Closing Nutrient Cycles in Decentralised Water Treatment Systems in the Mekong Delta

SANSED – PROJECT Final Report

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Report edited by:	**Ute Arnold, Frank Gresens** INRES-Plant Nutrition, University of Bonn Karlrobert-Kreiten-Str. 13 53115 Bonn

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Project Partners

University of Bonn	• Institute of Crop Science and Resource Conservation, INRES-Plant Nutrition[(1)] • Institute for Hygiene and Public Health[(2)] • Institute for Food and Resource Economics, ILR-Economic Sociology, [(3)]
Can Tho University	• College of Environment and Natural Resources (CENRes)[(4)] - Dep. of Environmental Engineering - Dep. of Environmental Science - Dep. of Environment Management and Natural Resources • College of Agriculture and Applied Biology[(5)] - Dep. of Soil Science and Land Management - Dep. of Animal Sciences - Dep. of Plant Protection • College of Aquaculture and Fisheries[(6)] - Dep. of Applied Biology • Hoa An Biodiversity Research Center[(7)]
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Leibniz University Hannover & Martin Luther University Halle – Wittenberg	• Institute of Soil Science & Institute of Agricultural and Nutritional Sciences, Soil Sciences[(9)]
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Foreword

In the Vietnamese-German joint research project SANSED, the suitability of decentralised water treatment systems to recover nutrients and to produce safe fertilisers was studied.

The SANSED project was initiated in the frame of the German-Vietnamese collaboration in research and technology on water research and environment, agreed on by the responsible ministries of both countries.
It was funded by both ministries, the German Federal Ministry of Education and Research (BMBF) and the Vietnamese Ministry of Science and Technology (MOST).
The project was coordinated by Can Tho University (Vietnam) and University of Bonn (Germany).

Within the project, a variety of treatment systems for both - drinking and waste water - were installed and operated at Campus II and Hoa An Biodiversity Research Center of Can Tho University. Besides operation, the substrates of the wastewater treatment units were tested on their suitability as organic fertilisers, supplemented by socio-economical and hygienic studies.

This book comprises the results of the project and demonstrates the necessity of interdisciplinary and international research in the field of drinking water supply and wastewater treatment technology.

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Dr. Le Anh Tuan
Can Tho University
Vietnamese Coordinator

Ass.Prof. Dr. Joachim Clemens
University of Bonn
German Coordinator

Introduction

Within the SANSED project, research on decentralised water treatment systems was carried out. Focusing on closing nutrient cycles, the technologies were selected according to their reuse potential and adapted to local conditions in the Mekong Delta.

In the previous project phase I, natural and socio-economic conditions had been investigated as well as the technological status of water-related infrastructure in the Mekong Delta.

Polluted surface waters as well as limited acess to safe drinking water demonstrated the need for suitable water treatement systems in this densly populated agricultural area.
The local situation, the actual land use and the expected development was the basis for developing possible solutions for water supply, waste water treatment, and reuse in agriculture.

Within project phase II, pilot systems were planned, established and managed.

Different technologies were investigated to regain valuable resources instead of discharging these. Thereby existing approaches were combined with new technological water treatement concepts and developed further. Practicability and acceptance of users was investigated.

The research comprised three levels connected to each other:

1. Water treatment
2. Substrate and fertiliser production
3. Reuse and application in agriculture

The following topics were investigated (see also Figure 1):

- Source separation and concentration of nutrients from urine
- Anaerobic treatment of brown and black water by biogas systems and further treatment of biogas sludge
- Soil Filter, Membrane bio reactor (MBR) and ponds as recipients of grey or pre-treated water
- Reuse of produced substrates in agriculture
- Determination of management options for drinking water supply and waste water treatment in defined areas

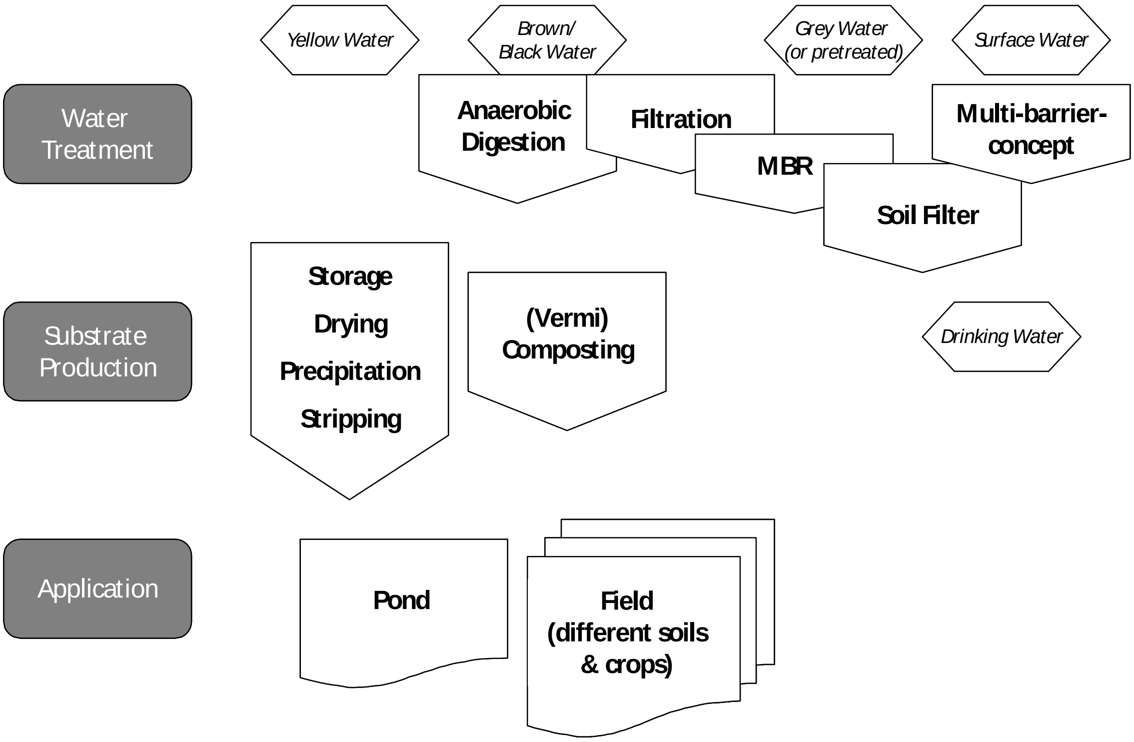

Figure 1: Flow Chart of research topics within the SANSD Project

Various companies and working groups of universities were carrying out jointly and severally these investigations on water treatment, substrate treatment, application in agriculture, and hygenic behaviour. Their main field of activity is listed in Table 1.

Systems and results are explained in detail in the particular chapters.

All in all, more experience and deeper understanding on operation and performance of decentralised systems in the Mekong Delta and in tropical areas generally was gained within SANSED II:

- By establishing different decentralised systems a "field laboratory" was created at Can Tho University for research, further development and for extension in Vietnam.
- Various companies created new products and/or improved existing ones and adapted these to Vietnamese conditions.
- Results on the advantages and limitations of the different treatment technologies and their proper management will improve the products and facilitate the selection of appropriate solutions and combinations for demanded, specific applications.
- By networking, especially by inter-disciplinary exchange, the project partners gained new insights and better understanding of their systems and missing links.

- Several German and Vietnamese students completed their studies with PhD, Master, and Bachelor thesis or did internships within the project, thereby delivering valuable results for the participating companies and learning about the companies and their topics.
- The newly established Water Forum provides objects, equipment and results for study, lectures and seminars for students and local experts, e.g. on biogas, water treatment, sanitation, analytics and others.

Table 1: Working groups and their research topics within the SANSD Project

Companies	
- Bioenergy Consult B^3, Potsdam	Biogas-Plant for waste water treatment, Co-fermentation
- Bioreact, Bonn	Enzymes for biogas plants
- Gewitra, Bonn	Yellow water concentration
- Gsan/ibau, Berlin	Aquaculture and reuse of substrate
- Hans Huber, Berching	Treatment of source separated waste water (DeSa/R)
- Ith, Bayreuth	Soil filter systems
- Sachsenwasser, Leipzig	Planning and training
Universities	
- Environmental Engineering and Ecology, Bochum & - College of Technology, Can Tho	Hydrogeology, Drinking water treatment and supply
- INRES - Plant nutrition, Bonn & - College of Technology & College of Environment and Natural Resources & College of Agriculture, Can Tho	Nutrient fluxes and treatment of substrates
- INRES - Plant nutrition, Bonn & Inst. Soil Sciences Hannover, Halle & - College of Agriculture & Hoa An Research Station, Can Tho	Re-use of newly produced substrates in agriculture and effects of substrate application to soils
- IHöG, Bonn & - College of Technology, Can Tho & Faculty of Public Health, Medical University of Can Tho	Microbiological examinations and hygienic behaviour
- ILR-Economic Sociology, Bonn	Socio-economic evaluations

Chapter I: Constructions and Drinking Water

I-1: Closing the loops in the Mekong Delta with DeSa/R®

Stefania Paris[13] and Thomas Netter[13]
[13] Hans Huber AG, Industriepark Erasbach A1, 92334 Berching, Germany

Keywords: DeSa/R®, ReUse, Vietnam, Mekong Delta, brown water, yellow water, grey water

Introduction

Today, 1.1 billion people do not have access to clean water and 2.6 billion have to live without adequate sanitary facilities (WHO / UNICEF 2005). Particularly critical are the living conditions in countries like Asia, Africa and Latin America where also the availability of nutrients for agricultural needs is frequently limited. Population growth, industrialisation and climate change increasingly contribute to the worsening of the situation.

Clean water is a scarce resource also in the Mekong Delta in South Vietnam. Only one third of the population there has access to hygienically safe drinking water. And only few central wastewater treatment plants exist in this region. The municipal and industrial wastewater from the big, congested urban areas are collected together with run-off-water though a poor sewer system, and in most cases discharged untreated into the river. As a result, the surface water, and in the end also the ground water, are heavily contaminated with pollutants and pathogens and the population is exposed to a permanent health hazard (Fig. 1).

Figure 1: Urban area in Can Tho, Mekong Delta: water drainages used as a sewer

In the Mekong Delta, not only safe water is limited but also the availability of the nutrients needed to grow rice and vegetables. Even though the soils in the Mekong Delta are fertile, half of the area under cultivation is contaminated by the high amounts of sulphur and sea salt. To increase the crop yield expensive mineral fertilisers are applied – most of them imported from China, Vietnam's neighbouring country.

Decentral vs. Central

Conventional systems with a region-wide sewer network and a central wastewater treatment plant are not a suitable solution for a developing country like Vietnam. Considerable investment and operating costs, high water consumption and elimination of nutrients in the treatment process are only some arguments against a wide implementation of the systems. A sustainable development of regions that suffer from water shortage becomes possible through the use of decentralised, resource-preserving system solutions with or without separation. Such system solutions are based upon the principle of water reuse close to source and recovery of nutrients. In this way wastewater becomes a secondary raw material that serves as a basic material for the production of service water of different qualities, recovery of phosphorus and nitrogen, and production of energy. Frequently, the term Decentralised Sanitation and Reuse (DeSa/R®), is used for such new sanitary concepts. Since Vietnam is only at the beginning of developing its infrastructures, the country has the unique opportunity to use these innovative technologies and methods for small decentralised recycling concepts, avoiding the resource-intensive systems industrial countries have developed.

Material and methods

Due to its conviction of the ecological and economical relevance of recycling, HUBER contributed to the phase II of the SANSED project with the implementation of decentralised wastewater treatment systems that enable the recovery of nutrients as well as the reuse of treated wastewater as service water. Such an alternative sanitary concept, the DeSa/R concept, was developed in summer 2006 in cooperation with the universities of Bonn (Germany) and Can Tho (Vietnam) and implemented on the campus of the Can Tho University for the treatment of separated wastewater flows. A dormitory for 100 male students was equipped with 10 waterless urinals and 10 separating toilets. These special sanitary facilities allow for the separate collection of yellow water (undiluted urine) and brown water (faeces and toilet flush water). Grey water (cleaning and wash water) is discharged and collected via a separate line. The individual wastewater flows are treated with innovative technologies, which are installed in a nearby building, the so-called DeSa/R® house (Figure 2). The following treatment systems are used:

- **Yellow water treatment (urine)**

  Yellow water is treated in a two-step chemical-physical process in a precipitation reactor (HUBER NuRec) followed by a stripping and absorption column (HUBER NitroRec). The arrangement of these two processes in succession allows for recovery of the nutrients phosphorus and nitrogen from undiluted urine, in the form of magnesium ammonium phosphate (MAP, powder) and ammonium sulphate ($(NH_4)_2SO_4$, liquid). Although undiluted urine is the smallest wastewater flow to be treated, it contains the highest rate of nutrients. These nutrients can be used as high quality fertilisers in agricultural applications.

- **Brown water treatment (faeces and toilet flush water)**

  Brown water is treated in a two-stage biogas reactor under mesophilic conditions. Under the exclusion of oxygen the organic material is converted into biogas, which can for example be used for cooking. After composting the fermentation residue can be used as a soil improver for agricultural land. Compared to the one-stage fermentation process with stirrer tank the applied two-stage method with solids retention (first stage: hydrolysis) and fixed bed (second stage: methanogenesis) offers the advantage that the hydraulic retention time is decoupled from the retention time of solids. It is only after hydrolytic decomposition of the organic particulate matter in the hydrolysis stage that the dissolved intermediate products pass into the methanogenesis stage where they are converted into methane and carbon dioxide.

- **Grey water treatment**

  The Membrane Bio Reactor (MBR) process (HUBER MCB) is used to treat Grey water. Organic pollution is decomposed by microorganisms of the activated sludge. Following filtration with ultrafiltration membranes (38 nm) produces virtually germ-free service water, which can be reused as irrigation water or for toilet flushing, cleaning and laundry washing. As grey water, compared to common domestic wastewater, is less contaminated by organic pollutants, contains fewer nutrients and usually a high concentration of detergents, it is especially suitable to be treated with the MBR method.

Figure 2: DeSa/R® House at the Campus of the University in Can Tho

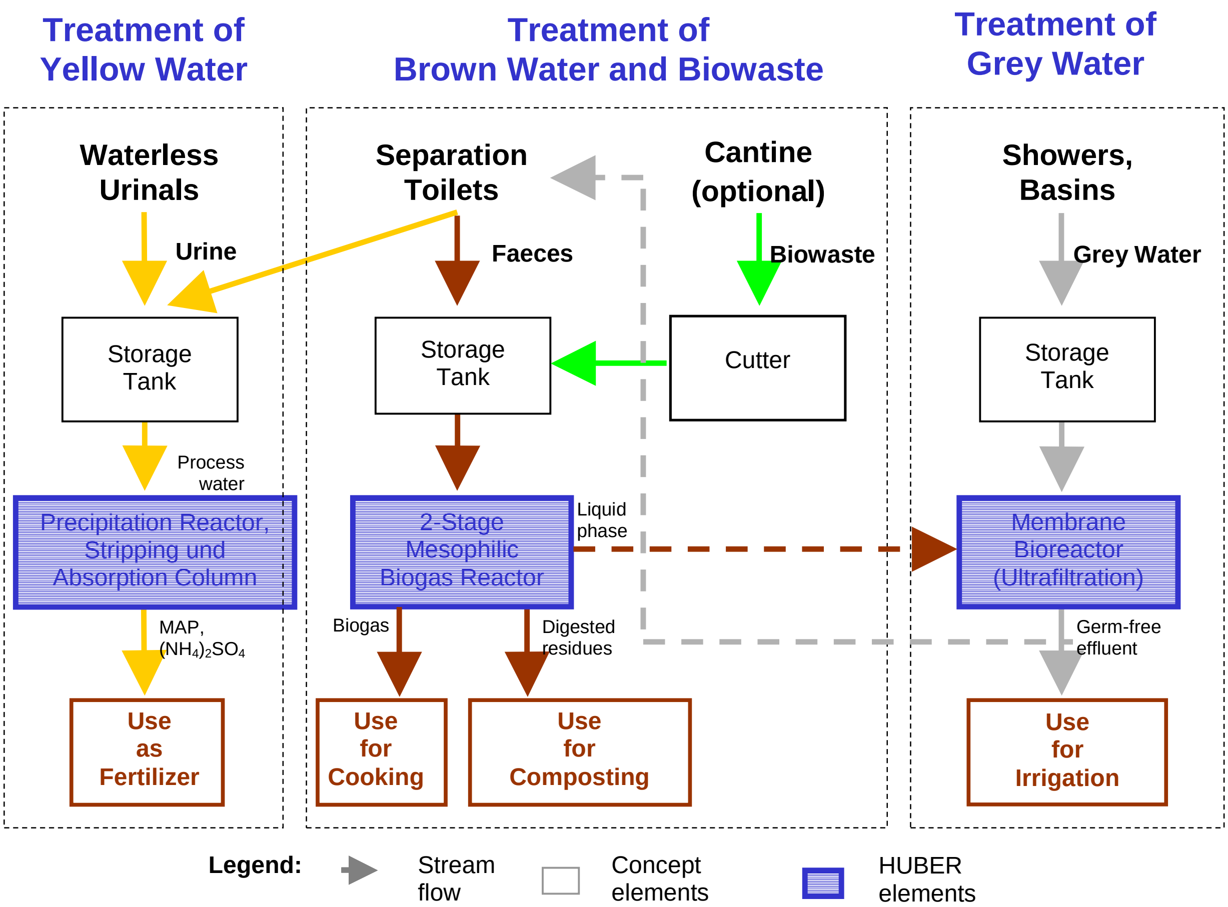

Figure 3: Flow chart of the DeSa/R® Concept at the Can Tho University

Results

Since October 2006, the individual wastewater treatment plants for yellow, brown and grey water have been investigated and optimized to meet the specific local requirements (Fig. 3).

- **Yellow water treatment**

  Antonini *et al.* (2008) carried out tests with the yellow water treatment plant. With the precipitation reactor posphourous removal rates of 98 % can be achieved. It is available in the form of the solid mineral fertilizer magnesium ammonium phosphate (MAP). By air stripping afterwards more than 95 % of the nitrogen could be removed from the urine, and virtually 100 % of this N could be recovered in the form of liquid ammonium sulphate.

- **Brown water treatment**

  Clemens *et al.* (2008) tested the anaerobic plant for brown water treatment over a period of about 180 days. During this period the hydraulic retention time in the 300 liter reactor was 20 days. An average COD removal of 55 % and a specific biogas yield of 192 l CH_4 kg^{-1} COD were achieved.

- **Grey water treatment**

  Concerning grey water treatment Paris *et al.* (2008) showed that, under the given nutrient conditions (BOD_5 : NH_4-N : PO_4-P = 100 : 12.5 : 3), an efficient biocoenosis can form in the activated sludge tank. The system operation was stable throughout the whole test period and showed very high COD elimination rates of on average 92 %. Permeate was nearly free of bacteria.

The results of the individual treatment technologies are presented in detail in the following chapters.

Conclusion and Outlook -

Adaption of treatment systems and technology transfer

In addition to the technical development of the DeSa/R® technologies the primary goal of HUBER was the adaption of the single treatment modules to the specific Vietnamese conditions, which include among others climatic, cultural and social aspects. Operator convenience has been recognised playing an essential role for increasing acceptance of "new" technologies in developing countries. So for example the two-stage anaerobic process represents a further development of the simple fermenter, which is commonly applied in rural areas for the treatment of faeces and manure. With the application of such technologies HUBER expects, at long sight, to achieve a wide acceptance and tries to provide a high benefit for the local population by closing local loops.

