Contribution of macrophytes to treatment processes in stabilization ponds. - Example of duckweed and water hyacinth.

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Abstract

Recently different systems of waste water and biomass reuse were studied in systems of stabilization ponds in the arid area of Niger. The objective of the presented study was to verify if waste water could be satisfactory treated in a pond system with continuous macrophyte harvesting. Two local aquatic plants, duckweed and water hyacinth were tested in a system of ponds using different hydraulic and BOD loadings. The results show a significant contribution of the water plants to the treatment process. At a production rate of 200 T-d.s./ha/year for water hyacinth and 20 T-d.s./ha/year for duckweed a removal efficiency of more than 70% was achieved for S.S, COD and TNK. The hyacinth contributes already at low residence time (4 days) to suspended solid removal (80%), being almost two times more effective than classical ponds. Duckweed contributes better to the treatment when placed at the head rather than at the end of the treatment file. On the other hand only 20% of TNK can be removed with the biomass, 4 times more for hyacinth than for duckweed. The contribution to the nitrogen removal is far more important in the open ponds. The same can be established for the pathogens, where the removal is far (100 fold) better in open ponds than in the duckweed ponds, most likely due to better light penetration. A good treatment efficiency and satisfactory level of biomass production can be better achieved if different subsystems are combined. The application of water plants in ponds is only usefull if the produced biomass is harvested.

Keywords

waste water, treatment, stabilization ponds, nutrient reuse, duckweed, water hyacinth

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.

The difficult economical conditions in West Africa make a quick set up of public equipment such as collective sanitation not very probable. The national policies of decentralisation give the responsibility of wastewater treatment to the local government. Knowing, that the latter have generally little financial income, the possibilities of mobilization of financial resources become once again more difficult. The wastewater treatment by means of stabilization ponds is, compared to other techniques, technically straightforward, inexpensive and the best choice for the developing countries (Von Sperling, 1996). Reuse of effluent and production of useful vegetal biomass, may constitute substantial financial benefits and cover partially or completely the operation costs of the waste water treatment system.

The biomass can be produced directly by using the pond surface or indirectly using the effluent for crop irrigation or aquaculture. The first method has two advantages, no extra land space is needed and the aquatic plants may contribute to the treatment. It has been established the aquatic plants help to settle suspended matter and withdraw nutrients and are more and more used in treatment systems (Kivasi, 2001). Though, if the plants are not harvested they will increase the organic matter flux towards the system. Another disadvantage of plants is the diminution of light penetration and though the diminution of disinfection potential of the system.

Since few decades the water plants are used with more or less success in waste water treatment (EPA, 2000). The widespread water hyacinth (*Eichhornia crassipes*) has been studied in improving effluent from oxidation ponds and as major component in integrated, wastewater treatment systems. Water hyacinth, though known as plague in water resource control, forms an attractive support for bacteria through its extensive root system and rapid growth rate. Promising experiences showed a potential of hyacinth biomass conversion to bio combustible or fibber source (lit). Other common water plant is duckweed (*Lemna minor*), studied for its ability to withdraw nutrients and heavy metals. The major advantage of duckweeds is its small size and its natural presence in almost all water ecosystems, while their major disadvantages have been their shallow root systems and wind sensitivity. Duckweed was successfully used as animal feed in poultry farming and aquaculture (Seidl et al 2003).

This study was a part of a European project on wastewater treatment and urban agriculture in West Africa. The objective was double: to assess the efficiency of simple treatment system under hot arid conditions, and to evaluate the possibilities of production of useful biomass. The transformation of biomass in aquaculture was already described by Seidl et al (2003) and the valorisation of effluent in agriculture by Seidl et al (2008). This article aims to determine the role or value of water hyacinth and duckweed in the treatment process.

METHODOLOGY

The University of Niamey (Niger, West Africa) 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, one meter depth and an approximate volume of 7 m3. The effluent was used for irrigation. Classical parameters of water quality like, conductivity, DBO, DCO, N, P and Coliforms were estimated according to the French standards (AFNOR) and the standards of AWWA (2002) for the raw waste water and the effluent of the each pond, whereby total and dissolved fractions were measured. The dissolved fraction was obtained by gentle vacuum filtration through Whatman GF/F glass fibre filter. The effluents of each pond were sampled once a week during a period of six month.

