for filtration and adsorption of solids
Stems and/or leaves	Prevent growth of suspended algae Reduce the effect of wind on water Reduce gas transfer between atmosphere and water. Transfer oxygen from leaves to root surfaces.

A significant reduction of BOD_5, nitrogen, phosphorus and heavy metal contents is achieved through the combined effect of bacterial activity, sedimentation of slowly flowing solids and chemical reactions. Plants absorb dissolved materials and incorporate them into their own structure, extracting pollutants from water and thus causing less environmental harm. Through their harvest and utilisation, an additional benefit is obtained, since nitrates, ammonium compounds, phosphates and organic compounds extracted from wastewater are nutrients frequently required by agricultural systems. These, particularly nitrogen and ammonium, are energetically and financially costly to produce and such costs usually imply foreign currency for developing nations and farmers (Gijzen 1996).

Aquatic plant production is a practical and environmentally friendly way of purifying municipal wastes and wastewater from industry, pig production and dairy units, with low operational costs and no sophisticated technology requirements for implementation. Removal of 91 per cent BOD_5, 98 per cent of suspended solids and all sedimentable solids was recorded in a decontamination system established at a small farm to depurate residual water from six to eight pigs in the south-west of Colombia (Table 5). This system has two 3 m^3 biodigesters, three water hyacinth channels (with a total area of 13 m^2) and a 28 m^2 pond covered with *Lemna* plants.

Table 5. Decontamination of pigpen residual water with water hyacinth (*Eichhornia crassipes*) and duckweed *(Lemna sp).* Average of five samples (Pedraza 1997).

Sampling site	BOD_5 mg/litre	Suspended solids mg/litre	Sedimentable solids ml/litre	Nitrate mg NO_3/litre
Biodigester inlet	8900	38208	825	69
Water hyacinth channel inlet	1100	5418	135	0.40
Water hyacinth channel outlet	375	164.5	0.55	0.64
Duckweed pond outlet	95	89	<0.1	0.30

In a larger-scale system, a 17 m^3-biodigester and 130 m^2 of water hyacinth were used to treat residual water from 80 sows. Reduction of 97 per cent BOD_5, 93.8 % suspended solids and 99.9 % of total solids was recorded in the water plant section (Table 6).

Table 6. Decontamination of sow unit residual water with water hyacinth *(Eichhornia crassipes)* (Pedraza et al 1996)

Sampling Site	BOD_5 mg/litre	Suspended solids mg/litre	Sedimentable solids ml/litre	Nitrate mg NO_3/litre
Channel inlet	1350	2854	50	1.3
Channel outlet	35	175	<0.1	0.22
Removal rate, %	97.4	93.8	99.9	83.1

Aquatic plants can be placed directly in channels excavated in the ground. If the soil is too permeable, the channels should be lined with cement or a mud and cement mixture. Their length must allow the retention of wastes for at least ten days. For example, the daily purification of 100 litres of wastewater requires 1 to 1.5 m^3 of channel volume (10 m length x 0.4 m x 0.4 m). The only maintenance activities required are the harvest of aquatic plants as channels get filled and sediment removal from the first channel every four to six weeks. Sediments can be applied to crops, while plants can be directly used to feed animals or as green manure (Chará 1995; CIPAV 1998).

Fish polyculture

The association of fish with different feeding habits is one of the most important practices to use the available pond food effectively and thus increase fish yield. Although algae cells grow profusely in nutrient rich water, their small size (generally less than 10 µm) is a limitation for the available harvesting techniques. This can be solved using phytoplankton-feeding fish that harvest this protein-rich biomass (more than 50 per cent of protein on dry matter basis). "Pollutants" are decomposed by bacteria and converted into biomass by plankton, which is consumed by fish. The fish, in turn, can be harvested as a nutritious and high-value product. Fish control algal and bacterial growth, contributing to water quality improvement. In a wastewater-fed pond at equilibrium, feed for fish is produced by algae; wastes are decomposed by bacteria; and foraging activity of fish avoids plankton overgrowth and mortality by excessive oxygen consumption during the night (Polprasert 1989; Chan 1993).

Fish density is an important factor, since at high densities there will be more nutrient uptake and hence more decontamination but less fish growth; at low densities, individual fish growth will be maximised but nutrient uptake will be lower. In waste-fed ponds, care should be taken to keep adequate levels of dissolved oxygen and ammonia.

In a fish polyculture established as a part of a decontamination system evaluated in 1995, fish production was equivalent to 2741 kg/ha/year. Polyculture was composed of Nile tilapia (***Oreochromis niloticus***), cachama (***Colossoma macropomum***) and bocachico (***Prochilodus***

reticulatus). The stocking densities used were 0.31, 0.33 and 0.17 fish m^{-2} for tilapia, cachama and bocachico respectively. The fishpond was fed with the effluent of an aquatic plant pond where the wastewater from a dairy stable was treated. Fish were also fed with bore (***Alocasia macrorhiza***) leaves and *Azolla* (Chará 1995).

Associated terrestrial crops

In conventional decontamination systems, areas adjacent to ponds or water channels are not productive. However, if plants are allowed to grow around these facilities, they can use the nutrients captured by aquatic plants, as well as the sediments periodically extracted from the channels.