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I-2: Experiences during Construction of a Biogas Plant in Hoa An

Matthias Plöchl[10], Thomas Vöhringer[10], Andreas Mikulcak[10]
[10] BioenergieBeratungBornim GmbH, Potsdam, Germany, mp@b3-bornim.de

Keywords: two-phase digester, anaerobic digestion, feedstock, biogas potential, biogas utilisation

Introduction

The aim of constructing a biogas plant in Hoa An was to demonstrate how anaerobic digestion could contribute to sanitation of rural and peri-urban wastes and residues from agriculture. A further objective, of course, was the provision of a new energy source especially in rural areas. A large range of feedstock can be used for anaerobic digestion: agricultural wastes, residues from crop processing, organic waste from food and feed, and of course, faeces and urine from animal husbandry and human dwellings.

During recent years three major types of digesters have emerged in developing countries: the Chinese fixed dome digester (Fig. 1), the Indian floating drum digester (Fig. 2) and very recently tube digesters (Fig. 3). These digesters usually have the capacity to convert the human and animal waste of one household and to deliver the energy demand of this household for cooking and lighting. I.e. the average volume of the digester is approximately 5 – 10 m³ and delivers around 0.5 m³ biogas per m³ digester volume (Akinbami *et al.* 2001, Omer and Fadalla 2003).

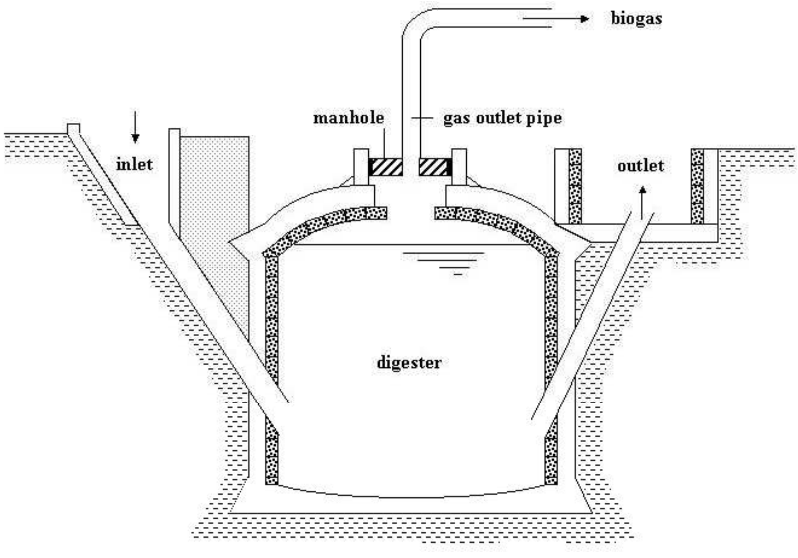

Figure 1: Fixed dome digester (Chinese type), slurry, dung and night soil are added through the inlet pipe (left), the digested slurry can be intermediately stored in the outlet pit from where it can be taken for fertilisation. The gas is stored above the digesting slurry, because of the limited space the opening and the gas outlet pipe have to be sealed carefully. The digester can be built with different materials e.g. clay for the outer wall and brick stones for the inner wall (figure adopted from Gunnerson and Stuckey (1986)).

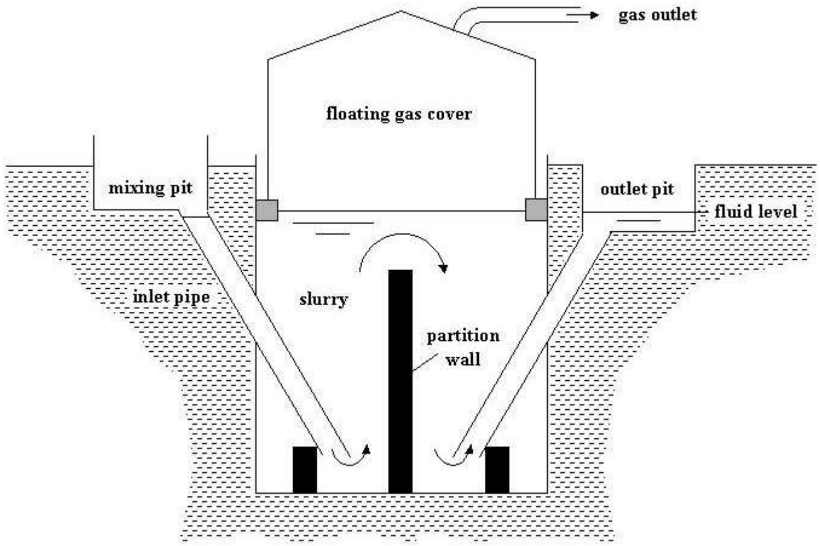

Figure 2: Floating cover digester (Indian type), slurry, dung and night soil are collected in a mixing pit from where the slurry enters the digester through the inlet pipe. In the example shown here there is a partitioning wall between inlet and outlet. The digested slurry is collected in an outlet pit. In difference to the Chinese type the gas storage is a floating gas cover, which allows to enlarge or to diminish the volume available for gas storage depending on the amount of gas produced. As this gas cover is made of steel there is less risk of uncontrolled gas outflow (figure adopted from Gunnerson and Stuckey (1986)).

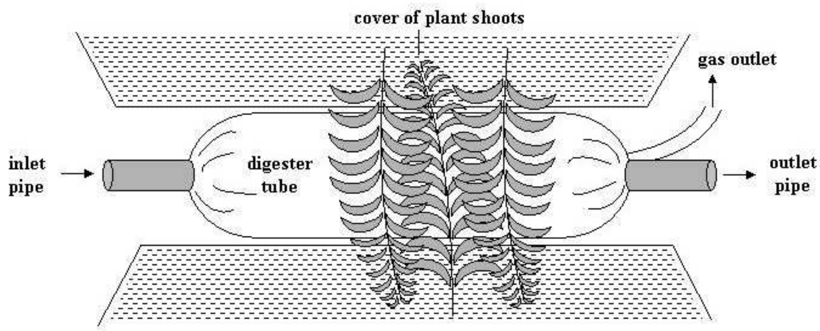

Figure 3: Tube digester: slurry, dung and night soil enter the digester through the pipe on the one side. The substrate flows slowly through the tube while the biogas is produced and transferred through a separate pipe to its storage. Liquid digested slurry leaves the digester through the pipe on the other side, whereas non-digested solids stay in the tube. The tube is usually covered with plant shoots like palm leaves or banana leaves to prevent a destruction of the foil.

The floating cover digester is constructed with concrete and steel whereas the fixed dome digester is usually built with the locally available materials, which can even be bricks. Tube digesters are constructed with folded polyethylene foils and porcelain pipes as inlet and outlet.

The digester to be build in Hoa An should be suitable for taking up the faeces from about 200 pigs and probably from more and other animals like buffalo, goats and poultry. But it was also supposed to include other wastes and residues like rice straw, weed, and residues from crop processing. Therefore the concept of two-stage digesters was adapted for the local conditions and the supposed feedstock.

Material and Methods

Feedstock

In Hoa An new animal houses were built to host pigs, buffaloes, cattle, goats and poultry. In general the faeces of these animals was used as feedstock for the biogas plant. Samples were taken from pig and cattle, which were available on Campus II of Can Tho University while the application in Hoa An was still under construction. In addition to animal faeces rice straw and water hyazinth were used as feedstock for the biogas plant. Hereof samples were also taken at Campus II of Can Tho University. These samples were analysed according to the standards of proximate feed analysis and were analysed or assessed for their methane production potential (Tab. 1).

Table 1: Characterisation of feedstock for biogas plant Hoa An

Feedstock	pH value	DM g kg^{-1} FM	ODM g kg^{-1} FM	N_{total} g kg^{-1} FM	$N\text{-}NH_4$ g kg^{-1} FM	org. acids g kg^{-1} FM	methane l_N kg^{-1} ODM	methane %
Pig faeces	6.8	283	212	10.5	1.06	11.9	311	63
Cattle faeces	7.7	197	164	4.2	0.32	3.0	260	60
Rice straw	8.4	867	747	11.7	0.07	0.8	239	53
Rice hull	6.8	857	839	4.2	0.02	0.1	28	62
Water hyazinth	4.8	70	56	3.8	0.47	3.7	462	61

First Biogas Plant Schematic

With the assumption that pig faeces and slurry from pig houses as well as rice straw would be the main feedstock, it was decided to build a two-stage biogas plant. Central part is a digester of 50 m³ volume (as decided in application), and as additional first stage an open top basin of 10 m³ volume for hydrolysis (Fig. 4).

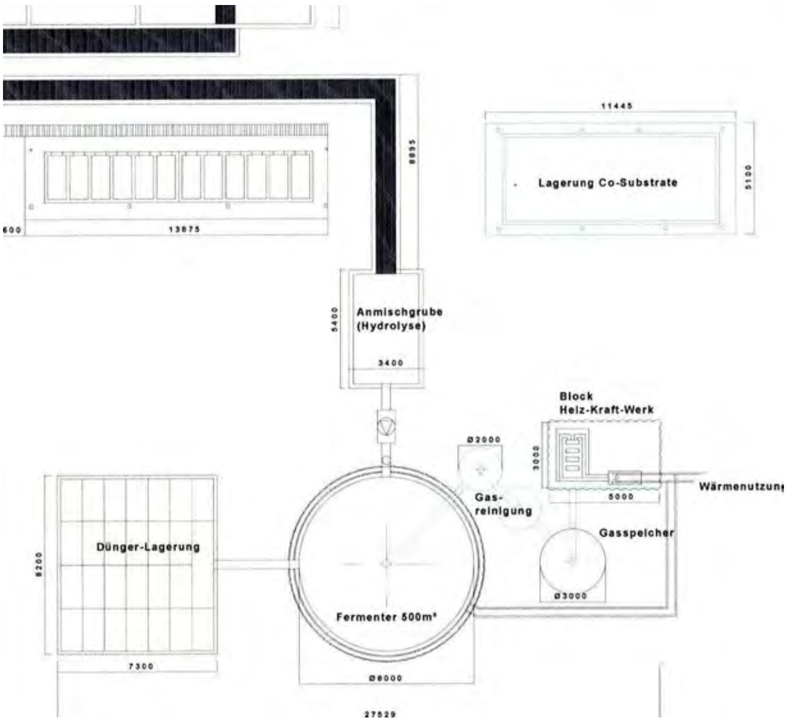

Figure 4: Initial schematic of biogas plant in Hoa An

The digester is fed directly with faeces and slurry, whereas the hydrolysis is fed with rice straw or other solid and / or fibrous material. Therefore the hydrolysis basin is equipped with moveable baskets of 0.5 m^3 volume, which enable a simple charging and discharching with feedstock. The hydrolysate is fed to the digester as well. Digestate is transferred to the slurry storage tank, part of animal housing, and therefore enter the usual pathway of utilisation. The residue from hydrolysis can be used for composting. The gas produced is kept in a separate gas storage and is finally used for combustion in a combined heat and power unit (CHP).

Refining the Planning

It was assumed that starting with this concept it would be easy to finish the drawings in a two or three step interaction with a Vietnamese colleague. This turned out as a misinterpretation of the situation. In principle it worked like the assumption but in detail it was much more complicated.

The initial scheduling was:

M2 to M15: planning of the biogas plant
M16 to M21: construction of the biogas plant
M22 to M23: start of operation
M25 to M34: checking of functionality

In the end the planning of the biogas plant could be, more or less, finished in month 20. There have been some essential modifications from initial conception to final planning. At first it was intended to use bricks for the construction in order to seal the walls appropriately. It was also planned to build a circular digester. Experiences at other constructions made us change this plan; instead, concrete was used as construction material for the digester and the hydrolysis basin and a cubic digester was built.

The construction of the baskets for the hydrolysis basin also turned out to be more difficult as expected. Finally we ended up with a steel frame construction which is covered with perforated steel sheet.

Another problem was the substrate or bedrock at the construction site. The bearing capacity of the soil is very poor; therefore it was necessary to create a deep foundation.

It also was expected that the actual construction could be conducted under the supervision of the personnel present at the SANSED office at Can Tho University assisted by one or two short-term visits from our part. Unfortunately, it was necessary to employ someone who stayed in Can Tho for the whole construction period.

Results and Discussion

The main concept of the biogas plant in Hoa An (Fig. 5) remained unchanged, although a whole range of small-scale modifications had to be done. The shape of the main digester was modified from a circular basis to a square one. Some modifications in construction material also had to be taken into account (e.g. concealed brick construction was replaced by steel reinforced concrete). There was also the necessity to reinforce the construction for the baskets of the hydrolysis basin. It was necessary to improve the housing of the gas storage as well as the one of the fibrous feedstock. Many modifications were only done during the construction phase as a response to shortages or quality specifications of materials.

The biogas plant was finally equipped with:

- Hydrolysis basin (10 m³) – disintegration of herbaceous, fibrous material
- Digester (50 m³) – anaerobic digestion of leachate from hydrolysis and animal faeces and slurry
- Gas storage (50 m³) – collection and storage of gas
- Bio-filter system with rice straw – removal of H_2S from biogas
- Combined Heat and Power Unit (CHP) – conversion of biogas into electricity and heat (will be contributed from a second project)
- Electric pumps – that the capacity of two electric pumps was sufficient for pumping the material between the different containers and for mixing the content of the containers

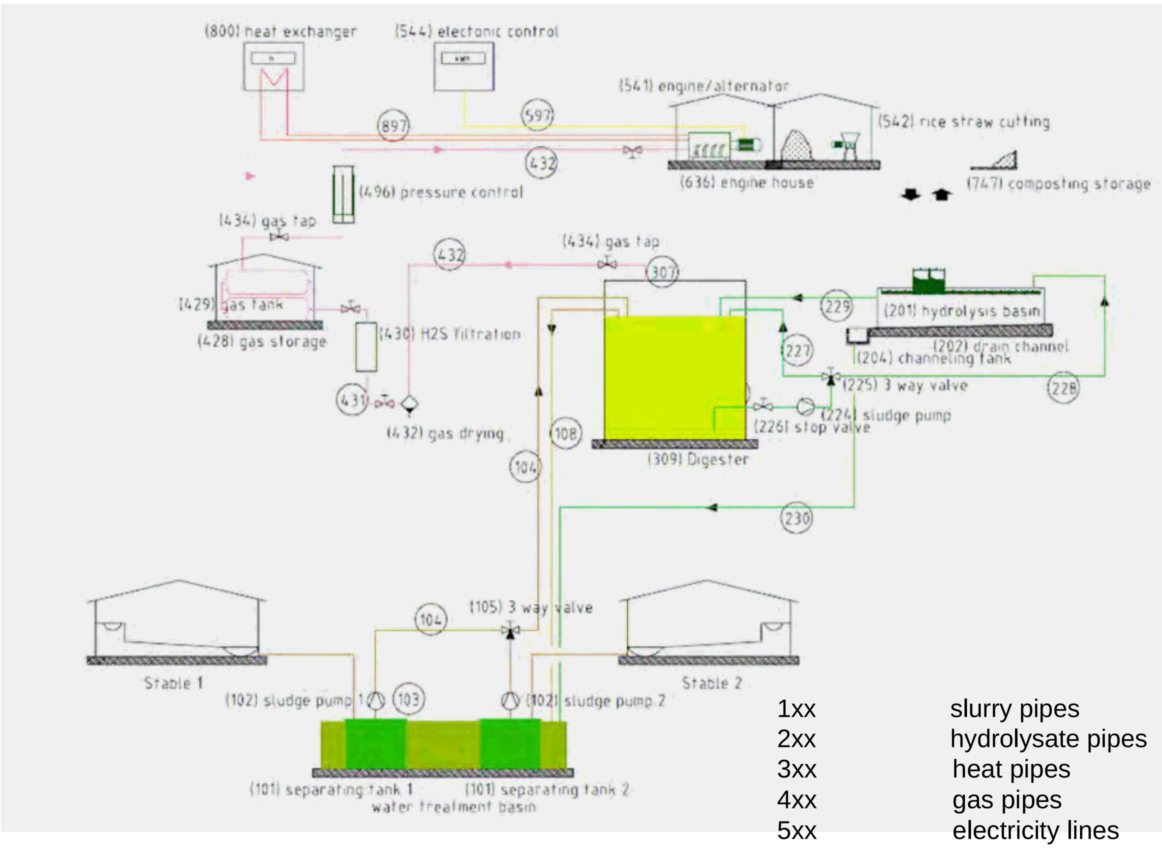

Figure 5: Flow schematic of the biogas plant in Hoa An

Planning and construction of the biogas plant were much more time consuming as assumed. The time period for planning was extended from 14 to 20 months. The construction took 5 months, according to original plans. But this could only be managed by having a construction supervisor on site during the whole construction period.

Conclusions and Outlook

For subjects, skilled Vietnamese partners were familiar with, planning responsibilities were almost done on their own (e.g. the deep foundation). For the construction of more sophisticated technical elements, additional training by German experts was necessary.
In general, it is very helpful to know about the different ways of thinking and doing to establish a good bilateral collaboration.
During the final planning phase, the construction of a second biogas plant - financed by the Government of Luxemburg (LUX-project) - was approved. In order to achieve synergistic effects, it was agreed that both plants deliver the produced biogas to a single storage unit before being fed to the CHP. Unfortunately the construction of the second biogas plant took much longer than expected. Thus, the biogas storage for both biogas plants is established, but the CHP – financed by the other project – was not running yet. The CHP unit is due to be installed in the near future so that Hoa An will benefit from a fully running biogas plant in the beginning of 2009.

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List of Abbreviations:	
CHP	Combined Heat and Power Unit
DM	dry matter
ODM	organic dry matter
$N\text{-}NH_4$	ammonium nitrogen
org. acids	volatile organic acids (fatty acids)
WM	Wet mass (fresh matter)

I-3: Mechanical-Chemical Treatment of Wastewater in Vietnam

Stefania Paris[13], Celine Schlapp[13] and Franz Heindl[13*]
[13] Hans Huber AG, Maschinen und Anlagenbau, Industriepark Erasbach A1, 92334 Berching, Germany
[13*] Huber Technology Asia-Pacific Pte Ltd, 1 Scotts Road Shaw Centre 19-10, 228208 Singapore

Keywords: mechanical-chemical treatment, robust and affordable technology, step-by-step implementation, water quality

Introduction

The German Federal Agency of Foreign Trade (bfai 2002) stated that wastewater management would be one of the greatest problems in Vietnam. Wastewater treatment plants are existent only in industrial zones and at larger industrial or commercial facilities where they serve for the treatment of wastewater from breweries, hospitals and other industries. There is no single municipal wastewater treatment plant for domestic sewage. Most of the domestic sewage is discharged without any treatment into rivers or lakes; such raw sewage disposal puts immense strain on the environment.

To limit the negative impacts of such uncontrolled wastewater discharge, targeted means for wastewater treatment in urban and rural areas are necessary. Screening is a simple method for the treatment of wastewater: Screens are modular units that can be quickly supplied and installed for decentralized or semi-centralized application. Screening systems can always and easily be upgraded by addition of chemical treatment. Own investigations of mechanical wastewater treatment systems (Huber *et al.* 2004) have shown that up to 50 % of the suspended solids could be removed by use of ultra-fine screens with a mesh size of 0.2 mm. By addition of flocculants, we could increase the capture rate up to 95 %.

Within the scope of the SANSED II project ("closing nutrient cycles via hygienic substrates from decentralized water management systems in the South of Vietnam") and in cooperation with the Ba Ria Vung Tau Urban Sewerage and Drainage Company a simple wastewater treatment concept including an ultra-fine screen (HUBER RoMesh screen) and a screenings compactor (HUBER Ro 7) shall be implemented in South Vietnam and adapted to local conditions. With this system a fraction of the raw wastewater collected from a settlement with much tourism (Long Hai Beach) shall be mechanically treated and then discharged into a nearby water body. In order to further improve the effluent quality (lower phosphorus and COD concentrations) and to relieve the receiving water, the mechanical treatment system can be upgraded by addition of chemical treatment (precipitation / coagulation / flocculation). The Southern Institute of Water Resources Research shall investigate the efficiency of various combinations of precipitants, coagulants and flocculants.