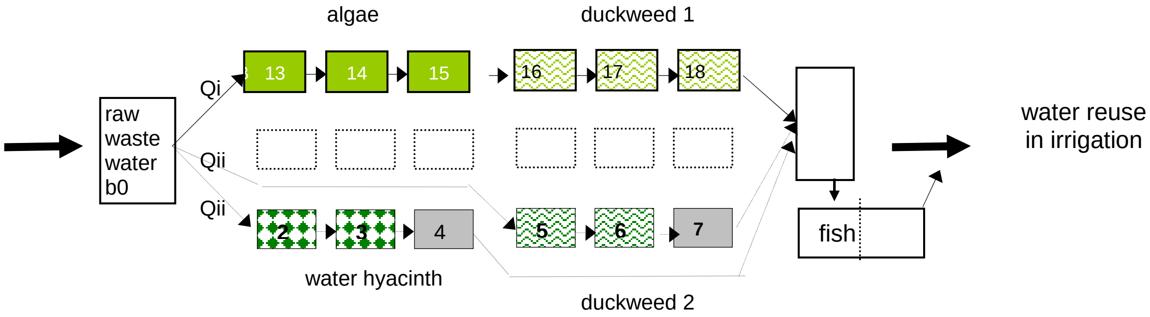

Figure 1. The over all set-up of the experimental treatment plant

The evaporation and evapo-transpiration were measured in vessels of 1 m² and 30 cm depth, covered or not by the water plants, by measuring the volume of water lost each day. The (evapo) transpiration was constant with the time for algae and duckweed, but rise for hyacinth due to the rise of temperature. The water temperature (3 PM at 10 cm depth) rose gradually during the experimental period from 25 to 31°C.

The treatment efficiency was studied from February to June 2002, in three series of ponds (figure 1). The first serie (n° 13 -18) was composed of 3 ponds with algae followed by 3 ponds covered with duckweed. The second serie (n° 2-4) was a set of 2 ponds covered by water hyacinth terminated with a polishing step. The third serie (n° 5-7) was a set of 2 ponds covered (again) with duckweed terminated with a polishing pond. The pilot was fed during day by raw waste water from the university campus. The flow was controlled by a pump filling a storage tank five times a day from 7 AM to 7 PM. 3 diverters were calibrated to give the combined treatment line (n° 13-8) about 3.5 m3/day and the other two other lines each about 1.5 m3/day. Figure 1 gives a schematic view of the pilot, while tables 1 and 2 give the operation conditions.

Table 1. Flow (n=3) and evapo-transpiration (n=97), from January to May and the corrected flows

N° asin	Q_i	13	14	15	16	17	18
Pond cover		no (algae)			duckweed		
evapo (mm/d)		8.36±1.60			7.50±1.46		
flow (m3/d)	3.5	3.44	3.33	3.21	3.09	2.98	2.87

N° asin	Q_ii	2	3		Q-iii	5	6
Pond cover		hyacinth				duckweed 2	
evapo (mm/d)		19.30±8.7				7.50±1.46	
flow (m3/d)	1.5	1.36	1.08		1.5	1.45	1.34

Duckweed (*Lemna minor*) and water hyacinth (*Eichornia crassipes*) were collected from water ponds near the river Niger, where they grow naturally. The duckweed production was estimated 3 times a week. The harvested biomass was weighed to obtain the wet weight, a small part was used for the estimation of standard parameters like solids, N, P and pathogen contents. The determination of N-content was done after drying at 60°C by the method for Kjeldahl nitrogen. The average standing crop was maintained for all duckweed basins at 200 gram fresh weight a square meter.

Table 2. Average values (n=15) for the influent and for the charges for the 3 lines. The algae treatment line (pond 13 to 15) is composed of 3 ponds, the others two lines of 2 ponds. Error given is equal to standard deviation related to the average. The average temperature of influent was 27.5°Cand the average conductivity was 645 µS/cm. (FS: faecal streptococci).

