Duckweed Ponds for Sustainable Sanitation in Developing Countries

Martin SEIDL[(1)], Sani Laouali[(2)] and Jean-Marie Mouchel[(1)],

(1) CEREVE, 6-8 Ave. Blaise Pascal Champs sur Marne, 77455 Marne la Vallée, France,
contact : seidl@cereve.enpc.fr
(2) UAM, Faculté des Sciences, Département de chimie, B.P.10662, Niamey, Niger

Abstract

We have studied the possibility of wastewater treatment in a system of urban agriculture based on stabilization ponds and duckweed producing ponds for fish breeding. The goal of the study was on one hand a check up of the treatment potential of duckweed under African conditions and on other hand estimation of financial possibilities of nutrient recovery in a duckweed – Tilapia agro-sanitary system.
We used a small pilot system at the university of Niamey (Niger), composed of 3 ponds with microphytes and 3 ponds covered with duckweed. The duckweed was harvested 3 times a week and fed to Tilapia in adjacent pond. The ponds were fed with 3.5 m^3/day of wastewater, corresponding to a global charge of 1.1 kg-BOD^5/day or 130 kg/ha/day. The first results give a relatively good efficiency for standard parameters like DCO and DBO : (about 70 %) and for nutrients N and P (about 80 %). Excellent pathogen removal of 4 log units (>99.95%) satisfied the discharge norms for agricultural reuse. Mean duckweed productivity was about 25 10^3 kg/ha/month depending on the nutrient charge. The results of Tilapia farming gave a satisfactory production of 475 $kg_{w.w.}$/ha/month. The global benefits of such a system might be about 1000 € /month for a unit treating 5000 inhabitant equivalents.

Keywords

Duckweed; stabilisation ponds; reuse; ecological sanitation; wastewater treatment; macrophytes; urban agriculture; Africa

INTRODUCTION

The African cities are, on one hand submitted to demographic expansion and, on the other hand to the consequences of the rural exodus. These factors increase the water consumption and the needs for management of wastewaters.
Because of the demographic pressure on the land, the elimination of solid and liquid wastes by mean of individual sanitation becomes less and less feasible. Urban environment and receiving waters become more and more fragile and ask for better protection against pollution.
The wastewater treatment by means of stabilization ponds is, compared to other techniques, relatively simple and inexpensive (Sperling 1996). Its economical yield may be improved by means use of the vegetal biomass production, and can constitute a credible alternative for the treatment of wastewater waters in periurban areas of West Africa.
A system that couples wastewater treatment and agricultural production meets the needs of sustainable water management. On one hand water is recycled and on other hand nutritious elements are recuperated and transformed in useful biomass. Such an agro-sanitary system makes a cheap treatment possible and may even become financially auto-sufficient. It's based on environment friendly technology, accessible to most of the developing countries. The advantages appear not only at the ecosystem level, but also in the social and economic sector as result of employment creation.

MATERIEL & METHODS

The main objective of the project is to test on small scale and under African conditions, the treatment of wastewater in a lagoon system using duckweed. The objective was double : to assess

the treatment efficiency of a system producing biomass and to evaluate the direct reuse in fish farming.
This system was inspired by previous experiences of CENHICA in Guyaba (Santiago, 1997) the reports of Sandec (Iqbal 1999) and World Bank (Skillicorn 1993) on duckweed and aquaculture, following the guidelines given by Oron (1994), UNEP (1997) and Charbonnel (1989). As far as we know wastewater treatment by duckweed was not studied before in West African countries.

Pond system
The University of Niamey operates since 1998 a pilot plant for domestic wastewater treatment based on stabilisation ponds. This plant is composed of 3 lines of treatment, each composed of 6 trapezoid basins with an area of 14 m² each, one meter of depth and an approximate volume of 7 m^3 (Idder et al 2000).
The duckweed treatment was studied from February to May 2002, in a serie of 6 basins. The first three basins used microphytes and the last three were covered with duckweed. During the day the system received 5 loadings of 700 litres (3.5 m^3/day) of wastewater from the university campus.
The fish was placed in separate tank to prevent contact with particulate matter from wastewater and the growing macrophytes.
Classical waterquality parameters (N,P,DBO, DCO, pathogens) were estimated according to the French standards (AFNOR).