Options for Mechanical-Chemical Wastewater Treatment

Mechanical treatment is known to be the simplest and most cost-effective method for the removal of suspended matter from wastewater. If the main emphasis is COD reduction, ultra-fine screening through a 0.2 to 1 mm mesh is a good option. The degree of COD removal can be further increased by addition of other modules. By addition of precipitants and flocculants it is possible to increase the COD removal efficiency to 70 % (Huber *et al.* 2004). Simultaneously the phosphorus concentration is significantly reduced.

Overall benefits for the environment that can be achieved with mechanical-chemical treatment (abbreviated as MeChem) can be demonstrated by means of comparative calculations (See Table 1). With a given investment budget, mechanical-chemical wastewater treatment removes about five times the COD freight in comparison with full-biological wastewater treatment according to German standards (Frommann *et al.* 2005). In view of the fact that the wastewater of around 90 % of Vietnam's population is still discharged without any treatment into rivers or the sea, it makes immense sense to implement partial wastewater treatment as a first and fast step, in order to quickly and substantially reduce pollution of the receiving waters.

Table 1: Total population served and resulting COD removal achievable with an investment budget of 1 million Euros

		Mechanical		Mechanical-Chemical		Biological
Parameter	Unit	Fine screening	Fine and micro screening	Fine screening with flocculation	Fine screening with precipitation	Biological ww treatment
C-specific investment	€/C	5	11	21	23	200
Connected population	PT	214,000	93,000	48,000	44,000	5,000
COD load	kg/d	25,680	11,160	5,760	5,280	600
Efficiency	%	20	50	50	65	95
Eliminated COD load	kg/d	5,136	5,580	2,880	3,432	570
Investment per eliminated COD load	€/(kg/d)	195	180	350	395	1,755

The system can be implemented step-by-step to a complete wastewater treatment plant as budgets for environmental protection projects are available (See Fig. 1). The steps taken depend not only on the available budget, but also on the effluent requirements and type of effluent reuse. Whereas for outfalls into the sea and large rivers, basic mechanical treatment may be sufficient (steps 1 to 2), for outfalls into more sensitive small rivers, streams or lakes mechanical treatment should be combined with chemical treatment by P-precipitation (steps 3 to 4). Disinfection (step 5) is usually required where receiving surface waters are used for bathing or as a freshwater recourse. Biological treatment (step 6) is the last and most expensive step. Chemical treatment is no longer needed, unless P-removal should be required (Huber *et al.* 2007).

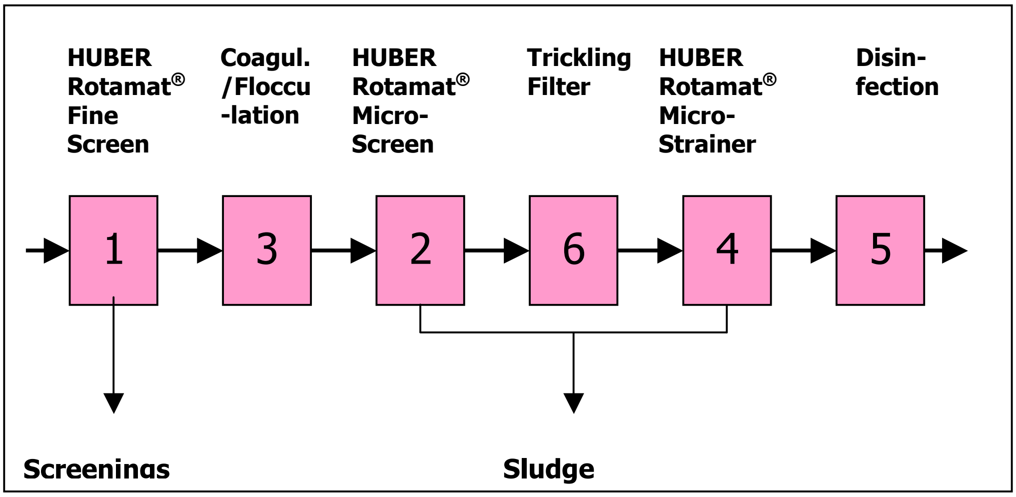

Figure 1: Step-by-step implementation of modular HUBER MeChem® Solutions (Huber et al., 2007)

Implementation of Mechanical-Chemical Treatment in Vietnam

Within the scope of the SANSED II project a simple MeChem concept for decentralized or semi-centralized wastewater treatment for a settlement in South Vietnam was implemented as an example. With a modular system a fraction of the raw wastewater from the tourist location Long Hai Beach is beeing mechanically treated and then discharged into a nearby receiving water body since August 2008. Installation of the treatment modules at the discharge point of a sewer main was carried out in cooperation with the local Ba Ria Vung Tau Urban Sewerage and Drainage Company and with the Southern Institute of Water Resources Research.

The system is designed for a maximum flow of 40 m^3 h^{-1} and includes ultra-fine screening as its central treatment stage. The arriving raw wastewater is mechanically pre-treated with an ultra-fine drum screen (HUBER RoMesh with 0.5 mm mesh openings) and then discharged. Removed screenings are gently dewatered in a screenings compactor (HUBER Ro 7), to reduce their mass and volume, and then discharged into a container (See Fig. 2). To permit easy disposal of screenings, they can be manually blended with quicklime for disinfection. Screened wastewater is used as spray water for the cleaning of the screen. Internal wash water recirculation saves freshwater for the operation of the entire treatment system. External freshwater is only needed for the operation of an additional high-pressure water jet for intensive cleaning and grease removal from the ultra-fine drum screen. The system can easily be upgraded by addition of a chemical treatment stage. Figure 3 shows the plant installed at Long Hai Beach, Vietnam.

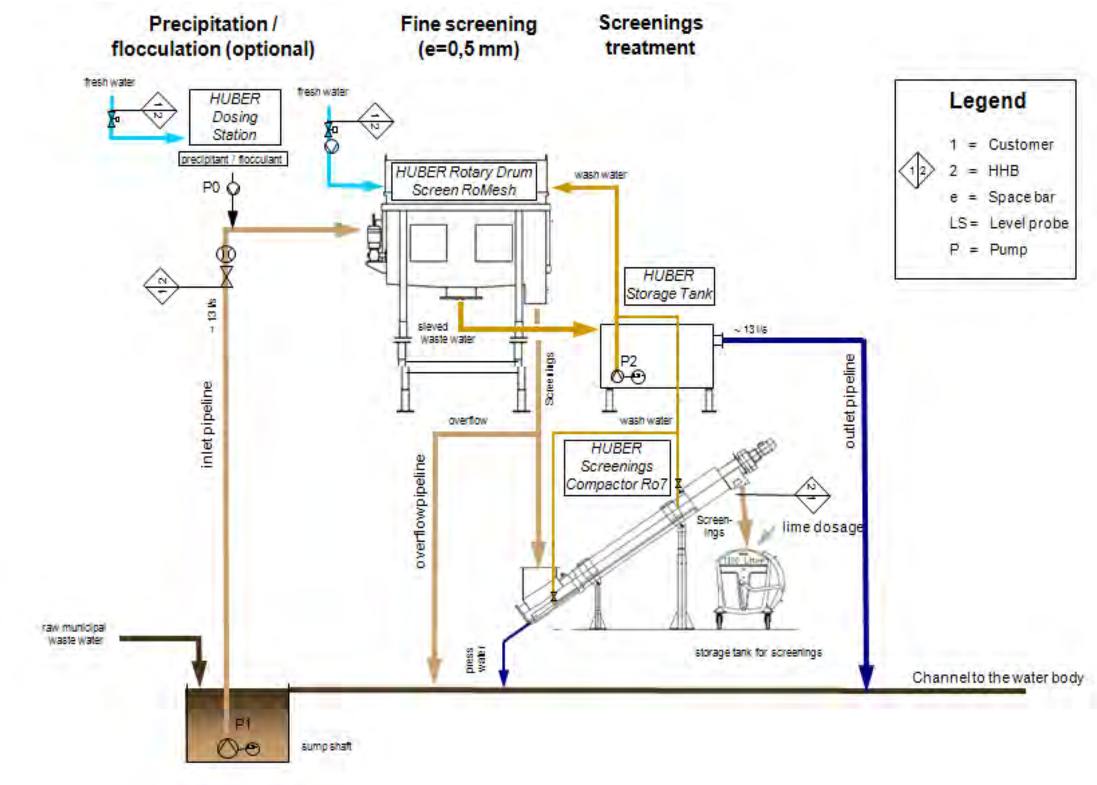

Figure 2: MeChem concept for partial treatment of municipal wastewater and effluent discharge

Figure 3: Ultra-fine drum screen (HUBER RoMesh) and screenings compactor (HUBER Ro7) at Long Hai Beach, Vietnam

Results

The complete equipment was installed in Germany, at the WWTP Neumarkt, before shipment to Vietnam (See Fig. 4). The pilot plant was tested with raw municipal sewage from a combined sewer system: a total of 12 test runs were performed to investigate the mass balance (See Fig. 5). Screening through the 0.5 mm mesh achieved a 50 % reduction of suspended solids and a COD reduction of 29 %. Removal rates depended on wastewater composition and dry or wet weather conditions. The return flows and freights from screenings compaction were negligible.

Figure 4: Ultra-fine drum screen (HUBER RoMesh) and screenings compactor (HUBER Ro7) at the WWTP Neumarkt, Germany

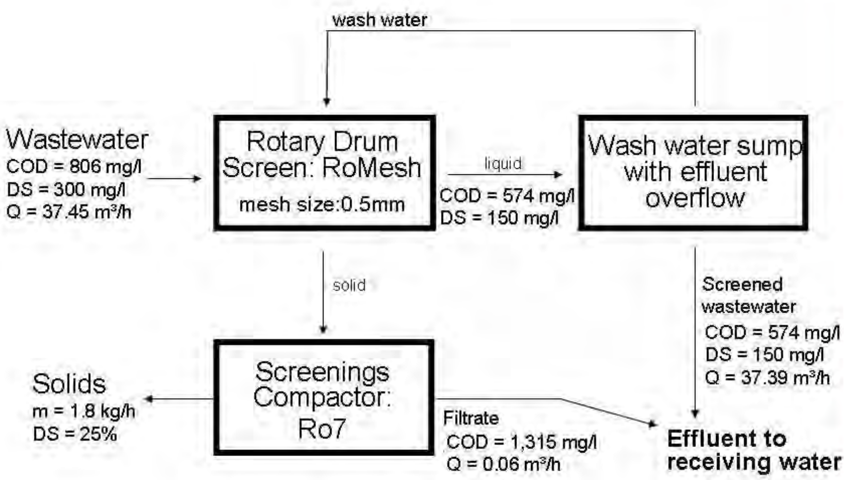

Figure 5: Mass Balance of the system as investigated at Neumarkt, Germany

The Southern Institute of Water Resource Research is going to investigate the system during continuous operation, determine its performance and optimize its operation (e.g. intermittent or continuous high-pressure cleaning) in Vietnam. In addition, they will test and select suitable precipitants, coagulants and flocculants for additional chemical treatment.

Conclusion and Outlook

Economic conditions in Vietnam are increasingly improving. During the year 2005 the gross domestic product of the country increased by 8.4 %. A report about Vietnamese water management (KA-Abwasser 2007) states that the World Bank plans financing of investments greatly improving water supply and wastewater management. From our own experience we know that practical solutions for the wastewater challenges in Vietnam require use of simple, robust and low maintenance technologies. Screening is such a technology and is an essential first stage for decentralized and semi-centralized wastewater treatment. This first stage can be easily upgraded with chemical treatment as a second stage. In spite of the fact that even this simple technology must be adapted to local conditions, there is a great possibility for its widespread use in Vietnam, because of its modular structure and its simple operation. The first basic treatment stages of the MeChem concept can be implemented easily and quickly; and thus lead to fast water quality improvement.

Supply and installation of the ultra-fine screen (HUBER RoMesh) and the screenings compactor (HUBER Ro7) within the scope of the SANSED II project ("Closing nutrient cycles via hygienic substrates from decentralised water management systems in the South of Vietnam"), as well as the planned testing and investigation program are co-financed by by the German Federal Ministry for Education and Research (BMBF). We would like to take this opportunity to express our gratitude for this support.

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List of Abbreviations:	
MeChem	Mechanical-Chemical Treatment
COD	Chemical Oxygen Demand

I-4: Building a Pilot Surface Water Treatment Plant – Case study in Hoa An Center, Can Tho University, Vietnam

Thomas Nuber[8], Frank Benstoem[8], Le Anh Tuan[4]
[8] Environmental Engineering and Ecology, University of Bochum, Germany
thomas.nuber@rub.de
[4] College of Environment and Natural Resources, CanTho University, Vietnam
latuan@ctu.edu.vn

Keywords: flocculation, sedimentation, sand filter, disinfection, water quality

Introduction

Clean water is one of the most important human needs for many daily purposes like drinking, washing, production, etc. However, water is often polluted by natural sources or after being used by households. Pollutants in water include dissolved mineral species, soluble organic by-products of life processes, organic and inorganic suspended solids, viruses, bacteria and higher life forms. For health safety and environmental conservation, all the water sources should be treated before and after usage.

The Mekong River Delta is known as the "rice bowl" of Vietnam. About 35 - 40 % people in the suburban and rural areas in the Mekong River Delta have access to clean water; this figure drops to 20 % in remote areas (Tuan 2003). In the Delta rural areas, farmers still access water directly from rivers, canals, ponds or shadow wells. Organic matter polluted and aluminized water is quite a worrisome issue in these regions. Small and medium-sized water treatment stations with the average capacity of between 50 and 1,000 cubic meters a day are economically available for small villages.

Can Tho University (CTU) is the biggest educational institution in the Mekong River Delta, Vietnam. The university hosts 20.000 students and staff approximately. One tenth of them are living in dormitories on Campus II. The dormitoriy residents use tap water for daily purposes supplied by the pipelines of the water supply system of Can Tho City. At Hoa An Biodiversity Application – Research Center (so-called in short Hoa An Center) - belonging to Can Tho University - two student dormitories and other research infrastructures are under construction. A long-term plan of CTU foresees to accommodate many students and teaching staff at Hoa An Center for their professional field studies.

In the framework of the SANSED-Project a pilot surface water treatment plant (PSWTP) is constructed at Hoa An Center. The PSWTP should be used for scientific purposes but it should also be able to supply the research station with potable water.

Today, a wide range of water treatment technologies such as sand filters, chemical purifiers, and other disinfection devices are available. However, hardly any single of these treatment methods can comply with all the domestic water supply quality parameters. On the other hand, high technology processes may be completely ineffective from an economical point of view. Typically, most water treatment plants use combined treatment systems to achieve the best results. For the design of the pilot surface water treatment plant the following conditions had to be met:

- Treatment steps are simple
- Treatment plant can be built with parts available in Vietnam
- Low costs and low maintenance but high efficiency
- Robust

Besides standard treatment components (e.g. sedimentation tanks, disinfection), tube reactors in which the flocculation takes place and a slow sand filter are applied. The tube reactors guarantee a reliable formation of settleable flakes even under sub-optimal operating conditions and do not need maintenance.

Theory

Water resources vary widely in regional and local patterns (Viessman and Hammer 1998). Water supply for domestic use has to satisfy water quality standards. Drinking water standards represent a threshold limit for specific physical, chemical, (micro)biological and bacteriological parameters which may only be exceeded incidentally, if at all. Water treatment technology is a very important impact factor for drinking water quality.

Freshwater from rivers and canals is widely used in areas where the water quality is not characterised by high salinity and / or acidity and / or pollution. Commonly, surface water taken from rivers and streams is first treated by flocculation and sedimentation. These technologies may be combined with a sand filter system in a next stage. The purpose of sand filtration is to separate the solids from the liquid. Finally, a UV lamp and / or a chlorination unit are used as a disinfectant.

The principal mechanism of flocculation is the destabilization of non-settleable particles in the raw water and the subsequent removal of the agglomerated small particles in the form of flocs. The process is achieved by mixing raw water with a coagulant such as alum compounds. Treatment involves agitation of the mixture in order to allow for contacting and floc development; treatment time is about half to one hour. Usually, the flocculation process is carried out in a flocculating tank. The flow velocity in the flocculating tank is kept between 12 - 18 cm sec^{-1} (Singh and Singh 2003). Sand filtration for water treatment is an easy and simple technology for small communities. During the filtration process, water quality is improved by passing through a porous substance which partly removes suspended and colloidal matter, reduces the number of bacteria and other organisms and induces changes in its chemical constituents (Huisman 1986).

Although previous stages of water treatment processes may lead to a better water quality, the disinfection process or water sterilization is always required. Sterilization virtually destroys all sorts of bacteria useful or harmful to human health, while disinfection restricts its destructive effect only to harmful bacteria (Singh and Singh 2003). Chlorine – correctly

dosed - can be applied as a disinfectant. It is fairly cheap and easy to handle.
The use of an UV lamp is also another method for disinfection.

Hoa An Site Description

Hoa An Center

Hoa An Centre (HAC) is a research farm designed for the university's students that specialize in wetland and Mekong River basin ecology research. HAC is located in Km. 41st, National Road No. 61, from Can Tho City to Hau Giang province (Figure 1). The total area of HAC is 112.31 hectares. The center is a waterlogged area of more than 100 hectares characterised by *Melaleuca* forest, a local plant and wild grasses conservation area, a system of closed dikes and canals, some rice fields, an animal husbandry farm and some household scale VACB-farming models (combination of garden-pond-pig-biogas).

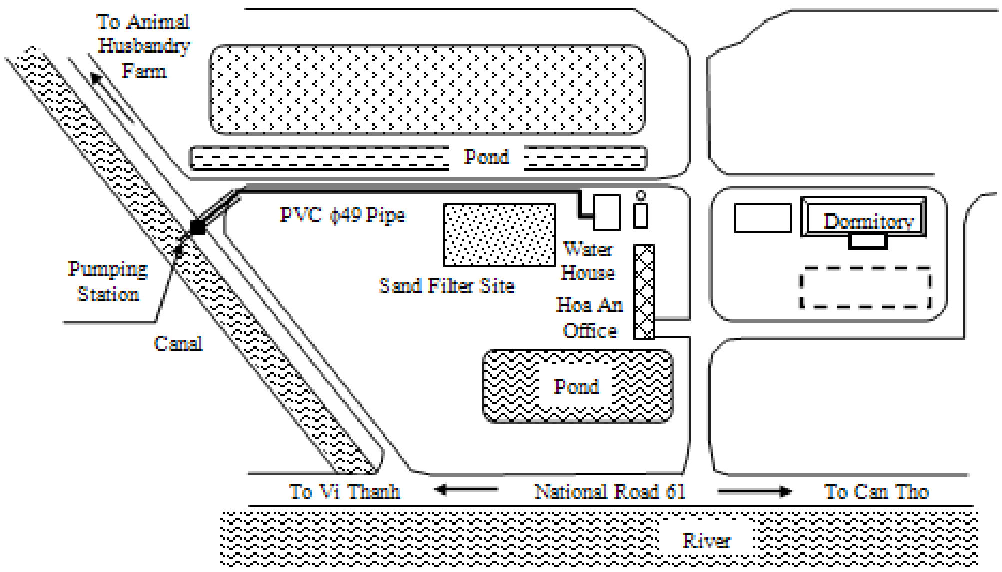

Figure 1: Hoa An Water House - PSWTP location

Water Quality in Hoa An

Hoa An is a typical acid sulfate soil area. The annual precipitation in this area is around 1,800 – 2,000 mm. The rainy season in which 90% of the precipitations are recorded extends from May to October. During the seven-month dry period, a serious shortage of rain water supply is typical. Groundwater is exploited and pumped from a depth of 80 - 120 meters for a small groundwater treatment plant. This water is characterised by a high iron content. In HAC, water draining from the fields and ponds is channelled through the *Melaleuca* forest. Surface water can be taken from the canal along the road leading to the Animal Husbandry Farm.