	SS mg/l	BOD5 mg/l	COD mg/l	TNK mg/l	FS /100 ml	m3/ha/d	kg-BOD/ha/d	m²/eq.
Qi	238±43%	315±15%	617±17%	75±13%	2.46E+06 ±56%	833	525	2.29
Qii & Qiii						536	169	3.56

Table 3. Growth and productivities of the used species, average values for a six month period. Error given is equal to standard deviation related to the average.

	n	water content	N content dry matter	fresh production kg/ha/year
Hyacinth	4	92%	2%	2 270 000±21%
Duckweed	3	94.4%	4.2%	326 000±8%

RESULTS

Over the whole experimental period the treatment efficiency for solids was significantly better for the ponds using macrophytes (figure 2). The efficiency is not only better but the effluent levels are also more constant. The algae or not cover ponds are more sensible to temperature and load fluctuations. The algae pond showed high oscillations due to periods with "bulking" and phytoplankton bloom.- From the composition of organic matter (figure 3) we can see that the biodegradability (expressed as BOD/COD) of the waste water passing through the hyacinth pond is not significatively modified, about 60 % remains rapidly biodegradable (expressed as BOD5). The high level of solid removal

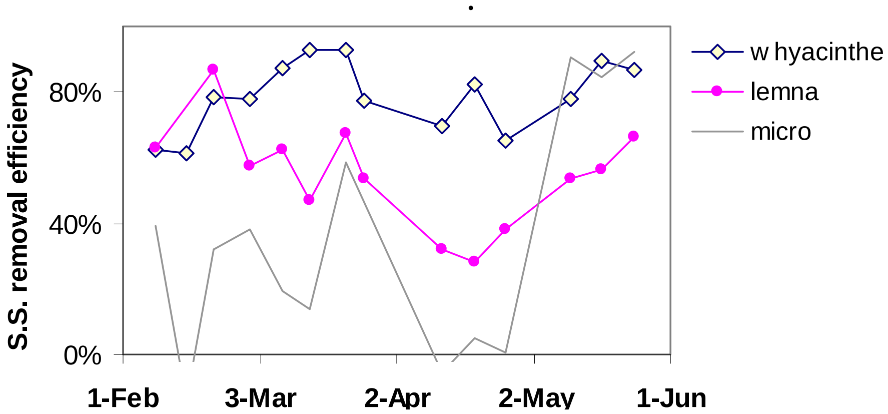

Figure 2. Evolution of the suspended solid removal efficiency for macrophytes (1 pond) and algae (2 ponds) corresponding to approximate residence time of 4 days.

indicates that an important fraction of particulate pollution will be removed most probably by settling. Indeed 90% of the particulate COD is removed against only 30% of the dissolved. The elimination of solids seems to be more in the mineral fraction than in the organic, which seems to be confirmed by the degradability of the solids expressed as pBOD/SS which is 57% at the entrance of the hyacinth pond and only 41% at the exit. The main difference between duckweed and hyacinth is less efficiency in solid removal most probably due to the more developed root zone of hyacinth. On other hand, the duckweed effluent shows very low levels of particulate biodegradable matter, suggesting its degradation.

Though the residence time for the algae pond is 25% shorter than for the macrophyte ponds, the treatment efficiency is appreciable and even better than that of duckweed (see fig3). Compared to the macrophyte ponds, the particulate BOD5 in the algae pond remains high, probably due to presence of algae.