Table 1 : Operational parameters of the duckweed system anaerobic basin load 160 g/m3/j facultative basin 325 kg/ha/day load treatment capacity 3.4 m²/equivalent (mean for the 3 basins)

flow	**evaporation**	**residence**	**load**	**duckweed**		**basin dimensions**	
in – out	micro – macro	min - max		density	production		
m3/day	mm/day	day	kg BOD/day	g/m²	kg/ha/j	m^3	m²
3.5 – 2.8	8.4 - 7.5	12 – 15	1.1	230	500 –1500	7	14.2

Macrophytes
The macrophytes used belong to the family of Lemnacea, habitually called duckweed and were collected from water ponds near the university where they grow naturally. The duckweed was harvested each two days by collecting between 30% and 50% of the surface of each basin. The harvested biomass was used for the growth estimation and for Tilapia feeding. The N-content of duckweed was estimated after drying at 60°C by the ISO method for Kjeldahl nitrogen.

Tilapia
The fish pond, with an area of about 30 m² and a depth of 50 cm was divided in two equal sections by a plastic grid and sown with minnows of Tilapia nilotica originating from the adjacent river Niger. The starting size was about 10 cm (12g) and initial density about 5 individuals a square meter (70 g/m²).
In one part, the fish were not fed, while in the second part, the Tilapia were fed with 500 grams of Duckweed freshly harvested on the three basins (Skillicorn 1993)In both compartments the fishes could feed on naturally present invertebrates and plankton.

RESULTS
We have chosen to design a highly loaded system to evaluate the possibilities of treatment in a compact pond system. The surface needed for treatment (3.4 m² per inhabitant) is only one third of the surface used in France (11 m² per inhabitant). Despite the short residence time (15 days for the whole system, taking in account the evaporation) the obtained results indicate a fair treatment efficiency (picture 1).

The results of table 1 show that the treatment efficiency of our pilot depends primary on the action of bacteria and microphytes in the first three basins. In less than one week more than 50% of pollutant load were removed. The duckweed has no effect on COD removal, a slight effect on BOD but very significant action on N, P removal. Seven day of residence in the duckweed section may not be enough to eliminate particulate BOD coming principally as phytoplankton from the microphytes basins . On the other hand harvesting can introduce or reintroduce some suspended solids in the water body.

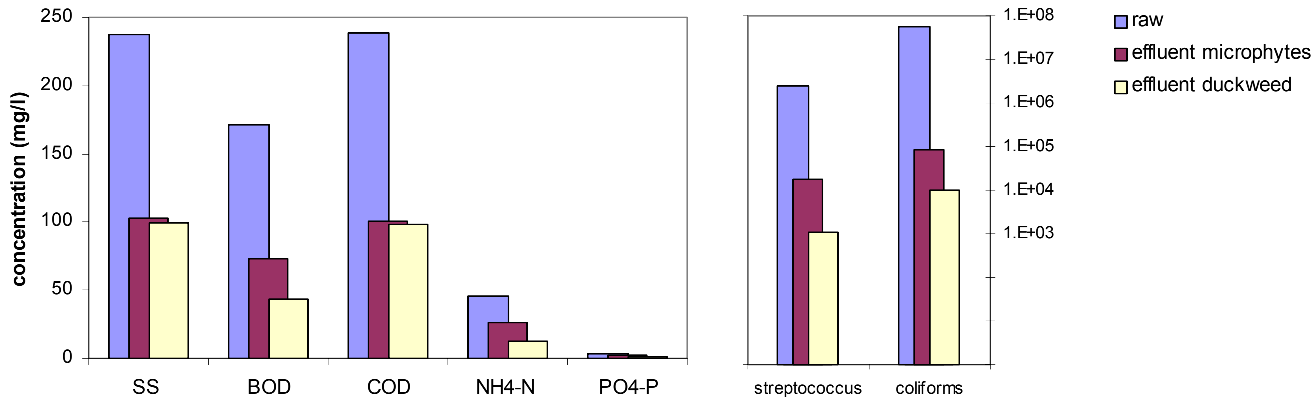
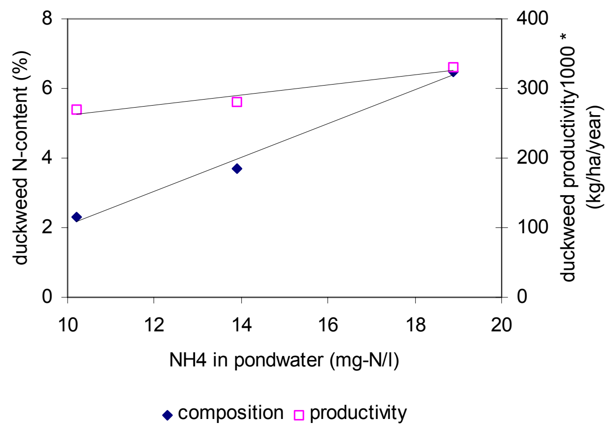


Figure_1 : Treatment efficiencies for the microphytes and duckweed section

The average efficiency of pathogen removal is satisfactory during the whole period and the effluent content of streptococci is meeting the WHO norm of 1000 CFU a 100 ml. The principal way of pathogens removal is the sun radiation in the microphyte section. The diminution of pathogen in the duckweed ponds can not be explained fully by the duckweed harvesting (Seidl et al 2003), suggesting a specific mechanism for pathogen removal in the duckweed ponds.