Integration of terrestrial crops to embankments has the following advantages: additional income is obtained from crops planted on dikes; sediments extracted from the bottom of the channels are easily applied to crops, thus reducing the cost of organic fertiliser; enriched water from ponds and channels available for crop irrigation contributes additional nutrients; pond and channel water with high mineral content is directly obtained through the roots, except when plants are small and are watered; fruits and vegetables can be used as food for fishes; and plants strengthen the dikes, improving their water-retention capacity.

In general, plants with non-invasive and moisture-tolerant root systems can be planted on the embankments. Crops most commonly planted in decontamination systems in Colombia are plantain (***Musa paradisiaca***), papaya (***Carica papaya***), bore (***Alocasia macrorrhiza***), sugar cane (***Saccharum officinarum***) and nacedero tree (***Trichanthera gigantea***) (Pedraza et al 1997). The latter is a native tree used for forage production in Colombia. Under local conditions it produces about 10 ton of dry matter ha/year with 18 per cent of protein in the foliage dry matter (Gómez et al 1995).

Socioeconomic aspects

In Colombia, as in other developing countries, water pollution taxes are being created or reinforced and polluters have to pay for contaminating water sources. In order to tackle this situation, it is necessary to invest in costly decontamination systems that add up to the expenses of the productive processes. However, the Productive Decontamination Systems installed so far in Colombia have demonstrated that adequate treatment of pollutants can generate revenues.

A system installed at El Vergel Farm in El Dovio, Colombia, to treat the wastewater from 4 to 6 pigs, associated with the production of plantain, papaya and fish, generated an annual profit of US$266 and savings in the use of firewood (US$2.24/week) or electricity (US$15/month) and artificial feed (US$15.6 pig/year) (Pedraza et al 1997). In Philippines, Moog et al (1997) found that plastic bag biodigesters were paid back in eleven months as a result of the savings in liquefied gas.

As a strategy to spread this innovation among small landholders, CIPAV invested the money of the Blue Planet award in a special fund called "*Small Initiatives for Water*". Two other Colombian NGOs contributed to the fund. Until July 1998, 70 per cent of the interests from this fund had been used to finance 35 proposals, of which 51 per cent were decontamination systems and 40 per cent were aimed at protecting springs and streams. The remaining 30 per cent of the interests are used to re-capitalise the fund. Farmers must submit written proposals including a budget with their contribution (generally manpower) and the amount solicited to the fund. A committee, of which farmers make a part, selects the proposals to be financed and evaluates their results, once implemented. This has stimulated the installation of decontamination systems by low-resource small farmers, who sometimes need individual support to cover the expenses.

Large entrepreneurial farmers finance the system with their own resources or through commercial credit, provided by the income that can be generated through the system. Experience has revealed that large farmers are mainly interested in replacing the electric power required in their productive units by biogas. When land is available, they use the biodigester effluent as a fertiliser for crops and pastures that also generate revenues through crop, milk and meat production.

Due to the cost of energy and the possibility of replacing it directly by biogas, biodigesters are the most appreciated element of the system. *Lemna* production in aquatic plant channels is also important for farmers since it can directly replace commercial feeds. The implementation process of a simple system in which changes in water quality can be clearly observed allows people to understand the process and become more conscious about the rational use of water. From this point of view the system can be used as a strategy of environmental education. All members of the family can get involved in management of the system.

Conclusions

These systems can provide several benefits described as follows:

Environmental benefits

- The main environmental benefit is the reduction of water pollution (60-70% of reduction in BOD_5, and Suspended Solids in the biodigesters and up to 97% when aquatic plant channels are included).
- Partial or total reduction in the demand of firewood or fuel in rural areas as a result of the production of biogas in the decontamination process.
- Recycling of organic matter and nutrients which reduces the use of chemical fertilisers.

Economic benefits

- Reduction of costs of collecting or buying firewood, or buying fuel, electricity or gas.
- Reduction of production costs as a result of the production of organic fertilisers and feeds in the farm.
- Production of fish and other foods that can be used either as food for the family or as a marketable product.

Social benefits

- Total or partial substitution of firewood by biogas that improves work conditions in the kitchen.
- Improvement in the quantity and quality of water available in rural communities.

It is demonstrated that the Productive Decontamination System is a very effective way of controlling water pollution. It is based on the use of solar energy (photosynthesis), and does not need fossil fuels, chemical fertilisers or pesticides and can be adapted to the technical and socioeconomic conditions of each farm.

References

Botero R and Preston T R 1987. Low cost biodigester for production of fuel and fertilizer from animal excreta. ACP EEC Convention of Rome. Wageningen.

Bui Xuan An, Rodriguez L, Sarwatt S, Preston T and Dolberg F 1997 Installation and performance of low-cost polyethylene tube biodigesters on small-scale farms. World Animal Review. 88 (1):38-47 FAO

Chan G 1993 Aquaculture, Engineering lessons from China. AMBIO Vol 22 (7): 491-494.

Chapman D 1992 Water Quality Assessments: A guide to the use of biota, sediments and water in environmental monitoring. Chapman and Hall. London 585 p.