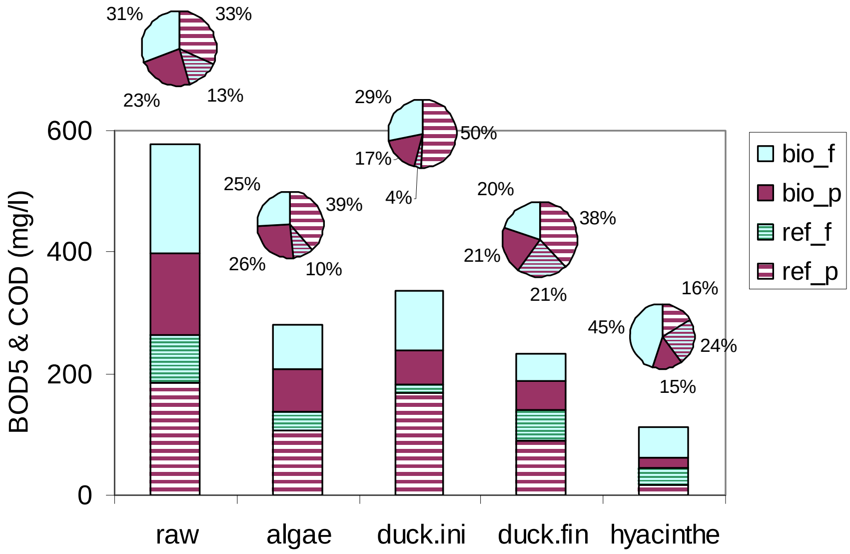

Figure 3. Composition of organic matter for raw waste water and after 5 days of different treatments using average concentrations of COD and BOD. It's supposed that the level of COD (total) depends principally of organic matter, that the particulate fraction (p) is the difference between total and dissolved fraction (f) and that the refractory fraction (ref) is the difference between total and biodegradable (bio) fraction measured as BOD5: bio_f=BOD5 filtered, bio_p=BOD5 particulate, ref_f=COD filtered - BOD5 filtered, ref_p=COD particulate - BOD5 particulate.

The lower efficiency is mostly due to lower residence time. If we look on the relation between residence time and the removal efficiency (figure 4), we can see that for macrophyte covered ponds there is no improvement with longer residence time, while a significant improvement can be observed for ponds without macrophytes. Figure 4 shows average efficiencies calculated as mean from weekly in- and effluent data for each basin and corrected for the evapo-transpiration. To compare the efficiencies for the same residence time, linear regression was used to recalculate a theoretical efficiency for a residence time of 12 days, being the maximum residence time of each treatment line. The utilization of BOD5 is not 100% pertinent to compare the efficiencies between the different treatments because the composition of BOD5 is not constant through the algae line. The influent BOD5 corresponds to the organic matter issued from waste water, while the effluent BOD5 in is composed (principally) from algae or algae organic matter. For this reason aside BOD5 also COD and the particulate and dissolved fractions, were considered.

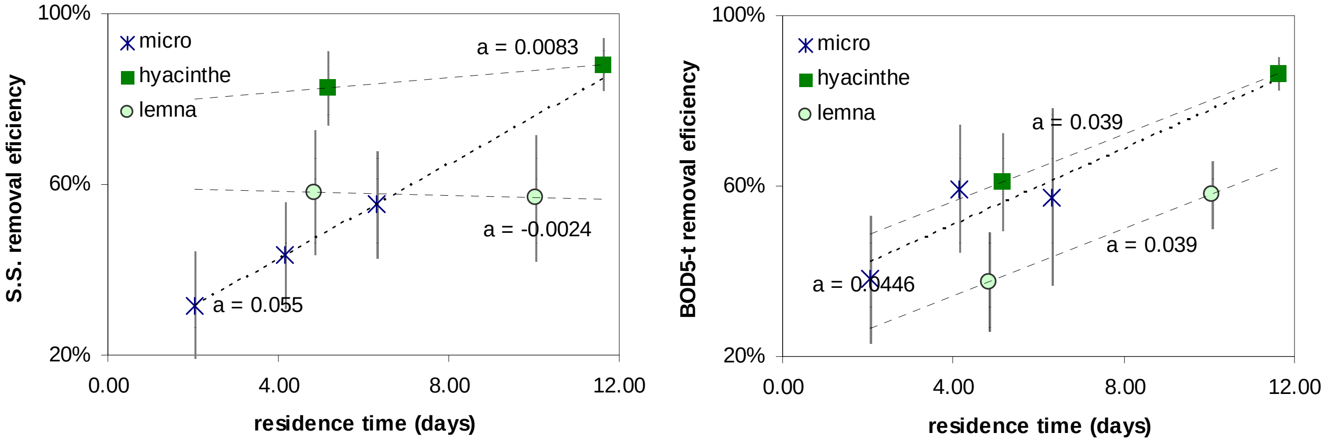

Figure 4. Mean of efficiencies observed during the experiment (7< n<15). The standard deviation (68% of observed values) is indicated by a vertical dash. The slope "a" gives a fraction of removal a day of residence time. A difference of less than 10% over the whole period (-0.008<a<0.008) is considered as not significant change for the experimental conditions used.