Two surveys for water sampling were carried out in HAC in March and November 2006. Water samples were taken from the river, canal, sluice, pond as the sampling locations areillustrated in Figure 2.

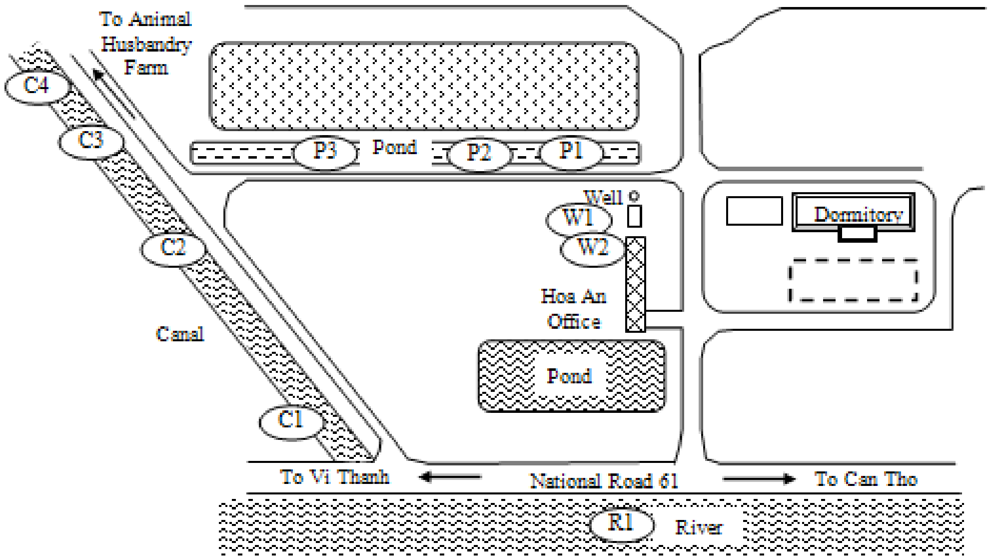

Figure 2: Water sampling locations

Note:	*R1*	*- in River*	*(17 March 2006)*
	C1, C2, C3 and C4	*- in Canal*	*(17 March 2006)*
	W1 and W2	*- in Well*	*(17 March 2006)*
	P1, P2 and P3	*- in Pond*	*(16 November 2006)*

Water samples were analyzed in the field and in the environmental laboratory of the Department of Environmental and Water Resources Engineering, the College of Technology, CTU. The water quality parameters are presented in Table 1.

Table 1: Water quality in Hoa An

Sample Code	BOD_5 (mg l^{-1})	COD (mg l^{-1})	Turbidity (NTU)	SS (mg l^{-1})	DO (mg l^{-1})	pH	EC (µS cm^{-1})	T.Coli	E. Coli
R1	3.50	37.50	54.00	62.00					
C1	2.50	9.38	2.50	56.00					
C2	4.00	18.75	104.00	128.00					
C3	12.00	37.50	62.00	74.00					
C4	13.50	37.50	93.00	117.00					
W1	3.00	18.75	75.00	84.00					
W2	12.50	56.25	84.00	94.00					
P1	122.50	255.41	33.90	102.00	5.50	7.30	563.00	$1.7*10^4$	$5.0*10^3$
P2	85.05	145.95	18.30	24.00	6.00	7.17	512.00	$5*10^3$	$3.1*10^3$
P3	113.40	210.81	35.90	64.00	5.60	7.19	485.00	$1.1*10^4$	$1.6*10^3$

The water quality parameters in the river and canal are rather good although the turbidity data are highly variable because of turbulences caused by boat traffic. The water in the pond has high BOD_5 and COD concentrations and high numbers of Coliforms. Stream water is recommended to take for treatment.

Water Treatment Concept and Dimension

Hoa An Center has a small water supply station fed with well water. However, the volumes do not satisfy the present and future demand. According to plans, in a peak period, there will be more or less 300 persons coming to the center for research and work. With a water supply standard of 120 l per day per capita, it is found that a drinking water supply plant with a capacity of 50 cubic meters per day is necessary to build. A PSWTP, as illustrated in Figure 1, is built. Water will be pumped from a canal by a submerged electric pump and pumped to the treatment station for purification. The water purification procedure is illustrated in Figure 3.

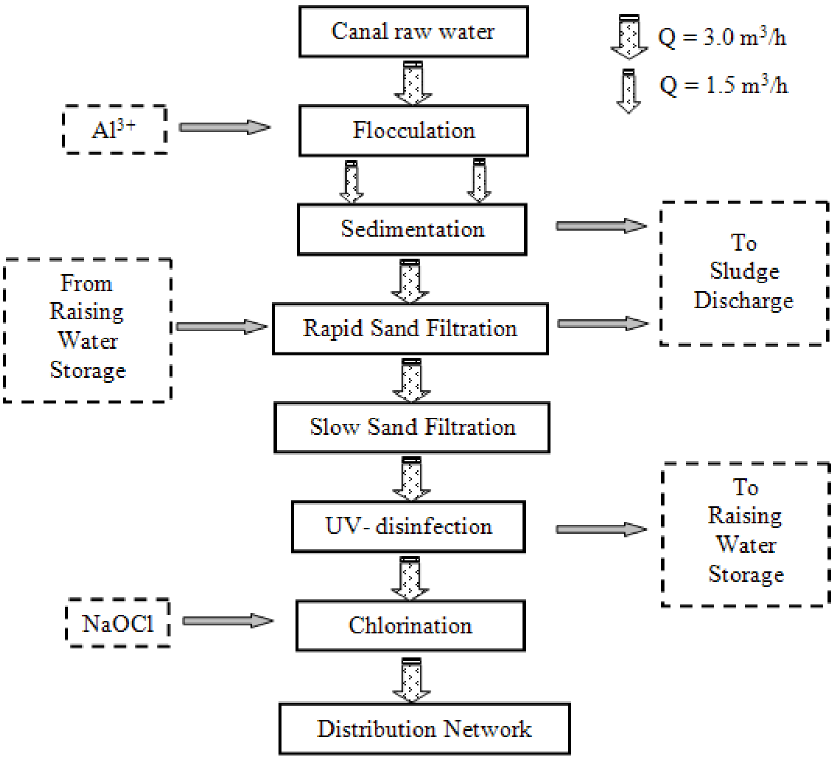

Figure 3: Water purification process

Pumping Station

The treatment plant is designed for a maximum water flow rate of 3 m^3 h^{-1}. The surface water is abstracted from the canal with the submersible water pump and transferred to the PSWTP. The submersible pump is located in a water intake tank representing a small pumping station. The tank itself is connected to the canal by an intake pipe surrounded by a fence and covered by a stainless steel net preventing larger particles (e.g. leaves, water hyacinth) from entering and blocking the system.

System Operation

For the destabilization and agglomeration Polyaluminiumchloride (PAC) solution is used as a flocculent. It is stored in a stock solution tank. A Stirrer is used to guarantee a homogeneous mixture when fresh PAC solution has to be prepared by dissolving PAC in water. The PAC stock solution is added to the water stream with a dosing pump. The typical "pulsated-dosage-characteristic" of the dosing pump is smoothened by a pulsation damper. This secures a continuous dosage for optimum mixing with the water stream and for maximizing measurement accuracy of the flow rate with flow meter.

During sedimentation most of the flakes formed in the flocculation stage settle down and therewith reduce the load of solids being discharged onto the rapid sand filters. The flakes settle in sedimentation tanks. Therefore the water stream coming from the top of the sedimentation tanks is redirected using a deflector. Due to the large diameter of the tanks the velocity of the water stream slows down and the flakes can settle down. The clear water is taken from the top of the sedimentation tank and is stored in another tank.

The treatment goal of the rapid sand filter is to remove small non-settleable residual particles. The water is pumped from the storage tank through two serially connected rapid-sand filters. The flow velocity can be adjusted through a valve. The filters can be backwashed by using water from the clear water storage tank. The backwash flow can be measured using a flow meter. Valves are needed to switch from operating process to backwash process. The slow sand filter induces aeration, reduction of dissolved organic substances and reduction of germs. The slow sand filter will be designed and built under construction supervision of ITH (Thilo Herrmann) and Le Anh Tuan.

For disinfection, the water is pumped through the ultraviolet disinfection lamp (UV). After that a sub-stream of the water is used to (re-)fill the rinsing water tank. This process is controlled automatically by a float. This sub-stream and the flow rate can be adjusted using valves.

The treatment goal is the persistent disinfection of the treated water. Either disinfection with the UV lamp or with chlorine or both can be applied. Sodium hypochlorite solution is added to the treated water by a dosing pump. A Pulsation damper is needed to smoothen the signal for a continuous injection in order to produce a homogenous mixture. After the chlorination step the treated water refills the water supply tank of the dormitory via an underground pipe. Table 2 gives the main design parameters of the PSWTP.

Table 2: The PSWTP dimension

Items	**Dimension**
Sedimentation Tank Area	$A = 2\ m^2$
Flow Rate	$Q = 3\ m^3$
Flow Velocity	$V = 0.75\ m\ h^{-1}$
Retention Time	T ~ 1 hour
Micro Flocculation Reactor	$D = 0.025\ m$, $L = 25\ m$, $V_{min} = 0.1\ m\ s^{-1}$
Macro Flocculation Reactor	$D = 0.070\ m$, $L = 15\ m$, $V_{min} = 0.1\ m\ s^{-1}$
Rapid-Sand-Filter	$Q = 3\ m^3$, $Vf = 12\ m\ h^{-1}$
Rapid-Sand-Filter Tank Size	D = 0.6 m, H = 2.4 m
Maximum Entire Electricity Load	8.2 kW

Conclusion and Recommendation

Basically, the construction of a pilot water treatment plant for Hoa An Center was executed at the end of 2007. The water treatment equipment and the electric panel were installed. The slow sand filter will be built in 2008. The plant is currently going through verification and adjustment stages. The manual and documentation of the plant were edited in English and Vietnamese versions (Nuber, T. *et al.* 2007).

Although the PSWTP was designed mainly for operation in an automatic modus, the role of a plant manager is very important. He should be trained to have a thorough understanding of equipment and control functions. Maintenance procedures should be documented in a protocol. Another important issue is to avoid pollution of the water source and to use the treated water responsibly. This issue has an economical meaning and an environmental education effect for Hoa An Center.

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I-5: Pilot Drinking Water Treatment Plant Hoa An – First Results and Further Ideas

Thomas Nuber[8], Harro Stolpe[8], Frank Benstoem[8], Le Anh Tuan[4]
[8] Environmental Engineering and Ecology, University of Bochum, Germany
[4] College of Environment and Natural Resources, Can Tho University, Vietnam

Keywords: drinking water supply, surface sater treatment, flocculation, tube reactor, jar tests

Introduction

The drinking water supply for the rural areas of the Mekong Delta is still a challenge. In the rural areas of the Mekong Delta a centralized and well organized water supply is barely existing. Here, the drinking water supply is often realized by small scale water supply stations using groundwater or surface water. One of the characteristics of the available surface water is the high amount of suspended solids. Regarding the suspended solids the drinking water supply stations do often have a flocculation treatment step followed by sedimentation and filtration units.

For the flocculation often aluminium salts are used as flocculants. Often the dosage is done manually. The formation of the flocs does not take place in separate compartments but within the sedimentation basins. Therefore, a stable water quality can not be guaranteed. Also the conditions which are required for the formation of the flocs, here the application of energy in particular, are not regarded consequently.
In the framework of the SANSED-Project a pilot water treatment plant (PWTP) using surface water was constructed at Hoa An Research Station. For the design of the pilot water treatment plant the following conditions were defined:

- treatment steps have to be simple
- the treatment plant can be built by parts which are available in Vietnam
- low costs and a minimum of maintenance necessary
- efficient treatment
- robust

Besides standard treatment components (e.g. sedimentation tanks, disinfection), a tube mixer and a tube reactor are used for flocculation. Tube mixers and tube reactors provide a reliable formation of flakes even under sub-optimal operating conditions and do not need maintenance.

This paper deals with investigations regarding the treatment using a tube mixer and a tube reactor. The goal of these investigations is an appraisal of the tube mixer and tube reactor in terms of their performance and their adaptability for the raw waters which are available at Hoa An Research Station and the Mekong Delta respectively.

Materials and Methods

Tube Mixer and Tube Reactor of the WTP

As already mentioned this paper deals solely with the flocculation step of the pilot water treatment plant at the research station Hoa An. A detailed description of the PWTP can be found in Bentstöm (2008). The flocculation of the PWTP is designed for a capacity of 1.5 m³ h^{-1} and realized with three process steps. In the first treatment step the flocculants – a Polyaluminiumchloride (PAC)-solution – is mixed to the water using a tube mixer. Within the tube mixer the diameter is spontaneously widened from 25 mm to 63 mm which causes local turbulences. Those turbulences increase the application of energy to the system. With this, an optimal mixing can be achieved. The dimensioning of the tube mixer is based on an approach by Bratby (2006). The dosage of the flocculants is realized by a membrane dosage pump by the company Prominent. In the second treatment step a tube reactor is forming micro-flocs and in the third step a tube reactor is forming macro-flocs. Both tube reactors are made of flexible tubes with defined lengths and diameters calculated by a dimensioning approach by Grohmann (1981).

For the formation of the micro-flocs a flexible tube with a diameter of 25 mm is chosen. Here, the application of energy is significantly lowered in comparison to the turbulances of the tube-mixer, so that the agglomeration of the suspended solids which are already destabilized by the added flocculants can take place. For the formation of the macro-flocs the application of energy is lowered again by using a flexible tube with a wider diameter (63 mm). Doing this, shear forces which affect the formed micro-flocs are reduced and therefore settleable macro-flocs can form.
Figure 1 shows a scheme of the mixing process and the formation of the flocs and the application of the energy to the system.

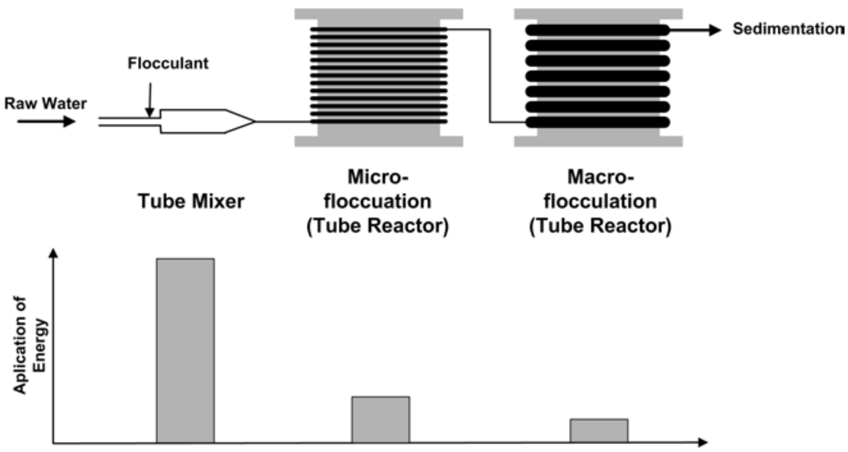

Figure 1: scheme of the flocculation step and the application of energy

Quality of the raw waters

One of the characteristics of the Hoa An Research Station regarding the water supply situation is the fact that there are two raw water sources available. For the investigations described in this paper, both raw water sources are used. For the determination of the raw water quality chemical-physical and chemical parameters are analysed on-site and in the Laboratory of the College of Technology of the Can Tho University respectively. Some selected parameters are illustrated in Table 1.

The first available raw water is surface water which is typical for the Mekong Delta. It is characterised with a high amount of suspended solids and a moderate organic load. The electric conductivity is in a typical range for surface waters.

The second raw water is characterized by a high organic load. The electric conductivity is rather high and the colour of the water is yellow-brownish which indicates a high concentration of humic substances (Jekel 1985, Abbt - Braun and Frimmel 2002). Also the measurement of the spectral absorption coefficient at a wavelength of 436 nm, as a degree for the colour caused by humic substances, lead to this conclusion.

Table 1: Selected parameters of raw water quality

Parameter	Unit	Raw Water 1	Raw Water 2
pH	-	6.97	7.30
EC	µS cm^{-1}	160	563
COD	mg l^{-1}	18.75	85.46
TSS	mg l^{-1}	128	24
Turbidity	NTU	104	40
SAC 436nm	1 m^{-1}	1.5	7.5

Jar Tests

According to the DVGW-worksheet W 218 jar tests are performed in order to test water samples on their behavior in terms of their flocculation behavior for different boundary conditions such as the flocculants dosage. For this a stirring device is used to simulate a flocculation process of a water treatment plant in a beaker. Here, several test series with the available raw waters are tested. Within one test series the dosage of the PAC-solution is increased from 0 mg l^{-1} up to 140 mg l^{-1} in steps of 20 mg l^{-1}.

The raw water is sampled from the canals and poured into beakers. The stirring device is put into the beaker and its rotational speed is adjusted to 300 turns a minute. Using a pipette the PAC-solution is added to the sample. After 30 seconds the rotational speed is reduced to 50 turns a minute. With this adjustment the stirring device is running for 20 minutes. After 20 minutes the water is poured into an Imhoff-cone. After one hour of sedimentation in the Imhoff-cone the turbidity is measured using the handheld "Turbiquant" from Merck Company. Also the volume of the settled flocs is read off from the scale of the Imhoff-cone.

The experimental procedure is illustrated in Figure 2.

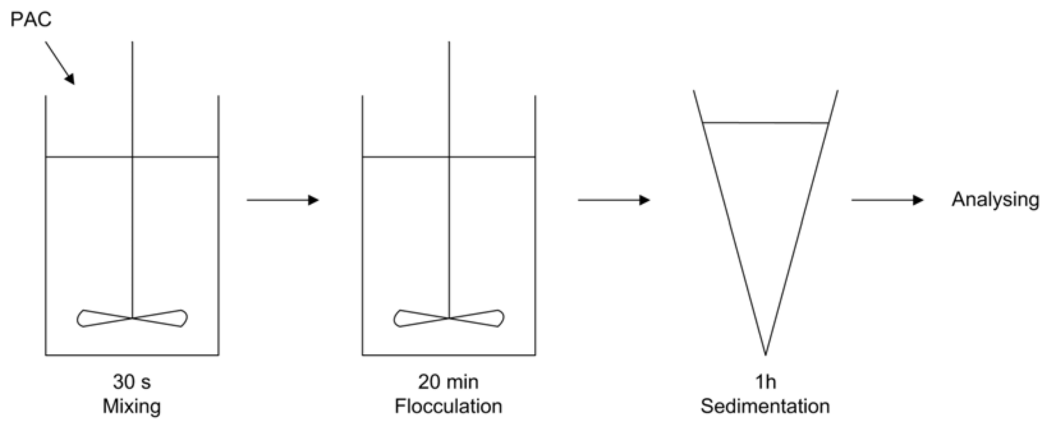

Figure 2: Experimental Procedure „Jar-Test"

Tests at the Pilot Water Treatment Plant (PWTP)

The chosen raw water is taken out of the canals by a submersible pump and transported through a PVC-Pipe to the PWTP. Within one test series the dosage of the PAC-Solution is increased from 0 mg l^{-1} up to 140 mg l^{-1} in steps of 20 mg l^{-1}. After the submersible pump is started the dosage pump is regulated to the required PAC-dosage. After 15 minutes the sampling starts.