Chará J 1995 Producir y descontaminar: Las ventajas de integrar las actividades agropecuarias con la acuacultura en condiciones tropicales. MSc Thesis. Maestría en Desarrollo Sostenible de Sistemas Agrarios. Universidad Javeriana. Bogotá, 88p.

Chará J 1997a Uso del recurso hídrico en el mundo y perspectivas para su manejo sostenible. Forero and Durana (eds) Sabanas, Vegas y Palmares: El uso del agua en la Orinoquia Colombiana. Corpes Orinoquia, Santa Fe de Bogota, 332 p.

Chará J 1997b Producción de energía y biomasa a partir de la excreta porcina. IN: Manejo de elementos de la producción porcina que puedan causar efectos ambientales. Asociación Colombiana de Porcicultores, Cornare, Corantioquia. 156 p.

CIPAV 1998 Descontaminación de aguas servidas en la actividad agropecuaria. Manual técnico. 13p.

Conde N, Chará J, Pedraza G 1996 Evaluación de un sistema de descontaminación de aguas a través de organismos y plantas acuáticas. Final Report ECOFONDO. CIPAV, 148 p.

Dominguez P, Guerra and Molinet 1995 Utilización de plantas acuáticas en el tratamiento de aguas residuales en instalaciones porcinas. Revista CENIC Vol 26 No. Especial. Resúmenes XII Seminario Científico. Cuba.

Gijzen H 1996 Anaerobic wastewater treatment: An important step in rational re-use strategies of nutrients and energy. IN: Proceedings of the IV Seminario-Taller Latino Americano sobre el Tratamineto Anaerobio de Aguas Residuales, Bucaramanga, Colombia.

Gomez M, Rodriguez L, Murgueitio E, Rios C, Molina C, Molina C, Molina E and Molina J 1995 Arboles y Arbustos Forrajeros Utilizados en Alimentación Animal como Fuente Proteica. CIPAV, Cali, 129p.

Etnier C and Guterstam B 1997 Ecological Engineering for Wastewater Treatment. CRC Press Inc. Boca Raton, 451 p.

Greenberg A, Clescer L and Eaton A 1992 Standard methods for the examination of water and wastewater. 18th edition. APHA, AWWA, WEF. EPS Group Inc. Maryland.

Living Water 1996 Ecological design principles for pond and wetlands based systems. Living Water, Edinburgh. Printed 7p.

Lloyd R 1992 Pollution and Freshwater Fish Fishing New Books, Oxford. 176 p.

Moog F, Avilla F, Agpaoa E, Valenzuela F and Concepcion F 1997 Promotion and utilisation of polyethylene biodigester in smallhold farming systems in the Philippines. Livestock Research for Rural Development. (9) 2: http://www.cipav.org.co/lrrd/lrrd9/5/phil95.htm

Nguyen Duc Anh and Preston T R 1997 Effect of management practices and fertilisation with biodigester effluent on biomass yield and composition of duckweed. Livestock Research for Rural Development. (9) 1: http://www.cipav.org.co/lrrd/lrrd9/1/anh91.htm

Nguyen Duc Anh and Preston T R 1998 Effect of exchange rates of medium with biodigester effluent on biomass yield and composition of duckweed. Livestock Research for Rural Development. (10) 1: http://www.cipav.org.co/lrrd/lrrd10/1/anh101.htm

Nzamujo and Bossou 1993 No water to waste: Biological Purification. ILEIA Newsletter 93 Vol 9 (1) 20-21p.

Pedraza G 1997. Implementación y evaluación de un sistema de descontaminación de aguas servidas con plantas acuáticas. M Sc Thesis. Maestría en Desarrollo Sostenible de Sistemas Agrarios. Universidad Javeriana - IMCA - CIPAV. 89p.

Pedraza G and Chará J 1997 Aspectos Tecnicos y Conceptuales en la Descontaminación Productiva De Aguas. En: Osorio, H. and Espinel, R. (eds) Memorias del V Seminario-Taller Internacional en Sistemas Sostenibles de Producción Agropecuaria. Cali, Julio 31 a agosto 3 de 1997. CIPAV.

Pedraza G Conde N and Chara J 1996 Evaluación de un sistema de descontaminación de aguas a través de la produccción de organismos y plantas acuáticas. Report. CIPAV, Cali, 106p.

Pedraza G Conde N and Chara J 1998 Evaluación económico–ambiental de un sistema de descontaminación de aguas a través de plantas acuáticas integrado a la producción agropecuaria. CIPAV, Cali. (In press) 16p.

Polprasert C 1989 Organic Waste Recycling, Asian Institute of Technology. Bangkok. John Wiley and Sons London. 357p.

Preston T R and Murgueitio E 1992 Strategy for sustainable livestock production in the tropics. Cali. SAREC-CIPAV. 89p.

Stowell R, Ludwig R, Colt J and Tchobanoglous G 1980 Towards the rational design of aquatic treatment systems. Paper presented at the ASCE Convention, 14-18, Portland, Oregon. Department of Civil Engineering, University of California, Davis, California.

Received 20 December 1998

Go to top