For suspended solids and COD-t the slope is significatively different for algae compare to macrophytes. For the efficiency of suspended solids removal an increase from 5 to 10 days of residence time does not have any effect contrary to algae. A hyacinth pond with 5 days detention time removes the same as algae ponds with 10 days of detention time (table 4). The removal efficiency for BOD, COD and TNK evolutes in the same manner for hyacinth and duckweed, though duckweed is less efficient. This tendency is the same for the dissolved fraction, though the efficiencies are slightly lower for the dissolved than the total concentration.

Table 4. Table: Theoretical efficiency for a serie of ponds with a residence time of 12 days calculated with linear regression from average removal efficiencies as showed in figure 3.Slope is given in % of removal a day.

C(mg/l)	**hyacinth**	std%	slope	**duckweed**	std%	slope	**algae**	std%	slope
SS	*88.3%*	*7.4*	<1	*56.4%*	*14.7*	<1	84.6%	19.5	5.5
BOD5-t	87.7%	7.7	3.9	65.6%	9.8	3.9	86.6%	16.9	4.6
COD-t	89.1%	4.6	2.8	56.6%	8.6	1.9	99.5%	12.2	7.4
TNK-N	71.1%	7.5	4.0	56.3%	7.7	3.2	70.1%	11.7	4.3

Position of the macrophyte in the treatment line

Another interesting aspect to evaluate is whether a macrophyte contributes in the same/ manner to the treatment exposed to raw or to pre-treated waste water. In figure 5 we can see the evolution of carbon (as COD) and nitrogen (as TNK) through a treatment file containing 3 ponds with algae followed by 3 pond containing duckweed (see figure 1). If we look at figure 5 we can observe for example that the dissolved COD remains the same after the second algae pond and does not change any more through the file. The contribution of duckweed is only significant in the nitrogen removal. Though the strongest nitrogen removal occurs in the algae ponds, the TNK concentration continues to fall down through the duckweed pond. If we look at the pathogen removal (Fecal coliforms), the tendency is comparable, about 3 log units in the algae ponds and only 1 log unit in the duckweed pond. This might be explained by less light penetration in the non covered ponds.

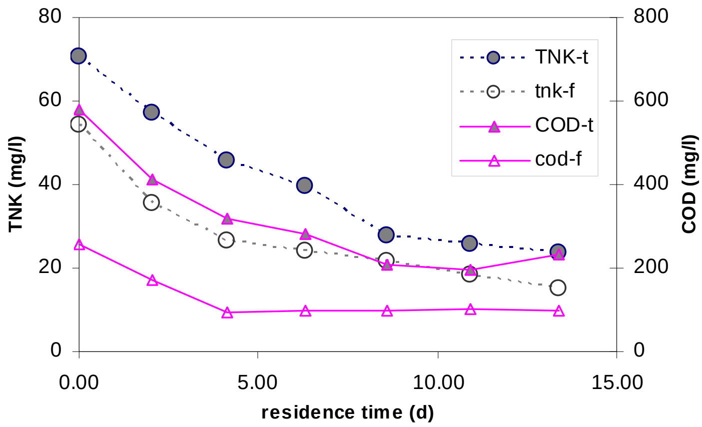

Figure 5. Evolution of the COD and TNK through a combined treatment file, 3 algae ponds followed by 3 duckweed ponds.

Table 5 gives a detailed comparison between the treatment efficiencies of duckweed if used as initial or as a final treatment step. Though the residence time is higher for the experiment with duckweed in the "final" position, we remark that COD removal is almost insignificant contrary to the "initial" position. As stated before (figure 4a), in the "initial" position duckweed contributes to COD removal through improved sedimentation and through degradation of the dissolved "BOD5" fraction. After 6 days of pre-treatment this fraction is not any more present in the waste water.