The samples are taken via sampling valves. After a sampling valve is opened the sample is taken after a steady flow is reached. Here, a 10 l sampling beaker is filled carefully. From this sample 1 l is filled into a Imhoff-cone. After one hour of sedimentation the turbidity is measured using the handheld "Turbiquant" from Merck Company and the volume of the settled flocs is read off from the scale of the Imhoff-cone.

The experimental procedure is illustrated in Figure 3.

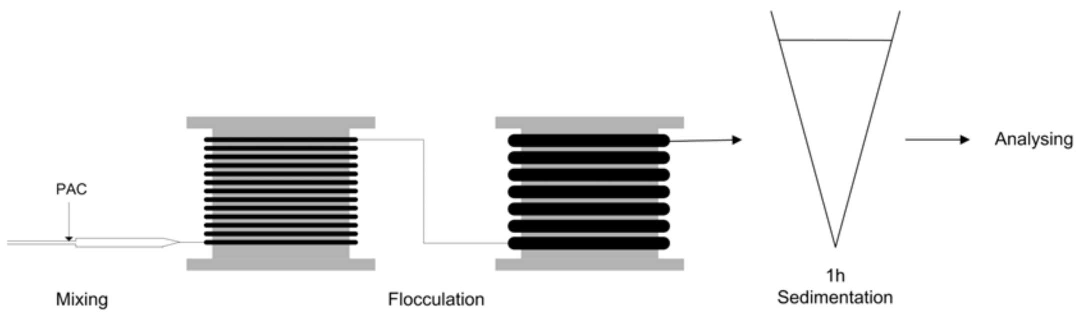

Figure 3: Experimental Procedure „Pilot Water Treatment Plant"

Results and Discussion

In Figure 4 the ratio between the turbidity measured after 1 hour of sedimentation and the turbidity of the raw waters are illustrated (relative turbidity) for some exemplary test series.

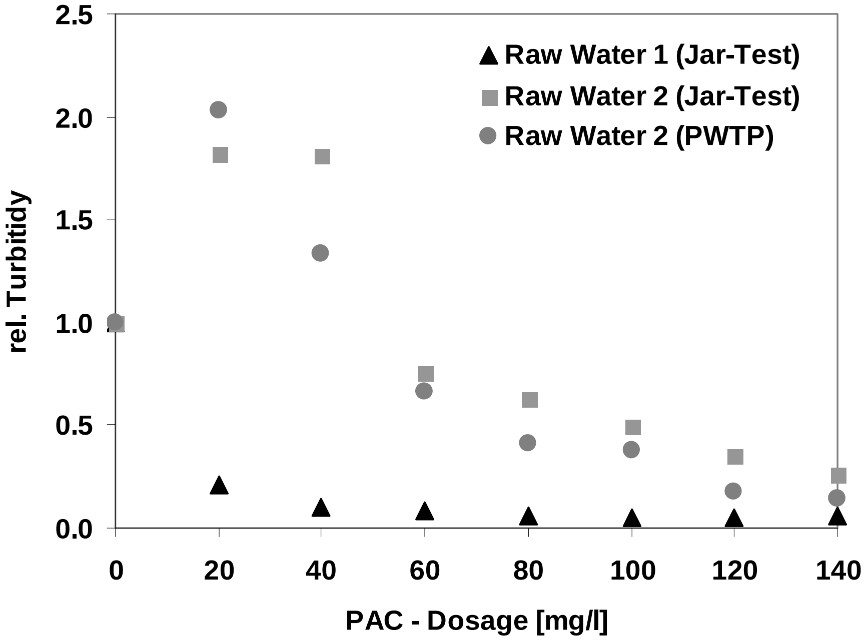

Figure 4: Relative Turbidity against PAC-Dosage

The results for the test series using raw water 1 which is characterized by a high amount of suspended solids and a low organic load show already a sufficient elimination of the turbidity using low PAC-Dosages. Using high PAC-Dosages the results show an elimination of up to 90 %.

The test series using raw water 2 which is characterized by a high amount of humic substances show the same results for the jar tests and for the tests at the WTP. Here, the turbidity at dosages of 20 mg l^{-1} and 40 mg l^{-1} exceeds the turbidity of the raw waters significantly. For the highest dosage of 140 mg l^{-1} the results show a decrease of the turbidity of 70 % to 80 %. Here, the observed increase of the turbidity and the relative high remaining turbidity with high PAC-Dosages are characteristic for raw waters with inhibitors.

This effect was already observed by Tobiason *et al.* (1994) performing jar-tests using artificially composed water. For the performed tests, humic substances as the cause for the inhibition are obvious. The raw water 2 has a yellow-brownish colour and a high SAC 436 nm indicating a high amount of humic substances. Additionally the high COD – value can be interpreted as an indicator for humic substances.

Also the observed formation of the flocs indicates the presence of humic substances. Humic substances lead to a formation of voluminous flocs with high water contents. (Jarvis *et al.* 2005). This can be shown by the high volume of the flocs observed by the test series of the jar tests and the tests at the WTP for raw water 2 (see Figure 5). Additionally it was observed that sedimentation for those test-series was not possible. This effect was not observed for the test series done with the raw water 1.

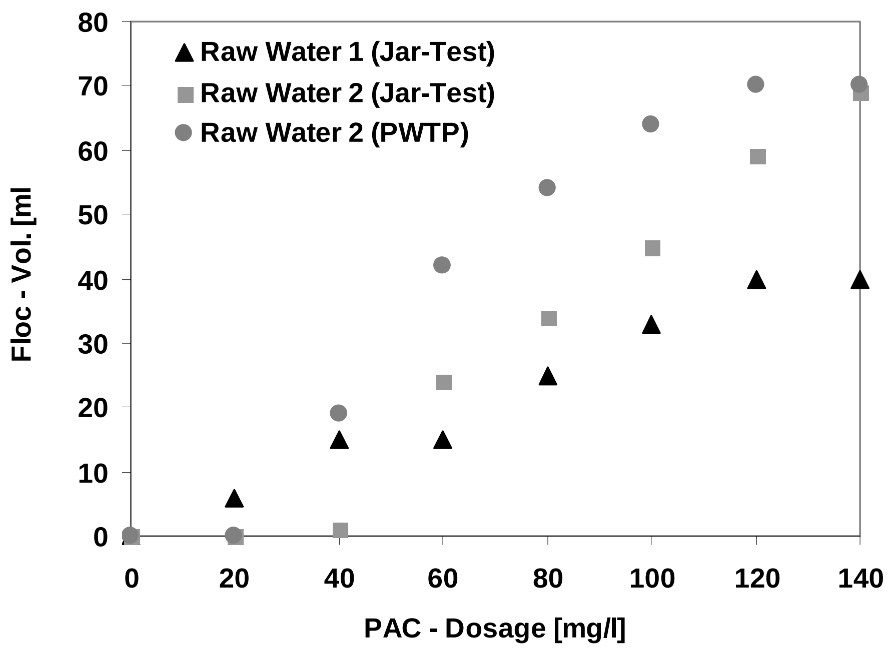

Figure 5: Floc – Volume [ml l^{-1}] against PAC-Dosage

Conclusions and Outlook

Regarding the results of the investigations the following conclusions can be drawn:

Flocculation is a sufficient treatment step for the surface water treatment at the research station Hoa An and the whole Mekong Delta respectively.

- Flocculation is especially for raw waters with a high amount of suspended solids a recommended treatment step. According to the results of the jar-tests 80 – 90 % can already be eliminated with a PAC-Dosage of 40 mg l^{-1}
- Flocculation for raw waters with humic substances is a challenging treatment step. Here the flocculation has to be embedded into a treatment concept regarding humic substances
- Flocculation can be realized by the combination of the tube mixer and the tube reactor an it can be simulated by simple jar tests

Considering the low costs, the reliability and the simplicity of the system, tube mixer and tube reactor can be an option for a reliable and simple surface water treatment in the Mekong Delta. Here, this system should be further developed and embedded into a drinking water treatment concept applicable to the conditions of the Mekong Delta.

Furthermore it should be pointed out, that the constructed pilot water treatment plant in Hoa An opens various opportunities for further research in the field of drinking water treatment.

Besides the investigations described in this paper, research on other treatment components and methods can be done as well as research on innovative methods such as the underground storage of rainwater. With such future activities the existing pilot water treatment plant in Hoa An could contribute many ideas to solving the challenges of the drinking water supply of the Mekong Delta.

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Chapter II: Source Separation and Fertiliser Production

II-1: Nutrient fluxes and behaviour acceptance of the source separation system at B23 – a natural scientific and sociological study

Susanne Wohlsager[1], Christopher Scharfe[3], Phan Thanh Nguyet[4], Joachim Clemens[1], Ute Arnold[1]

[1] INRES – Plant Nutrition, University of Bonn, Germany, susiwohlsager@web.de, a.clemens@uni-bonn.de, uarnold@uni-bonn.de

[3] Institute for Food and Resource Economics (ILR), University of Bonn Germany cscharfe@uni-bonn.de

[4] College of Environment and Natural Resources, Can Tho University, Vietnam pt-nguyet2000@yahoo.com

Keywords: separation toilets, yellow water, brown water, urine storage, acceptance, survey

Introduction

Human excreta contain high amounts of nutrients. The major part of nitrogen (N), phosphorous (P) and potassium (K) is excreted via urine whereas the major part of pathogens is excreted together with organic matter in the faeces (Roche 1984, Vinneras 2002, Otterpohl 2006). In separation toilets urine and faeces are divided and thus treatment of the separated fractions and subsequent application as fertiliser can be more specific than for combined waste water.

To calculate the nutrient potential and the input on the agricultural soil the nutrient content of these fractions should be known. As there is only little published data available for developing countries, the nutrient load in brown (faeces with water) and yellow water (urine with water) was measured at a newly installed system at Can Tho University, Vietnam.

Separation of urine and faeces is practiced at a lot of farms in Northern Vietnam (Humphries 1997), whereas in Southern Vietnam squat toilets over fishponds are common practice.

To find out and make sure that separation toilets are an acceptable solution for improved decentralised sanitation in South-Vietnam, an explorative survey on attitudes towards and acceptance of the separation toilets, installed at B23 dormitory, was carried out.

Besides the acceptance of the toilets and the nutrient content of gained urine and faeces, treatment of excreta is an important issue.

This study also queries if urine should be treated prior to application as a fertiliser in order to reduce possibly existing pathogens. Storage is a simple treatment for urine that has been shown successfully under European conditions (Schönning *et al.* 2001). To find out about the situation under tropical conditions, nutrients and micro organisms were examined in a 9-months batch experiment.

Material and Methods

At the dormitory B23 of Can Tho University, 10 separation toilets with water flush system (Gustavsberg / Berger) and 10 local waterless urinals were installed for 100 students. Different plastic pipeline systems transport each fraction (brown water, yellow water, urine, grey water) from the bathroom to the subsurface (2 metre depth) concrete collection tanks.
For measuring the inflowing amounts in January 2007, the volume was calculated by the increase of the water level and ground area of the tank.
The nutrient amounts were compared to the values calculated by a formula of Jönsson *et al.* (2004), taking the available nutrition data of the Food and Agriculture Organisation (FAO 2007, data for 2002 - 2004).
The experimental setup of the urine treatment by storage was a batch experiment comprising four treatments: Open storage, closed storage, undisturbed closed storage and diluted closed storage. For the first three treatments undiluted urine was taken, that had been collected directly from male students urinating into plastic canisters. Diluted urine out of the separation toilets was collected at the end of the pipeline to the collection tank.
During the storage time the 4 replications of the open, closed and diluted closed replications were determined regularly after shaking.
Field parameters were determined directly in the storage bottles by WTW MultiLine 340i. Total nitrogen was measured by Kjeldahl according to VDLUVA method book 1, A 2.2.2 with a titanium dioxide based catalyst. Ammonium was determined by Kjeldahl according to DIN EN 25 663. Kjeldahltherm type KB 20, Gerhard Vapodest 20, Gerhard was used for these analyses.
E.coli, total *coliformes* and faecal *streptococcus* were detected according to the „Directive of the Council of the European Community about the quality of bathing water" 76/160/EWG official journal of the EU 5.2., 1976. E.coli and total coliformes were detected by the MPN-method, faecal streptococcus quantitative.
Salmonella sp were measured according to ISO 6579, Helminth eggs according to the directive of the WHO („Analyses of Wastewater for use in Agriculture", 1996) and *Coliphages* according to ISO 10705-2, reference phage phi X 174 DSM4479 *E. coli* WG5 ATCC 700078.
Total nitrogen, ammonium and microbiological parameters were measured at CTU laboratory immediately after taking the samples.
For further analysis samples were frozen and measured at IPE Bonn. Phosphorous was determined by molybdenum blue method according to Murphey and Riley (1962). Potassium and sodium was analysed by flame photometer Eppendorf Elex 6361 with propane. Calcium and Magnesium were determined by flame atomic absorption spectrometer Perkin-Elmer at 2500°C, Calcium with nitrous oxide and pressurised air, Magnesium with acetylene and pressurised air.
For sociological studies Icek Ajzen's 'Theory of Planned Behavior' (1991) has often successfully been applied to explain environmentally friendly behaviour (Chan 1998, Lienert and Larsen 2006). It was therefore taken as a theoretical basis for the empirical survey implemented by the socio-economic workgroup, and used to deduce six dimensions of

variables, being ‘Demographic Variables’, ‘Attitude towards the Behaviour’, ‘Subjective Norm’, ‘Perceived Behavioural Control’, ‘Behavioural Intention’ and ‘Behaviour’.

Using a questionnaire with 44 questions, 50 students in B23 were interviewed face-to-face by Vietnamese interviewers in November 2007. Five out of ten students living in each room were selected randomly using the “last-birthday-key” method. The interviews were conducted within a short period of time and in a discreet manner, avoiding other students being able to listen to the interviewer’s responses. Besides keeping privacy, prevention of response distortion by having the students discuss about the questions and finally receiving the groups instead of each individual’s opinion was a reason for that.

In order to point out differences between users’ and non-users’ attitudes, a control group of 50 students in the neighbouring dormitory B22 was interviewed additionally, using a shortened version of the questionnaire. The findings as presented in this paper are only a brief selection to give a first overview. A full analysis of acceptance and attitudes towards separation toilets in B23 and B22 was published in summer 2008.

Results and Discussion

A number of interesting key facts concerning the social background of the students could be found out. Two thirds of all 100 students interviewed (in B23 and B22) are of rural descent, since ‘farmer’ was stated as the father’s profession by 72 % of the respondents. 73 % predominantly used traditional fishpond squat latrines during childhood while only 8 % grew up with a modern water closet. However, an upward tendency of the use of latter can be ascertained since the rate of students still using fishpond latrines at home has decreased to 56 % while 21 % have installed modern toilets already. Thus, conventional sitting toilets with automatic flush are becoming more prevalent, a trend matching the SANSED solution for decentralised sanitation by source separating systems as well as Vietnam’s National Rural Clean Water Supply and Sanitation Strategy up to 2020 issued by the GoV (Mard and Moc 2000: 38).

At the source separation system at dormitory B23, in average per day and 100 students, 1 m^3 brown water, 50 l yellow water (out of it 6 l undiluted urine form the waterless urinal) and 5.5 m^3 grey water were discharged into the tanks. Assuming that one student urinates about 3 times per day in the dormitory, leading to approximately 70 l of urine without dilution, the measured inflow is very low. Additionally about 300 to 600 ml water will rinse via the front urine drain, depending on half or full flush and duration of pushing. The small amount of 6 l undiluted urine per 100 students proves that the urinal is used infrequently.

The surmise, students would probably use nature for urinating, was not affirmed, 98 % of the students from B23 use the sanitation facilities in the dormitory when they are present.

When installing the urinals, smell stops had been forgotten initially. This led to inconvenient smell and reduced disposition to use, explaining the low inflow to the yellow water tank in January 2007. Anyhow, in November 2007 an informative meeting with the students was held. Besides repeated cleaning instructions, the students were appealed to restart using the urinals. Furthermore the promise to install a flush, if the meanwhile installed smell stops would not work, was given. Therefore the urinal use could be enhanced again. Since the acceptance survey was implemented subsequent to the informative meeting, 46 % of the students committed to use the urinal when urinating. Still another 54 % continued to use the separation toilets. 32 % even stated, they have never used the urinal so far. As shown in Figure 1, bad smell, the missing flush and the adverse location of the urinal too close to the separation toilet are some of the main reasons for this behaviour.

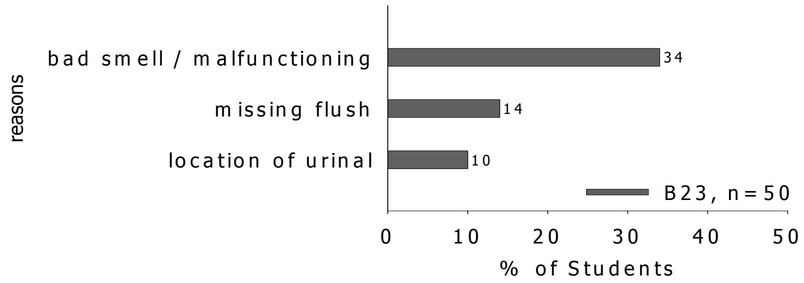

Figure 1: B23 students' reasons for not using the urinals

For obtaining the nutrient fluxes in excreta, the concentrations measured in yellow and brown water were multiplied by the corresponding daily volumes and extrapolated per year (see Table 1, left hand).

Taking the available nutrition data (66 g $person^{-1}$ day^{-1} for grand total protein and 48.8 g $person^{-1}$ day^{-1} for vegetal protein) of the FAO web site (2007, data for 2002 - 2004), according to Jönsson *et al.* (2004), the total amount results in 3.13 kg N and 0.45 kg P $person^{-1}$ $year^{-1}$. The distribution of nutrients between urine and faeces was assumed as given by Jönsson *et al.* (2004), who suggests that 88 % of N and 67 % of P are found in urine (see Table 1, right hand).

Table 1: Measured yearly nutrient mass flows in yellow and brown water at dormitory B23 and expected yearly nutrient amounts and distribution in yellow and brown water in Vietnam based on formulas of Jönsson *et al.* (2004)

	Measured		Calculated	
Fraction	N [kg $100students^{-1}$]	P [kg $100students^{-1}$]	N [kg $100students^{-1}$]	P [kg $100students^{-1}$]
Yellow Water	43	3	275	30
Brown Water	245	40	38	15
In total	288	43	313	45

Contrary to the expectations, the nutrient load in brown water was quite high, in source-separated urine very low. The total nutrient load however corresponds quite well to the calculation (see Figure 2).

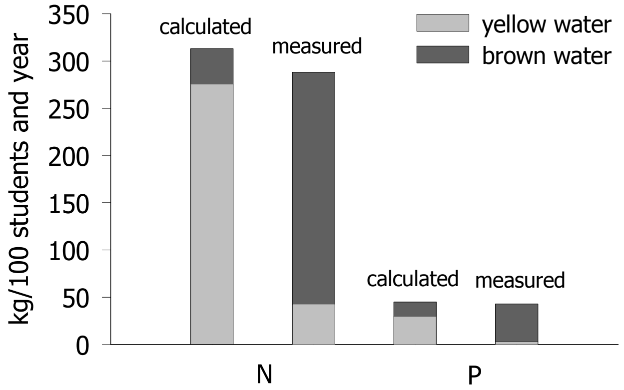

Figure 2: Expected and measured N and P amounts and distribution in yellow and brown water at the dormitory B23 (Calculations according Jönsson *et al.* (2004))

As not all excreta will go to the collection tanks - the students also use other toilets during the day – the excreted nutrient amounts per person would be slightly higher as in our measurements. These results fit quite well to the formula of Jönsson *et al.* (2004). Regarding the distribution of nutrients between yellow and brown water it seems that separation toilets were misused and urine was rinsed through the brown water pipe. This assumption is proved by the survey: A total of 90 % of the students in B23 are standing when using the separation toilet for urination, accordingly the urine with its high nutrient concentrations is placed into the rear brown water drain. When using a conventional one-pipe toilet, even 100 % of the students questioned stated to be standing when urinating.