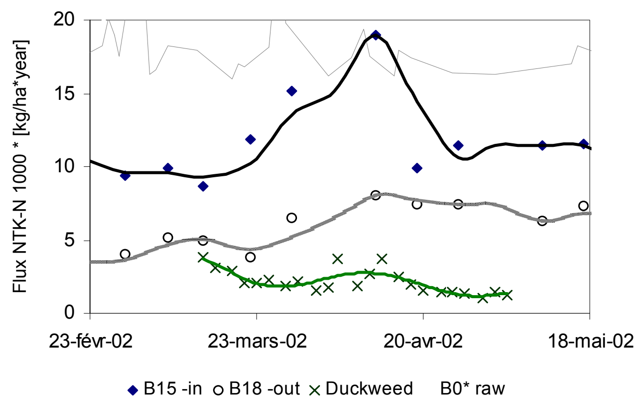


Figure 2 and 3: Estimation of the nitrogen fluxes in the phytoplankton and duckweed section

The average production of duckweed in our pilot was about 820 kg/ha/day decreasing as mentioned above from 1390 to 360. - The average standing crop was kept about 0.2 kg/m². As mentioned in the literature (Iqbal 2001, Santiago 1997) the nitrogen content of the harvested duckweed was strongly correlated to the N-content of the pod water (figure 2)

During the test period the maximum temperature of water rose gradually up to 35°C. This increase was followed by increasing ammonia which attained 30 mg/l of NH_4-N. Combination of both factors altered the duckweed growth at the end of the experimentation. The optimum temperature for duckweed growth is about 30 to 32°C depending on the specie (Iqbal 1999) and further rise inhibits its growth. A comparable action was established for ammonium by Caicedo et al (2000) suggesting 20 mg/l of NH_4-N as maximum.

As can be observed in figure 3 the most important organisms in the nitrogen cycle are bacteria, followed by phytoplankton and macrophytes. At the beginning of April we can see an increase of nitrogen flow from the maturation pond to the duckweed section. This is most probably due to algal bloom. As the standing crop is almost constant we can estimate that the withdrawn quantity by duckweed harvesting is equal to that produced and thus the N-flux is equal to N-assimilation rate 2.2 $*10^3$ kg-N/ha*year (1.1 to 3.8). During the production period the mean N-load of duckweed section was $14*10^3$ kg-N/ha*year, while $6.7*10^3$ kg-N/ha*year left by the overflow. The duckweed assimilation accounted for almost 30% of nitrogen removal in the macrophyte section. The remaining decrease is most probably the result of nitrification / denitrification processes.

One of the direct valorisation forms of harvested macrophytes is fish breeding (Iqbal 1999, Alaerts 1996, Skillicorn 1993). The fish form a product with a more important added value than the macrophytes themselves. The aquaculture is the most simple application of duckweed, because the plants do not need to be stored, transformed or transported.
During the study we have obtained a fish production of 5.6 10^3 kg/ha/year for the fed population and 4.3 10^3 kg/ha/year for the non-fed population. This order of magnitude agrees with data given by Iqbal (1999) which states a production of 7 10^3 kg/ha/year in mixed fish culture using duckweed as sole fish feed. The conversion ratio of duckweed of 4.5% for the fed Tilapia is rather low compared to 10% given in the literature (Skillicorn 1993). Compared to the natural fed population this ration or the gain obtained by duckweed feeding was only 1.5 due to abundant natural feed.

Thanks to high nutritional value, comparable to soybeans, duckweed represents a strong market value. It can be compared to another local plant the Bourgou (Equinocloa stagnina), which is used as animal feed. The market price of duckweed is most probably situated something lower than that of Bourgou commercialised at 25 CFA([1])/kg. We estimate it at 100 CFA a bucket or between 10 and 30 CFA/kg. The usual price of the carp (Tilapia) is between 800 and 1200 CFA/kg. Taking a duckweed surface of 1.7 m²/habitant used in our pilote and a the productivity achieved a treatment capacity of 1000 equivalents can generate monthly 150 000 CFA (230 €) by means of fish production. This amount roughly equilibrates operating costs (electricity, device renewal and wages). The conversion ratio of duckweed – Tilapia should be at least 2.5% to make fish cultivation financially attractive, otherwise a direct commercialisation of duckweed as animal feeding (chicken) should be preferable. Low duckweed prices and high conversion factors make fish breeding an optimal solution.