Table 5. Concentration in mg/l of dissolved and particulate COD and TKN, and the removal efficiencies, for 2 different position of duckweed within a line of waste water treatment by stabilization ponds. "Std" indicates the standard deviation, "t_R" stands for residence time in days.

duckweed treatment	fraction	COD (n=14) C_{IN}	C_{OUT}	R%	std	TKN (n=8) C_{IN}	C_{OUT}	R%	std
initial	filtered	258	108	63.4%		19.3	12.8	36.0%	
t_R =5.1d	particulate	359	227	45.8%		51.5	27.2	52.1%	
	total	617	335	**53.6%**	9.0%	70.8	40.0	**50.1%**	7.7%
	F/T	0.42	**0.32**			0.27	**0.32**		
final	filtered	100	96	16.0%		26.8	15.0	51.9%	
t_R =7.1d	particulate	174	138	25.4%		14.9	8.98	32.3%	
	total	280	234	**20.8%**	19%	41.8	23.5	**47.6%**	15%
	F/T	0.36	**0.41**			0.64	**0.64**		

If we look at the nitrogen we remark that the removal efficiencies are the same, though in the final position the TKN is mostly present in dissolved form as NH4, contrary in the initial position where the majority of TKN is in the particulate form. In the primary position duckweed contributes to the

TKN removal through sedimentation like DCO and in both positions duckweed eliminates TKN through assimilation.
Figure 6 resumes the nitrogen transformations for all systems studied. Algae are the most performing, like the macrophytes, though in 40% less of time. The contribution of aquatic plants in the whole N cycle is less important that that of bacteria.

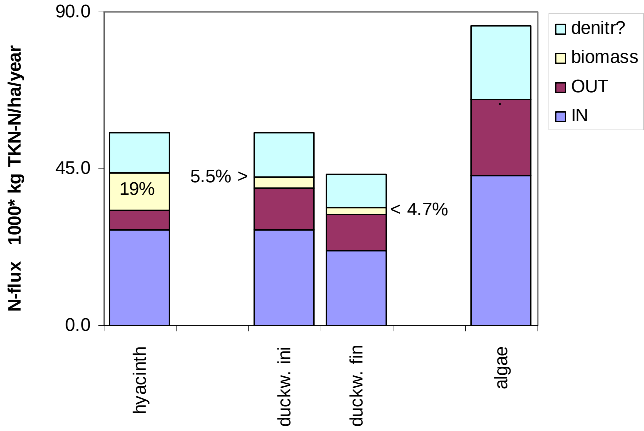

Figure 6. The Nitrogen fluxes from the different treatment lines related to the total treatment surface of each. The residence times were hyacinth 11.6 day, duckweed 10 day, duckweed final 7.5 day and algae 6.3 days.

CONCLUSIONS

Our results show the feasibility of the wastewater treatment combined with aquatic plant production. The systems used, attains biomass production rates removal efficiencies for BOD and COD comparable to other aquatic plant systems in the literature (Alaerts 1996, Vermaat 1998, Steen 1998). Only 3 to 4 m² were needed to treat an equivalent of habitant.
The results show a significant contribution of the water plants to the treatment process. A removal efficiency of more than 80% was achieved for S.S, COD for water hyacinth and about 60% for the duckweed. A classical pond with algae needs a residence time almost two times higher to achieve the same removal. The solid removal in macrophyte ponds does not improve with increased residence time, an effect already observed for otherplants in similar conditions (Kone et al 2002) . The main difference between duckweed and hyacinth is less efficiency in solid removal most probably due to the more developed root zone of hyacinth. On other hand, the duckweed effluent shows very low levels of particulate biodegradable matter, suggesting its degradation. The duckweed is 10 times less productive (20 T-d.s./ha/year) than hyacinth, and converts 4 times less nitrogen in biomass. Though its advantages are multiple, it's easier to harvest, its biomass contains 2 times more nitrogen, the plant can be used directly as fodder and is not invasive in natural environment (Iqbal 2001, Oron 1987). In the primary position duckweed contributes to SS, DCO and TKN removal through sedimentation. In final position duckweed contributes only to TKN (NH4) elimination through assimilation. On the other hand the nitrogen removal is more important in the open ponds probably due to better nitrification / denitrification showing the preponderance of microbial transformations. The same can be established for the pathogens in open ponds, as their removal is far (100 fold) better in algae ponds than in the duckweed ponds.
The aquatic plants improve the treatment and if used it should be used at the head of treatment to enhance the pollutant removal by sedimentation. To remove also efficiently pathogen the macrophyte pond should be followed by algae ponds or a filter.

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