To establish a new system like separation toilets successfully, knowledge about the social background and habits of the users, is crucial. However, the users of separation toilets also have to be informed well about the way of use and purpose of the system to avoid misuse, as most of the students in B23 are more conversant with basic toilet systems.

However, some students still seem to be unaware about the fact that the smell situation of the urinals has been improved, resulting in 'smell' still being stated as the main reason for not using them. Despite that, overall acceptance of the new systems installed by SANSED in B23 is high. When asked to compare the separation toilets in their room with conventional sitting water closets, 70 % of the respondents in B23 assessed the separating toilets as positive, while 26 % uttered a neutral and only 4 % a negative attitude.[1] Being asked about their preference, if they had the free choice between any toilet model for their dorm, an impressive 84 % of all 50 respondents in B23 would choose a separation toilet as the one installed.

During urine treatment by storage precipitates were formed in undiluted urine after one day. The crystalline part of the dried (105°C) precipitates consisted of 74 % Hydroxylapatite ($Ca_{10}(PO_4)_6(OH)_2$) and 26 % Halite (NaCl). Additionally, out of the total amounts in urine, 100 % magnesium, 98 % calcium, 32 % phosphorous were precipitated and recovered in

[1] The categories 'positive', 'neutral' and 'negative' derive from an index, aggregated from a battery of seven items, that had to be assessed by the students in comparison to a conventional WC on a scale from one to five. These items are: 'comfort', 'hygiene', 'expedience', 'environmental friendliness', 'odour', 'easiness to clean' and 'sitting position'.

the bottom layer (in 1.2 % of the urine volume). As expected, only 2 % nitrogen, 3 % potassium and 4 % sodium were precipitated.

This data prove that the amount of precipitates is limited by the magnesium and calcium concentration in urine (Udert *et al.* 2003 a,b,c). To reach higher phosphorous concentrations in the precipitates these ions can be added.

After excretion the pH in urine is around 6 - 7. Within two days the pH increased to pH 9 for closed storage. Urea hydrolyses is the reason for the pH increase (see equation 1). The pH was significantly lower in open storage compared to closed storage, as the ammonium concentrations were significantly lower in open storage.

After one week most nitrogen was present as ammonium. Due to urea hydrolyses (see equation 1) in all bottles, ammonium increased during the first weeks.

$$NH_2(CO)NH_2 + 3H_2O \rightarrow 2NH_4^+ + OH^- + HCO_3^- \qquad \text{(equation 1)}$$

The total nitrogen concentration in fresh urine was 6890 mg N l^{-1}.

After 9 months of closed storage still 93 % of nitrogen could be recovered. In contrary, open storage led to a loss of 90 % within 9 months (see Figure 3).

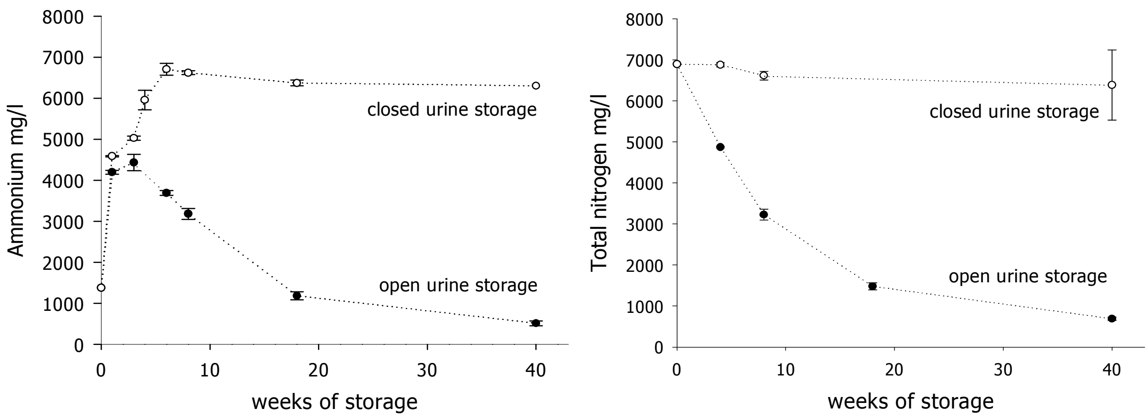

Figure 3: Ammonium and total nitrogen concentrations in mg l^{-1} during open and closed storage of undiluted urine

The data show explicitly that open storage leads to high nitrogen losses. At the prevailing pH, ammonia is formed and fumigated as gas.

These losses can be prevented -nearly completely- simply by closed storage.

After a storage period of 4 weeks *Coliforms*, *E. coli* and *Salmonella sp*. could no longer be detected in both, diluted and undiluted urine. The content of faecal *Streptococcus sp.* decreased significantly by 6 log units per 100 ml (see Rechenburg *et al.* 2008). No helminth eggs and coliphages were found in urine.

The pH and ammonium / ammonia increase due to urea hydrolysis makes the urine toxic for a lot of microorganisms (Vinneras 2002).

Conclusions and Outlook

For installation and maintenance, the following points should be considered to ensure proper function, corect use and to avoid smell:

- Corect installation of devices, especially connections of pipes, pipe slope should to 1 % or higher
- Installation of smell stops in urinals
- Insallation of a lid/possibility to open pipes in case of blockages
- Installation of urinal in practical position, e.g. not opposite of toilet
- Information for users about significance and correct use of toilets
- Regular cleaning and cleaning with acetic or citric acid necessary
- Regular supervision, e.g. of tightness, smell stops in urinals

To gain a maximum of urine for furhter use, urinals have to be installed additionally to separation toilets, as according to our study 90 % of young men stand to urinate.
To use urine as fertiliser, treatment by storage (about 4 weeks) is recommended for hygienic reasons. To avoid nitrogen losses and smell, urine should be stored in closed tanks.
Separate use of supernatant or precipitate may be wished depending on the nutrient need of cultivated plants. The supernatant contains nitrogen but only traces of magnesium, calcium and phosphorous. The precipitate is rich in posphorous.

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List of Abbreviations:	
B23 and B22	Names of dormitories
CTU	Can Tho University
FAO	Food and Agriculture Organization
GoV	Government of Vietnam
IPE	Institute for plant nutrition
$NH_2(CO)NH_2$	Urea

II-2: Nitrogen and Phosphorus Recovery from Human Urine

Samantha Antonini[1], Stefania Paris[13], Joachim Clemens[1]
[1] INRES - Plant Nutrition, University of Bonn, Germany, sam_antonini@uni-bonn.de
[13] Hans Huber AG, Industriepark Erasbach A1, 92334 Berching, Germany, ps@huber.de

Key words: yellow water, urine, recycling, MAP, energy, DeSa/R

Introduction

Conventional centralised wastewater treatment systems as they have been implemented in developed countries can be characterised as "end-of-pipe" solutions: they give rise to high costs and lead to the elimination of valuable nutrients. The concept of "source control" on the other hand may be an innovative way of promoting the sustainability of wastewater management. The so-called "No Mix" technology aims at collecting the various wastewater streams separately at source and treating them individually with the objective of recovering nutrients, producing biogas and reusing the clarified water. Hans Huber AG has developed a pilot system (DeSa/R®: "Decentralised Sanitation and Reuse"), which integrates source separation of individual wastewater flows with ground-breaking technologies for specific treatment of the different streams. This novel sanitary concept was installed on the premises of the University of Can Tho under the scope of the SANSED project, with the aim of assessing the acceptance, the practicability and the performance of processes and equipment under social and environmental conditions as they prevail in developing countries such as Vietnam.

This paper focuses on the separate collection and treatment of human urine. The so-called "Yellow Water" fraction accounts for only around 1 % of all municipal wastewater, but contains most of the nutrients (more than 75 % of the total N load and around 50 % of the total P load) (Wilsenach and Van Loosdrecht 2002). The Huber Yellow Water Treatment module consists of a two-step chemical-physical process in a precipitation reactor followed by a stripping and an absorption column. These processes generate magnesium ammonium phosphate (MAP, solid form) and ammonium sulphate (liquid form), two products which can be reused as fertilisers (DüMV 2003).

Materials and Methods

Source Control

The new sanitation infrastructure required for the separate discharge and collection of yellow, brown and grey water was installed in the existing dormitory "B23", which accommodates 100 male students in 10 rooms on the grounds of the University of Can Tho. Each bathroom was equipped with one separation toilet and one waterless urinal (manufacturer Gustavsberg / Berger). Both yellow water streams (diluted and undiluted) are discharged via separate pipes into a 2.5 m^3 storage tank located between the dormitory and the "DeSa/R® House", which accommodates the Huber treatment plants. A submersible pump directly transfers the stored urine to the Yellow Water Treatment pilot plant. In addition, undiluted urine was collected directly in plastic containers from male students living in a neighbouring dormitory.

The Yellow Water Treatment System

A schematic representation of the Yellow Water Treatment module, divided into the steps of precipitation (NuRec), stripping (NitroRec1) and absorption (NitroRec2), is given in figure 1.
In the precipitation reactor, magnesium oxide (MgO) is dosed with a ratio of 1.5 mol of Mg per mol of P to an approximate volume of 50 l of stored urine with the aim of initiating struvite (MAP) precipitation. The mixture is stirred for 30 minutes, followed by a 3 - hour sedimentation phase during which the particles are left to settle. The precipitate is collected in a filter bag whereas the phosphorus - depleted urine is transferred to a separate collection tank. In this so-called conditioning tank, optimum conditions (prevalence of nitrogen in the form of NH_3) are created for the stripping process: the temperature is raised to 40°C by means of an integrated heating unit, and the pH is increased to 10 by adding sodium hydroxide solution (NaOH, 50 %) to the urine.

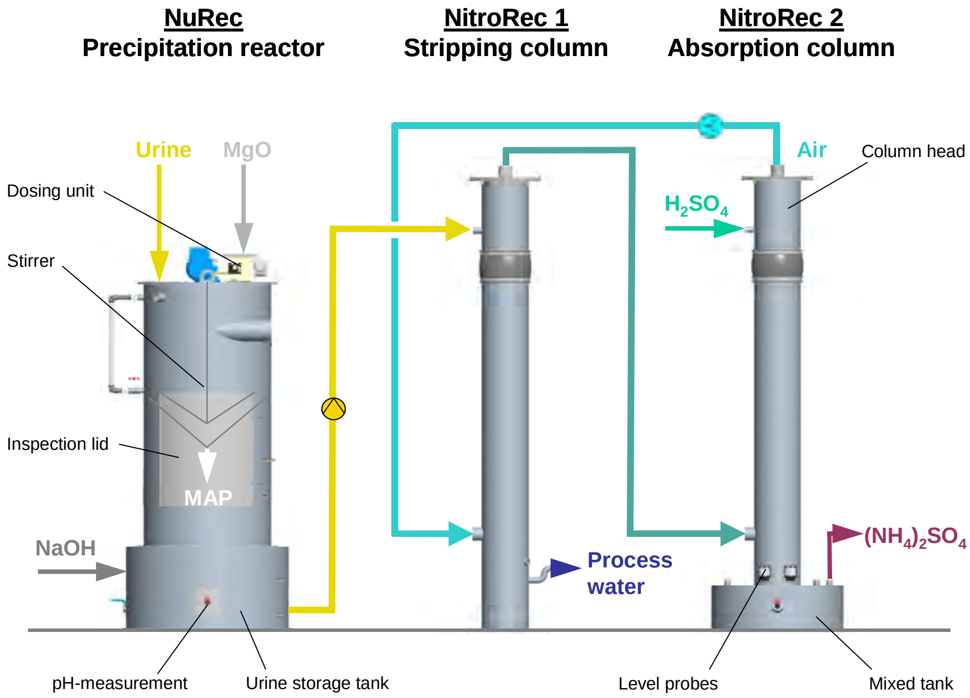

Figure 1: Flow Chart of the Huber NuRec and NitroRec for Yellow Water Treatment (*source: Hans Huber AG*).

The conditioned urine is then pumped to the top end of the stripping column, through which it flows in counter-current with an air stream. The ammonia passes from the liquid to the gas phase, and the ammonia-enriched air is carried to the base of the absorption column. Inside this second column, the air comes in contact with a 1:10 sulphuric acid (H_2SO_4) solution, which absorbs the ammonia from the gas phase in order to produce a liquid fertiliser in the form of ammonium sulphate ($(NH_4)_2SO_4$). Both the absorption and the stripping columns are filled with plastic media, thus aiding the transfer of nitrogen from the liquid to the gas phase, and vice versa. The air circulates in a closed loop through both columns in order to maximise ammonia recovery. The N and P depleted waste stream is disposed of.

Experimental Set-Up

Precipitation experiments were performed with both diluted and undiluted urine. Given the rather time-consuming nature of the precipitation stage, investigations were made into decreasing sedimentation times. The precipitation process was mimicked in the laboratory by using a jar tester (30 minutes stirring) and Imhoff cones (3 hours sedimentation).

The stripping and absorption stages were performed with undiluted urine only. Given the high buffer capacity of urine, 1 l of NaOH (50 %) was required per cycle to raise the pH from 9 to 10 (i.e. 0.25 mol NaOH per l of urine). The heating unit had to be switched on for about 15 minutes in order to reach a temperature of 40°C at the end of 30 minutes. The capacity of the stripping feed pump ranged from 30 to 90 l h^{-1}. Experiments were performed at both high (80 l h^{-1}) and low (30 l h^{-1}) flow rates, whereas the acid flow through the absorption column and the air flow rates were kept constant (55 l h^{-1} and 130 m^3 h^{-1} respectively; acid volume of 20 l H_2SO_4).

Sample Collection and Analysis

Samples were collected before and after each stage of treatment (i.e. raw urine, urine post precipitation, conditioned urine or feed to stripping, urine post stripping or waste stream, sulphuric acid before and after absorption) in order to assess the efficiency of the various processes. The samples were transferred into glass bottles and stored in the fridge in the laboratory facilities of the College of Technology. All samples were analysed for phosphorus with Hach-Lange test cuvettes (LCK 350), and for nitrogen by using the CTU Kjeldahl method. The generated precipitate was analysed in Germany for its composition by X-Ray diffraction spectrometry (XRD) and X-Ray spectroscopy.

Results and Discussion

Source Control

Regular communication with dormitory residents revealed that the acceptance and/or correct usage of the separation toilets and the waterless urinals turned out more problematic than expected. As a matter of fact, the majority of the students originate from rural areas of the Mekong Delta, where pit and fishpond latrines are common practice. Taking into account the lack of experience and poor hygienic awareness, it seems comprehensible that exhaustive maintenance and operating instructions (e.g. regular cleaning with citric acid to prevent blockages, different flushing methods for urine and faeces, etc.) had been ignored by the residents. This can be illustrated by the fact that some students believed they were not allowed to use the waterless urinals because these had not yet been equipped with a flushing device. Also, many odour complaints had been raised as a result of incorrect installation of the urine drainage system. For that reason, urinal drains were equipped with "smell stops", dormitory residents attended educational advertising meetings, and regular visits of the bathrooms in the company of the students led to improved usage and maintenance of the modern sanitary facilities. This was confirmed by increasing nutrient concentrations recorded in the urine storage tank. Total phosphorus and nitrogen concentrations for example increased from 80 mg l^{-1} to 116 mg l^{-1} and from 1300 mg l^{-1} to 1800 mg l^{-1} respectively (mixture of diluted and undiluted urine) when the toilets and urinals were used as advertised by the manufacturer.

Process Control and Optimisation

From a chemical point of view, the precipitation of MAP was highly efficient with PO_4-P removal rates of 98 % in both diluted and undiluted urine. In the case of undiluted urine, the concentrations of soluble orthophosphates decreased on average from 311.22 mg l^{-1} to 5.20 mg l^{-1}; for urine with a dilution factor of around 3, the concentrations decreased from 110.83 mg l^{-1} to 2.30 mg l^{-1}. The MAP productivity on the other hand was largely influenced by the dilution factor. With average starting loads of 15.5 g PO_4-P, about 110 g of MAP could be produced; with a starting load of 1.6 g PO_4-P, 32 g of solid fertilizer were generated (the diluted urine, which was extracted from the storage tank, contained debris such as foliage etc.; hence the actual amount of MAP generated was less than 32 g!). MAP losses occurred when it came to recovering the precipitate from the filter bag. Between 10 and 30 g of struvite remained trapped within the fibres of the relatively thick filter material after each cycle. Such losses were insignificant at high PO_4-P input loads (81.5 % MAP recovery), but when using diluted urine only about 8.5 % of the final product (2.74 g of MAP) could eventually be reclaimed. Electricity consumption during the precipitation stage was low (<1 kWh).

The results of the bench-scale trials are presented in Figure 2 and show that the majority of the particles in Imhoff cones 1 and 2 (MgO dosage) had settled down after as little as 20 minutes. Chemical analysis confirmed a 93 % PO_4-P removal. Similar results were obtained on pilot scale: sedimentation times of 1, 2 and 3 hours each time resulted in 98 % PO_4-P removal and identical rates of MAP recovery.

Around 70 % of the crystalline elements could be identified and quantified; results show that the major components are P_2O_5 (40 %), MgO (24 %), N (5 %), CaO (2 %), and Na_2O (1 %). It has to be noted that only crystalline structures can be measured with these methods; the remaining 30 % are probably made up of amorphous forms of the elements listed above.

At the lower flow rate, ammonia removal efficiencies of up to 95 % could be achieved during the stripping process. However, decreasing the flow rate increased the process time (and therewith the energy consumption) required for efficient ammonia removal to more than 5 hours. At high flow rates, the stripping process was completed after 45 minutes only with lower ammonia removal rates ranging between 60 and 75 %. In other words, with an incoming load of 260 to 270 g N, only about 12 g N failed to be stripped at low flow rates, whereas more than 70 g N were lost with the waste stream at high flow rates. A sort of compromise was achieved by circulating the conditioned urine during 3 hours at a high flow rate through the stripping column, and then discharging the N - depleted liquid to waste (total process time of less than 4 hours).

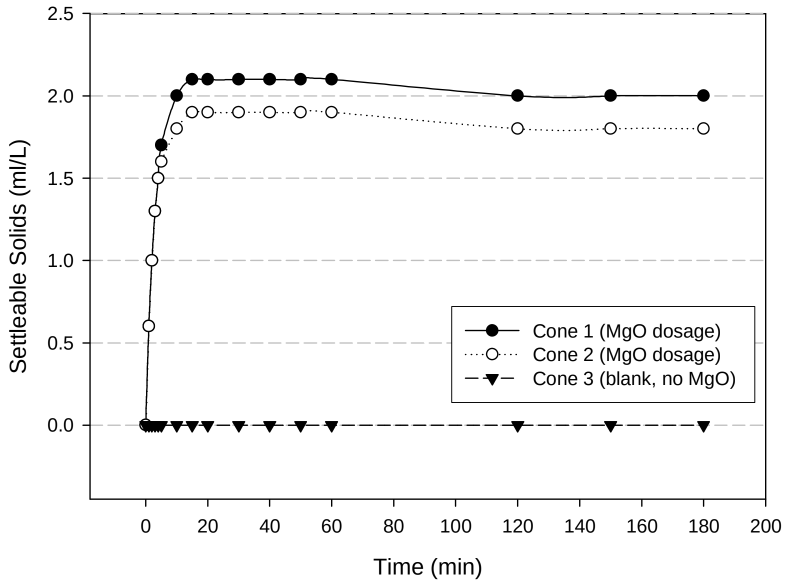

Figure 2: Settleability of MAP particles

Figure 3 shows that with this process design in place, N concentrations decreased on average from 5300 mg l^{-1} to 200 mg l^{-1}, thus representing a removal efficiency of around 96 %.