CONCLUSIONS & DISCUSSION

Our results show the feasibility of the wastewater treatment in a urban agro-sanitary system. The stabilisation ponds used, attains removal efficiencies for BOD and COD comparable to other systems in the region, but with significantly better pathogen removal. Only 3.4 m² were needed to treat an equivalent of habitant. The effluent meets the WHO guidelines for reuse in agriculture. To obtain a lower concentrations of carbon and nitrogen in the effluent a lower load or a higher residence time can be applied. The utilisation of settler/digester at the entrance of the treatment.
The macrophytes play an important role in the elimination of the nutriments as nitrogen and phosphorus. About 20% of the dissolved nitrogen entering the duckweed system was immobilised

[1] CFA local currency in 12 countries of West Africa, 655 CFA = 1 Euro

and extracted with the harvest. Nevertheless the bacterial action remains the most important factor in the N-balance. The duckweed production obtained is comparable to that described in the literature (Steen 1998, Vermaat 1998, Santiago 1997, Alaerts 1996, Edwards 1992) and represents about $300*10^3$ kg/hectares/year of fresh weight. For an optimal duckweed production care should be taken to maintain the temperature and the ammonium below 30 mg-N/l and 30°C.
The study showed that a Duckweed – Tilapia system is able to generate sufficient income for the maintenance and operating of treatment facilities starting already at 1000 habitant equivalents. Once the treatment facilities set up, the maintenance can be financed by means of urban agriculture. Such agro-sanitary systems can form a solid base for sustainable wastewater treatment in West Africa.

REFERENCES

ALAERTS G. J., RAHMAN MAHBUBAR P., KELDERMAN P. (1996) Performance analysis of a full-scale duckweed-covered sewage lagoon water research : 1996, vol. 30, no 4, pp. 843 - 852 [10 pages.]

CHARBONNEL, YVES (1989) Manuel du lagunage à macrophytes en régions tropicales. Rapport ACCT (Agence de Coopération Culturelle et Technique -13,quai André Citroen - 75015 Paris)

J. R. CAICEDO, N. P. VAN DER STEEN, O. ARCE AND H. J. GIJZEN (2000). Effect of total ammonia nitrogen concentration and pH on growth rates of duckweed (Spirodela polyrrhiza), Water Research, Vol.34 (15):3829-3835

EDWARDS P., HASSAN M. S., CHAO C. H. AND PACHARAPRIKITI C. (1992) Cultivation of duckwoeds on septage-loaded earthen ponds. Biosource Tech 40, 109-117.

IDDER, T. & LAOUALI S.M. (2000) Experiences pilote (Aquadev- UAM Niamey) de traitement des eaux usées urbaines par lagunage Séminaire International sur l'Assainissement Urbain en Afrique, Dakar-Gorée, 18-12-2000

IQBAL Sascha (2001) Duckweed Aquaculture Potentials, Possibilities and Limitations for Combined Wastewater and Animal Feed Production in Developing Countries EAWAG SANDEC (http://www.sandec.ch/files/duckweed.pdf)

ORON G. D. PORATH and H. JANSEN (1987) Performance of the duckweed speciaes Lemna gibba on municipal wastewater for effluent renovation and protein production Biotech.Bioeng 1987(29):258-267

SKILLICORN, P.; W. SPIRA; W. JOURNEY. (1993). "Duckweed Agriculture. The New Aquatic Farming System for Developing Countries". The World Bank. Washington DC. USA.

SANTIAGO, J. F; M. DEL C. NOVOA; A. CANO; A. CERVANTES (1997) Tratamiento de Residuales porcinos y domesticos mediante el cultivo de Lemna. Voluntad Hidraulica (87):54-60

SEIDL Martin , Sani Laouali, Tahar Idder and Jean-Marie Mouchel (2003) Duckweed - Tilapia system : a possible way of ecological sanitation for developing countries. Proceedings of IWA conference AGUA 2003 Multiple uses of water for life & sustainable development 29 septembre - 3 octobre 2003, Cartagena de Indias, Colombia

SPERLING Marcos von (1996) Comparison among the most frequently used systems for wastewater treatment in developing countries. Water Science and Technology Vol 33(3):59–72

STEEN P. A.BRENNER & G. ORON (1998) An integrated duckweed and algae pond system for nitrogen removal and renovation. Water.Sci. Tech. (38):335-343

VERMAAT J. E., KHALID HANIF M.1998 Performance of common duckweed species (Lemnaceae) and the waterfern Azolla Filiculoides on different types of waste water Water research : 1998, vol. 32, no 9, pp. 2569 - 2576 [8 pages.]

UNEP (1997) Appropriate technology for sewage pollution control in the wider Caribbean region. United Nation Env. Program rapport and appendix 195p *www.unep.org*