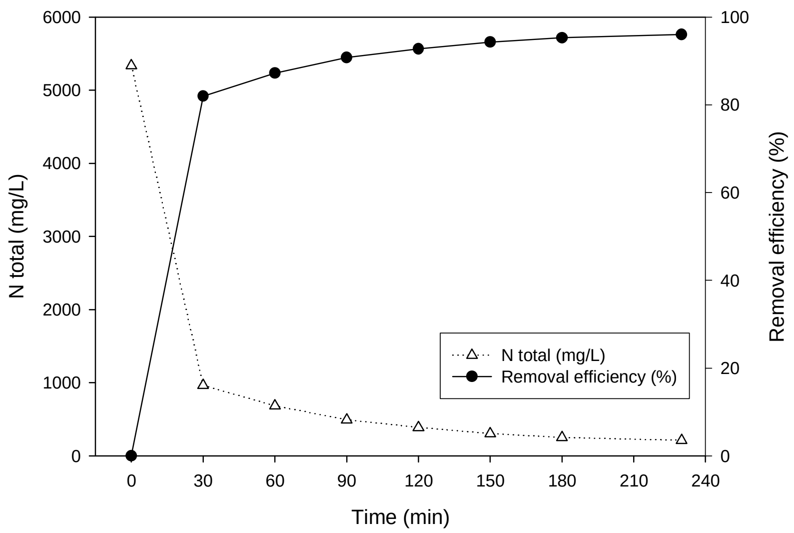

Figure 3: Removal rates and efficiency of ammonia stripping during recirculation mode.

It was not possible to confidently assess the efficiency of the absorption stage due to repeated events of acid contamination with urine via the aeration system. However, the collected data leads to the hypothesis that the ammonia recovery by absorption reaches almost 100 % during recirculation mode.

Energy consumption during stripping and absorption varied from 2 - 3 kWh at high flow rates, to 9 - 10 kWh at low flow rates, and 4 - 6 kWh when circulating the urine for 3 hours at high flow rates. In order to complete one entire treatment cycle, capital costs of 205,000 VND arose for chemicals (MgO, NaOH, H_2SO_4), between 2 and 10 kWh of energy were consumed depending on operational settings, and a minimum of 10 hours of labour were required.

Conclusions and Outlook

Data has shown that the physical-chemical processes (precipitation, stripping, absorption) applied for urine treatment are highly efficient from a chemical point of view.

The efficiency of P-removal is as high as 98 % with MAP recovery rates of around 80 % when treatment is performed with undiluted urine. If MAP is to be produced with diluted urine, an alternative for the filtration unit should be considered as most of the struvite particles cannot be recovered from the fibres of the filter bag. In this case, the cost-effectiveness of the process remains dubious. Reducing the sedimentation time from 3 to 1 hour for example would considerably reduce process time without influencing treatment efficiency.

Urine recirculation during the stripping stage made it possible to achieve an N-removal of 96 % whilst maintaining the operation time below 4 hours. The majority of this nitrogen could be recovered during the absorption stage.

The given local conditions (staff skills, laboratory facilities, power failures etc.) made it rather challenging to run the pilot plant reliably over longer time periods (automatic mode could not be achieved) and rendered process optimisation virtually impossible. Also, the pilot plant is an exact copy of its German counterpart and has not been adapted to environmental conditions as they prevail in tropical climates (e.g. recurring failures of the touch screen). The equipment is of the same high - tech standard as that of the unit in Germany, which made the task of training Vietnamese scientists rather strenuous and caused difficulties in case of equipment failure (e.g. no notion of kit maintenance leading to frequent breakdowns; expensive European equipment, for which spare parts are not available locally).

In the future, energy consumption could be decreased by switching to solar energy, or by using the solar energy to heat the urine for optimising stripping efficiency. As the plant has been designed for treatment of undiluted or only low-diluted urine, it relies on the proper maintenance of modern sanitation facilities such as separation toilets and waterless urinals. An overall energetic balance needs to be established in order to assess the efficiency of this plant as compared to conventional wastewater treatment and fertilizer production.

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Hans Huber AG, Industriepark Erasbach A1, 92334 Berching, Germany

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List of Abbreviations:	
CaO	Calcium oxide
CTU	Can Tho University
DeSa/R	Decentralised Sanitation and Reuse
H_2SO_4	Sulphuric Acid
MAP	Magnesium ammonium phosphate
MgO	Magnesium oxide
Na_2O	Sodium oxide
NaOH	Sodium hydroxide
NH_3	Ammonia
$(NH)_2SO_4$	Ammonium sulfate
P_2O_5	Phosphorus pentoxide
PO_4-P	Orthophosphate
VND	Vietnamese Dong
XRD	X-ray diffraction

II-3: Collection and Concentration of Urine to Produce a Mineral Fertilizer

Nguyen Thanh Phong[4], Le Anh Tuan[4], Samantha Antonini[1] and Carsten Cuhls[12]
[1] INRES - Plant Nutrition, University of Bonn, Germany, sam_antonini@uni-bonn.de
[4] College of Environment and Natural Resources, Can Tho University, Vietnam
nguyenthanhphong@ctu.edu.vn, latuan@ctu.edu.vn
[12] Gewitra company, Hannover, cuhls@gewitra.de

Keywords: urine, yellow water, evaporation, concentration, nitrogen, phosphorous

Introduction

Vietnam, with its agriculture-based economy, is a country which has known a strong development in recent years. As a result of this economic growth and a rising food demand, the fertilizer demand has increased strongly. Chemical fertilizers are being used as a favourable source of nutrients; however, the farmers have to pay money for these and may face pollution problems when applying excessive dosages to the soil. Increasing fertilizer prices and decreasing resources are strong incentives to investigate into alternatives for mineral fertilizers. In the south of Vietnam, the recycling of nutrients from human urine could be an innovative method for recovering valuable nutrients and reusing these as a plant fertilizer. Nutrient recovery could be achieved by making use of the solar energy for removing the liquid fraction from stored human urine with the aim of generating a solid end product as a concept in Figure 1.

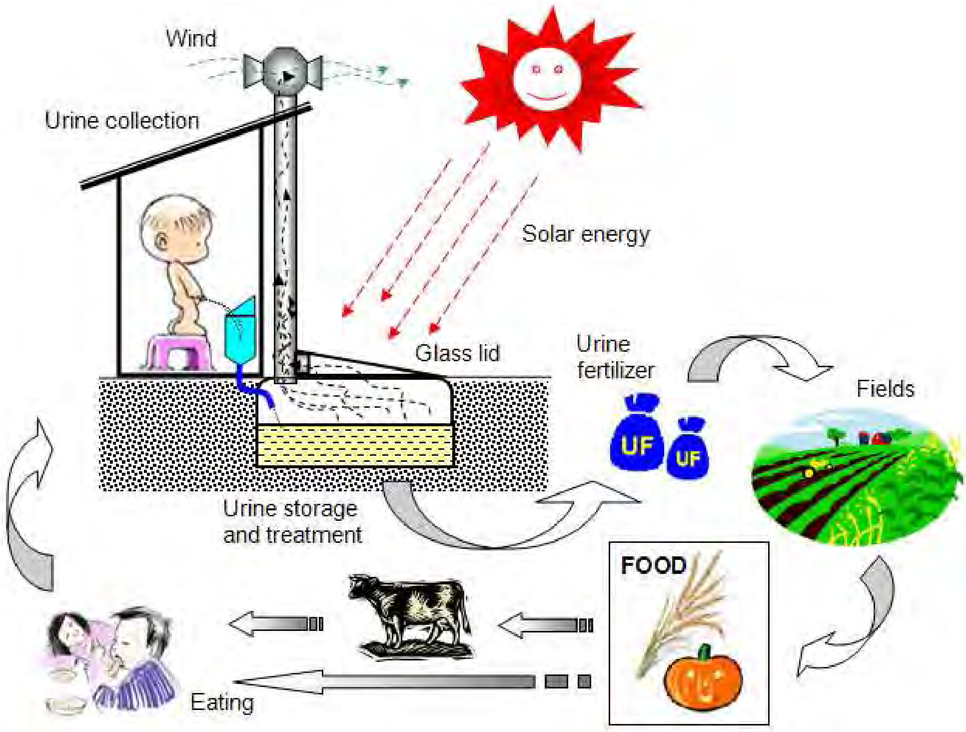

Figure 1: Human urine used as a mineral fertilizer source (Tuan *et al.* 2005)

Indeed, the Mekong Delta area is characterised by a tropical climate with high numbers of sunlight hours each year. Temperatures are relatively constant and high throughout both the sunny and the rainy seasons, with an average value of around 27°C (Tuan 2006). Furthermore, the nutrients in urine are in soluble form. The major element in urine is nitrogen (N), which can be found in the form of urea (80 %) and ammonia (7 %). Phosphorous (P) is present in the form of inorganic phosphates (> 95 %), and potassium is mainly found as free ions (Vinnerås and Jönsson 2004).
The concentration of heavy metals on the other hand is very low. In summary, the nutrient content of urine is high and these soluble nutrients are available for many plant types as they can easily be absorbed.

Material and methods

Urine Collection and Treatment

Diluted urine was collected from a storage tank located behind the dormitory "B23" on the grounds of Can Tho University (CTU). This dormitory, which accommodates 100 male students in 10 rooms, has been equipped with 10 separation toilets and 10 waterless urinals. Both diluted and non-diluted "Yellow Water" streams are discharged into the storage tank mentioned above. For the trials in Hoa An, non-diluted urine was collected directly in plastic containers from male students living in a neighbouring dormitory.
Three different treatment units, all built with material readily available in Vietnam, were implemented: the so-called batch, circulation and continuous systems (Figure 2). The batch system is a "low-tech" alternative which consists of a urine holding tank made of concrete, a glass cover and separate inlets and outlets for the urine and the distilled water respectively. The urine remains in the reactor until all liquid has evaporated.

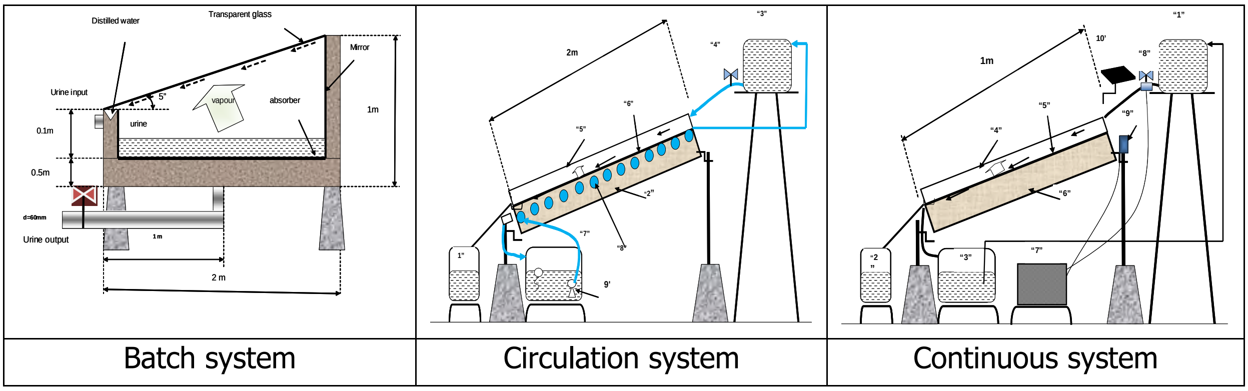

Figure 2: The different treatment systems employed for urine treatment

The continuous system and the circulation system are both made of metal and require an energy source to operate a recirculation pump. In both cases, the urine flows over a dark fibre material (area for crystallisation to take place) located below a glass cover. The urine is circulated in a closed loop until the absence of liquid causes the submersible pump to switch off. In addition, when being pumped back to the inlet of the circulation system, the urine has to pass through a series of pipes located below the dark cover, which causes an additional temperature increase.

Experimental Set-Up and Sample Analysis

A first series of experiments focusing on treatment efficiency and optimisation of all three systems was carried out at CTU using diluted urine. 10 litres of diluted urine (urine : water ratio of 1:6) were transferred into all three units. The change of nutrients within the various systems was monitored for one week; sampling of urine and evaporated water took place on a daily basis. The collected samples were acidified with sulphuric acid to stabilise the urine and to conserve nitrogen. The required amount of acid was determined by titration of the urine.

In order to minimise nitrogen losses in the form of NH_3 with the evaporating water, experiments were performed into decreasing the pH of urine down to 4 (prevalence of NH_4^+ ions). Two acids (sulphuric and phosphoric acid) were used to achieve such low pH values, with special focus on the hypothesis that phosphoric acid could further increase the nutrient content of the final product. As an alternative to the addition of acid solution, acid soil was tested for its efficiency to lower the pH of urine and its capacity to absorb nutrients.

A further assessment of the performance of the batch system with undiluted urine was performed at Hoa An Research Station. 50 litres of undiluted urine were placed into the concrete holding tank and left in the reactor for 1 month of treatment. During the first week, known volumes of urine and distilled water were collected on a daily basis, thereafter sampling intervals were increased.

All samples were analysed at CTU for their concentration of phosphorus (Hach-Lange test cuvettes, photometer) and nitrogen (Quantofix method), and the pH and the electricial conductivity (EC) were recorded. *Escherichia coli* (*E.coli*) and total coliforms were counted at CTU before and after treatment. Temperature was recorded at 15 minute intervals inside and outside the three systems by using Tynitag data loggers.

Results and discussion

Temperature

The various treatment units were characterised by a distinctive behaviour in terms of temperature evolution. As expected, the temperature within the reactors was, during the daytime, much higher than the ambient temperature (differences of up to 40°C).

The temperature data recorded inside the circulation and the continuous systems reached peaks of up to 80°C; these indicate that temperatures increased and decreased rapidly in the morning and evening respectively. It took only 3 hours (from 11 a.m. to 13 p.m.) for temperatures to increase from 40°C to 80°C for example. The maxima could be maintained for about 4 hours every day. At night time on the other hand, the temperature inside the reactors was lower than the ambient temperature. This indicates that both systems can absorb the heat very well, but that they cannot store the solar energy for longer time periods. This could be explained either by poor insulation or by the fact that both treatment units are made of metal. Metal can absorb - but also release heat very quickly. As soon as the system is not exposed to solar radiation anymore, temperatures within the system decrease rapidly. The batch system is made of concrete and therefore characterised by a different temperature evolution than the metal reactors. It took much longer for temperatures to increase and decrease inside this unit. The afternoon peaks, which were reached after 3 to 4 hours, were lower with an average value of around 60°C.

Microbiology

The bacteriological data collected from the three urine drying systems showed that almost all pathogens were killed after three days of operation. This decrease of pathogens can be explained by the high temperatures and the extreme pH values which were achieved within the various systems during treatment. Most microorganisms do not survive such adverse conditions.

Nutrient Recovery

With an initial starting volume of 50 l of undiluted urine, it was possible to recover between 300 and 400 g of solid material after 30 days of treatment in the batch system. The collected raw urine had N and P concentrations of 5000 mg l^{-1} and 315 mg l^{-1} respectively, thus representing a nutrient load of 250 g of nitrogen and 16 g of phosphorus. Evaporation of the liquid fraction was effective with volumes of distilled water increasing from about 1.7 l on day 1 to 2.5 l on day 14, then decreasing again until virtually all liquid had evaporated on day 30. More than 90 % of the liquid fraction could be removed after 16 days of treatment. Chemical analysis revealed that nutrient losses via the evaporating water were negligible in the case of phosphorus. For nitrogen on the other hand, about 30 % had been lost with the evaporating water droplets. This can be explained by the high pH values (pH 9.5) and the high temperatures (20 - 60°C), which both cause nitrogen to be present in the form of volatile ammonia gas.

The evaporation rate of the continuous and the circulation systems was ~ 1.1 l $m^{-2}d^{-1}$ (experiments performed with diluted urine). The increase of nutrients in both systems also showed similar trends. After 1 week of treatment, the nitrogen concentration of the urine had increased from 980 mg l^{-1} to 1800 mg l^{-1}. On the other hand, the phosphorous concentration measured in the concentrated urine samples had decreased from 590 to 570 mg l^{-1}. These losses can be explained by the fact that – as expected - phosphorus crystals had settled down on the black fibre material. Unfortunately, it was not possible to find a method allowing easy recovery of the crystals from the black fabric. An alternative or a field of application for a piece of textile saturated with nutrients would have to be elaborated. In addition to this, both units were prone to corrosion as they were made of metal, and blockages of the circulation pipes became increasingly frequent during treatment because of precipitate formation.

Taking all these factors into account, the “low-tech” batch system appeared to be the treatment option most adapted to the local conditions. The relative nutrient contents of the dried urine product were 7 % of nitrogen, 16 % of phosphorus and 2 % of potassium. The remaining 75 % were probably made up of other minerals such as Na, Cl, Ca, Mg etc.

Nitrogen losses during the drying process could be prevented by adding sulphuric acid to the urine. At low pH, the nitrogen remained in the system during operation instead of leaving the system with the evaporating water. An additional experiment involving the addition of phosphoric acid instead of sulphuric acid to adjust the pH demonstrated that the phosphorus concentrations in the processed urine increased even further. Chemical analysis showed an increase from 0.5 g P l^{-1} to 6 g P l^{-1} after 3 days of treatment only. Acidifying urine with phosphoric acid to a pH of 4 seemed to be the most beneficial way to dry urine in the batch system. In addition to preventing nutrient losses, acidification can prevent bad odour and inhibit microbial activity. Table 1 summarises the disinfection ability of three urine drying systems.

Table 1: The disinfection ability of three urine drying systems

System	Circulation	Continuous	Batch
Max. inside temperature (°C)	80	78	60
Max. temperature retention time (hours)	3 (10:00 - 13:00)	4.5 (10:00 - 14:30)	4.5 (10:00 - 14:30)
Average different temperature (°C) (Inside - Outside)	40	30	20
Disinfection ability evaluation	Very good	Very good	Good
Nutrient recovery	Medium	High	Medium
Required energy	Yes	Yes	No
Corrosion	Yes	Yes	No
Longivity	Low	Low	High
Price	Expensive	Expensive	Cheap
Suitable system for urine drying	Not reasionable	Not reasonable	Reasonable

Further experiments revealed that acid soil is not a good additive for trapping nitrogen due to the large volumes involved in reducing the pH of urine. In this case, 12 kg of soil were required to reduce the pH of 10 l of urine from pH 7 to pH 4.

Conclusions and Outlook

Recycling nutrients from human urine has many advantages: rather than diverting municipal wastewater directly into canals and rivers as it is common practice in the south of Vietnam, valuable nutrients can be recovered by transforming the so - called “Yellow Water” into a stable and safe product. In this way, nutrients contained in human urine can be used as a fertilizer in agriculture instead of causing environmental pollution such as eutrophication of lakes and rivers. Also, farmers could spend less money when replacing mineral fertilizers with urine-based nutrients.

This concept was put into practice by drying human urine with 3 different treatment systems, of which the operational procedures are based on the principle of solar distillation (i.e. evaporation of the liquid fraction by making use of solar energy).

The batch system is a "low-tech" treatment unit made of concrete and characterised by high treatment efficiency. Its operation is more reliable than that of similar reactors made of metal and using pumps and pipes for urine circulation (power failures, blockages etc.). When starting with an input of 50 l of undiluted urine, about 90 % of the water could be removed after 16 days of treatment. At the end of 1 month, between 300 and 400 g of dry solids could be recovered. These contained up to 100 % of the initial P load, and about 70 % of the initial N load. Nitrogen was partially lost in the form of volatile ammonia because of the high pH values and temperatures prevailing within the system. In the future, ammonia losses can be minimised by acidifying the collected urine prior to treatment. When using phosphoric acid, the P concentration of the final product can be increased even further.

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II-4: Greywater Recycling in Vietnam – Application of the HUBER MBR Process

Stefania Paris[13], Schlapp Celine[13] and Tino Köhler[13]
[13] Hans Huber AG, Industriepark Erasbach A1, 92334 Berching, Germany

Keywords: greywater, treatment with MBR, clarification efficiency, recycling, quality requirements, hygienic parameters

Introduction

Greywater is the part of domestic wastewater that is free of faeces. The volume and concentration of this separately collected wastewater flow depend on the consumer behaviour and vary according to its source. The average amount of greywater produced per day in a German household is 70 l per person, which is more than 50 % of the total wastewater production (Mehlhart 2001). This figure corresponds to the average figures provided for Chinese households (80 l $person^{-1}$ day^{-1}, GB/T 50331-2002), but significantly exceeds the South African average of 20 l per person and day (Adendorff und Stimie 2005).
Compared to domestic wastewater, greywater generally contains less organic pollutants and less nutrients but a high amount of tensides. The effluent from bath tubs, showers or wash hand basins contains for example a by approx. two decimal orders lower number of total and faecal coliform bacteria (*E.coli*) (Nolde 1995 and Bullermann *et al.* 2001).
Due to its relatively low content of pollutants, greywater is easy to treat with MBRs. The pollutants are decomposed by the bacteria in the activated sludge tank. The following membrane filtration unit separates the treated greywater from the activated sludge. The treated greywater is of high quality and hygienically safe so that it can be reused, alone or combined with rain water, for toilet flushing water, laundry washing or for irrigation purposes.
Within the scope of the SANSED II research project HUBER has been successful in adapting the MBR system for greywater treatment to the specific conditions in Vietnam and testing the system in operation in a small city in the Mekong delta, South Vietnam. The wastewater from kitchen sinks and the bathrooms of a dormitory on the campus of CanTho University was clarified in the HUBER GreyUse® plant over a period of three months. The project aim was the production of high quality service water from greywater for safe reuse as toilet flush water.

Greywater Treatment Plant

The so called HUBER GreyUse® plant for treatment of greywater consisted of a 1 mm screen and a Membrane Bio-Reactor (MBR) with submerged ultrafiltration modules (Fig. 1 and 2).

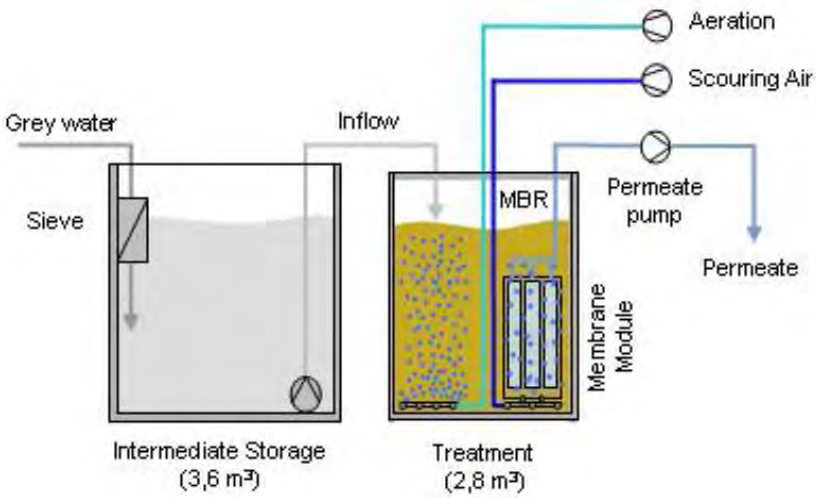

Figure 1: Flow diagram, HUBER GreyUse® plant in Vietnam

Operating parameters:
- Flow: 3,000-4,500 l/d
- MLSS: 3.0 -4.5 g l-1
- F/M: 0.06 kg COD/(kg MLSS *d)

Figure 2: Surface of the activated sludge tank and membrane modules, HUBER GreyUse® plant

Characteristic of Greywater

As typical in many places in Vietnam, personal hygiene, laundry washing and cooking took place in the same area and in a partly non-covered backyard of the dormitory. Students did not have any aids such as dishwashers or showers. Food leftovers and shampoo packages were usually disposed of via a centrally located gully and partly flushed away by rain water. The separately collected greywater therefore contained a lot of coarse matter and was pretty much diluted during storm events. While the average COD in the inlet to the aeration chamber was 223 mg l^{-1} during dry weather, the pre-screened greywater was relatively diluted under stormwater conditions with a COD of 137 mg l^{-1} (Fig. 3). Compared to literature values (Burnat and Mahmoud 2005) nitrogen concentrations were relatively high throughout the whole test period (average: NH_4-N = 18.7 mg l^{-1}). This proves that it is general practice among Vietnamese youths to relieve themselves under the shower. The high amount of suspended solids can be explained by the intake of grit through the drain line. Average concentrations of relevant parameters in the inflow are shown in Table 1.

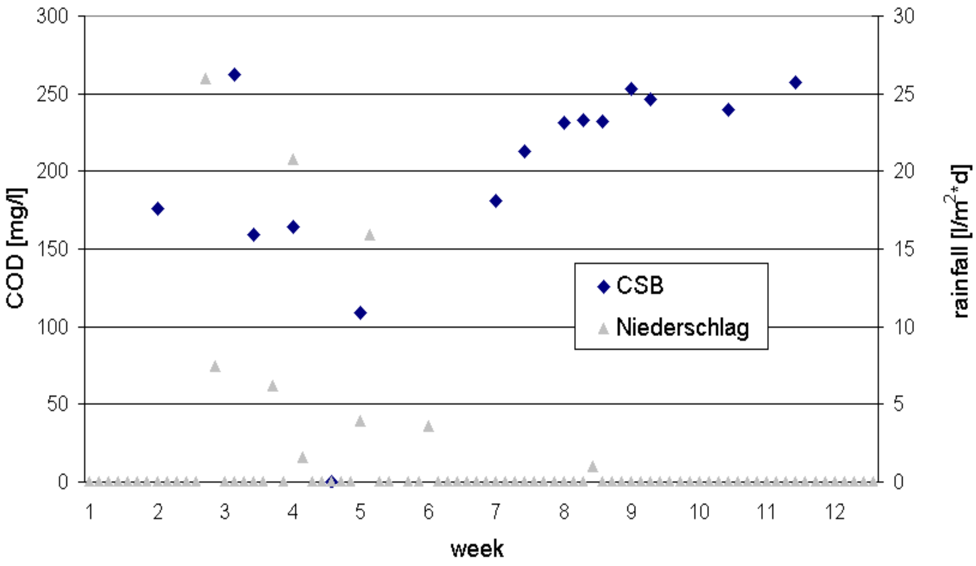

Figure 3: COD concentration in pre-screened greywater depending on the weather

Table 1: Composition of greywater from different sources (extract from fbr sheet H201 and average values in geywater from dormitory B23, Vietnam)

Parameter	Unit	From bath tubs, showers, wash hand basins, washing machines, kitchens (fbr sheet H201, 2005)	From showers, laundry washing, cooking in the dormitory, Vietnam
COD	mg l^{-1}	400 - 700 (Ø 535)	208
BOD_5	mg l^{-1}	250 - 550 (Ø 360)	151
SS	mg l^{-1}	-	63
TP	mg l^{-1}	3 - 8 (Ø 5.4)	4.9
TN	mg l^{-1}	10 - 17 (Ø 13)	24.2
Anionic tensides	mg l^{-1}	-	27.3
pH	-	6.9 - 8	7.1
Temperatur	°C	-	27.4
Total coliform bacteria	1 ml^{-1}	10^2 - 10^6	$4,7*10^5$
Faecal coliform bacteria	1 ml^{-1}	10^2 - 10^6	$6,6*10^3$

Treatment Results

The test results showed that, under the given nutrient conditions (BOD_5: NH_4-N : PO_4-P = 100 : 12.5 : 3), an efficient biocoenosis could be achieved in the activated sludge tank. The system operation was stable throughout the whole test period and showed very high COD elimination rates of on average 92.2 % (fig. 4). The COD concentration in the permeate ranged continuously below 28.2 mg l^{-1} (fig. 5). Also the clarification efficiency of tensides was excellent, with only 0.79 mg l^{-1} anionic tensides measured in the effluent. The permeate was at all times free of solids and virtually germ-free. Thus, all effluent values met the standards specified in sheet H201 (fbr 2005) for the reuse of treated water for toilet flushing, laundry washing and irrigation (Table 1).

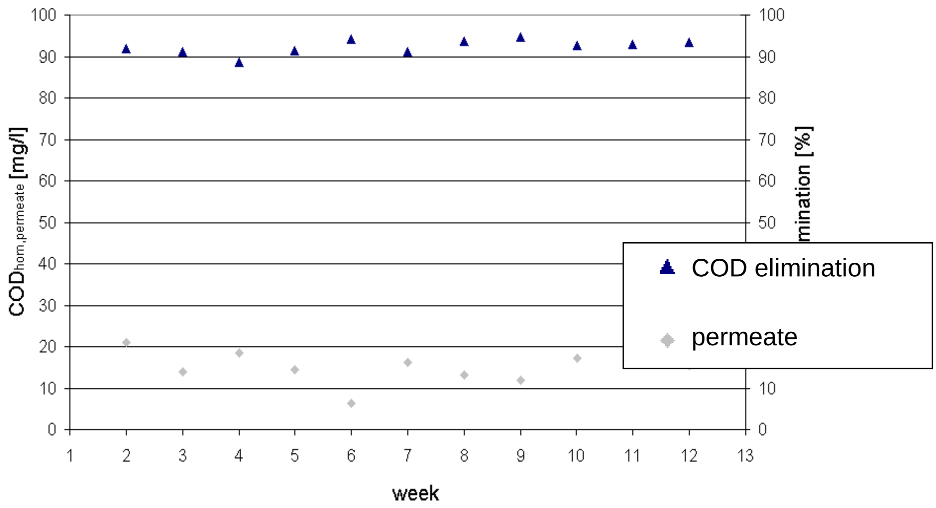

Figure 4: COD concentration in the permeate and COD elimination

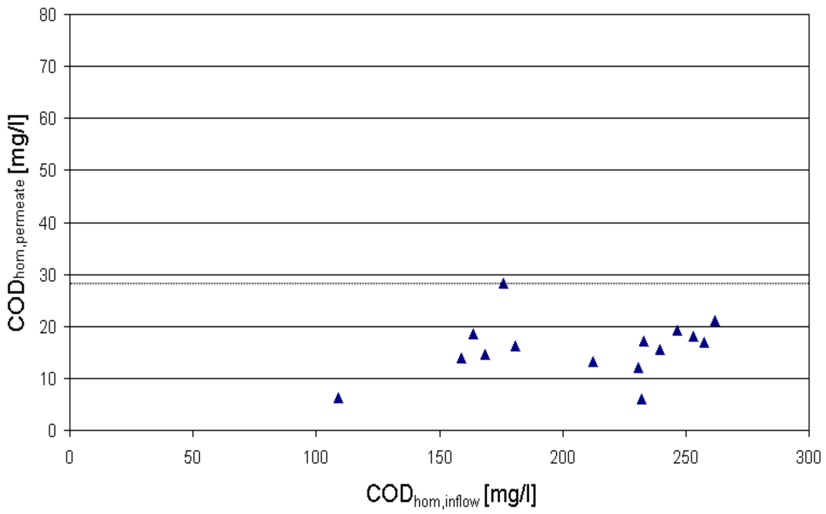

Figure 5: COD concentration in the Permeate depending on the COD concentration in the inflow

Table 2: Requirements on effluent quality for the reuse as toilet flush water, laundry wash water and irrigation purposes (fbr sheet H201) and effluent properties of the MBR plant in Vietnam

Parameter	Reference value from fbr-H201 1) (limit value from RL 76/160/EWG) 2)	MBR plant effluent Can Tho, Vietnam
BOD_7	< 5 mg l^{-1} (-)	< 4.2 mg l^{-1}
Oxygen saturation	> 50% (80 - 120%)	> 50%
Anionic tensides	-	0.79
Total coliform bacteria	< 100 ml^{-1} (100)	< 1 ml^{-1}
Faecal coliform bacteria	< 10 ml^{-1} (20)	< 1 ml^{-1}
Pseudomonas aeruginosa	< 1 ml^{-1} (-)	-

1) fbr sheet H201 *2) EU Directive for bathing waters 76/160/EWG*

Conclusion

The HUBER GreyUse® plant has proven to be a sturdy system able to produce high quality service water from greywater. Even under difficult local conditions, such as varying inlet concentrations, the quality requirements for reuse of treated wastewater in households and for outdoor applications could be met throughout the whole test period. The fresh water demand can be reduced significantly if this service water is used for toilet flushing, cleaning and irrigation. Greywater recycling therefore involves also economic benefits in addition to ecological advantages. Interesting saving potentials exist particularly in the industrial sector for hotels, camping sites or sports facilities where the water consumption is very high. Also in densely populated world cities greywater recycling is an appropriate method to save precious water.

The investigations made within the scope of the SANSED II project ('Closing nutrient cycles via hygienic substrates from decentralised water management systems in the South of Vietnam') are co-financed by the Federal Ministry for Education and Research (BMBF). We would like to take this opportunity to express our thanks for this financial support.

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List of Abbreviations:	
COD	Chemical Oxygen Demand
BOD_5	Biological Oxygen Demand
SS	Suspended Solids
TP	Total Phosphorus
TN	Total Nitrogen
F/M_I	Food to Microorganism ratio

II-5: Brown Water Treatment by Vermicomposting and Horizontal Soil Filter at Hoa An

Matthäus Birkel[1], Nguyen Thi Bach Kim[4], Susanne Wohlsager[1], Joachim Clemens[1], Ute Arnold[1]
[1] INRES - Plant Nutrition, University of Bonn, Germany, matthaeus.birkel@gmx.de
[4] College of Environment and Natural Resources, Can Tho University, Vietnam ntbkim@ctu.edu.vn

Keywords: separation toilet, brown water, constructed wetland, *Perionyx excavatus*, composting, soil filter

Introduction

According to WHO / UNICEF (2004) in Vietnam only 33 % of inhabitants have direct access to sanitation systems like latrines, pit latrines or toilets with septic tanks and in rural areas access is even lower. Especially in South Vietnam´s densely populated Mekong Delta region (39,000 km²) with over 17 million inhabitants, wastewater mostly discharged untreated into the Mekong river, is expected the major source for human diseases (General Statistics Office 2003, CIA 2008). Within the SANSED project a separation system for domestic wastewater was implemented at the student dormitory at Hoa An Research Station to treat the yellow (urine) and brown water fraction (faeces + flush water).

Brown water contains less nutrients than yellow water and it bears a higher hygienic risk (Vinneras 2002). Nevertheless it contains a reasonable amount of nutrients and organic matter to be reused and applied in agriculture. Vermicomposting is one treatment option for brown water to generate compost (soil conditioner) and worms (protein source or fishing bait). In the course of composting organic substance and disease-causing micro-organisms in excreta are reduced.

Within this study a pilot plant, consisting of three connected treatment units - composting site, settling basin and a horizontal soil filter -, was constructed to treat the solid and the fluid part of the brown water stream separately. A further idea of this study is to support farmers with information about wastewater treatment and composting techniques in general - provoking impulse towards sustainable wastewater treatment in the region.

Material and methods

Construction of Brown Water Treatment System at Hoa An Dormitory

At Hoa An dormitory eight separation toilets (manufacturer: Gustavsberg / Berger) were installed. The yellow water is treated by solar - heated concentration (system by gewitra®, see Chapter III-3) while the brown water is treated by composting with worms and horizontal soil filtration.

The toilet brown water from the dormitory was connected by two pipes (d = 114, slope 1 %) to the composting unit (Figure 1). There, the solids are separated through a layer of dried rice straw.

Figure 1: Connecting pipes at Hoa An dormitory

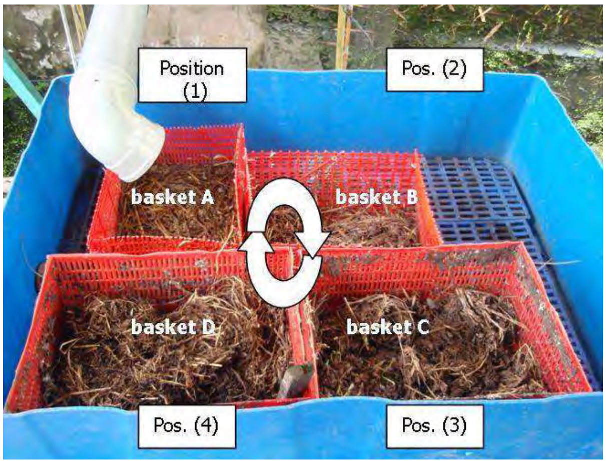

Figure 2: Basket position and identification (A, B, C, D) after 4 weeks (one composting cycle)

The composter (Figure 2) consists of a sawed plastic basin (1,1 x 0,8 x 0,25 m) that is fixed to the top linkages of a metal wagon. The basin contains a grid (h = 5 cm) with four baskets on top (max. load: 15 kg per basket). These are rotated regularly to the next position (see Figure 1). The cycle includes the collection of faecal matter (1), storage and initial worm input (position 2), composting (3) and harvest or further composting (4).

A sieve at the outflow of the composting unit holds back further particles that can be returned to the vermicomposting process. The liquid fraction passes the settling basin (0.8 m³) and is filtered again through a Subsurface Flow Constructed Wetland (horizontal soil filter) before it enters the fish pond. The bottom and walls of the soil filter were covered with a plastic foil stuffed to the drainage pipes (3 mm slits, h_{IN} = 0.25 m, h_{OUT} = 0.05 m) and filled with gravel (angle 30°; grit size 5 mm, 10 mm around drainage pipes) and yellow sand. The flow schematic is shown in Figure 3.

Cyperus alternifolius was planted on the soil filter. The plant can take up a reasonable amount of water and nutrients and is used by many farmers in the region to gather rice crops.

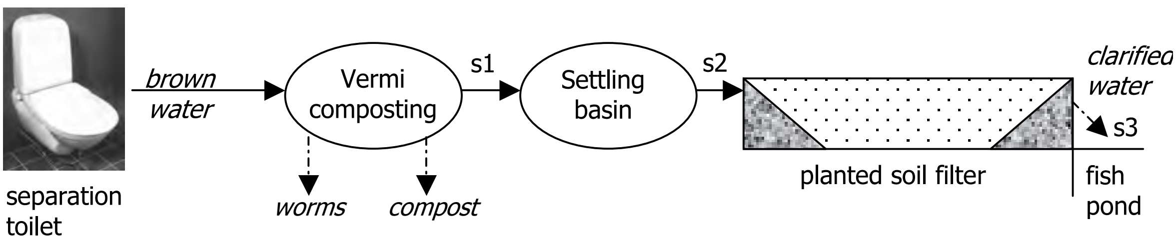

Figure 3: Pilot plant flow schematic as implemented at Hoa An Research Station

Sampling and Chemical Analysis

Faeces collection and treatment with vermiculture

To investigate the vermicomposting the following data were collected every week for 5 weeks: weight of each basket, pH, EC and dry matter of faeces and compost were analysed at Can Tho University. Organic dry matter, C/N – ratio, nitrogen, phosphorous and potassium were measured at the University of Bonn.

Initial worm weight was taken when the worms were placed into basket A. After five weeks the weight of all worms was measured.

Sampling the fluid brown water fraction

The inflow to the composting unit was measured once after collecting material for three days. The liquid fraction was sampled every week at three positions (s1 - 3, see Figure 2). The sampling included the analysis of pH, EC (WTW) and concentrations of nitrogen, phosphorous and potassium by Hach Lange test kits.

Set up to measure Greenhouse Gas Emissions

A sample raster with 15 sections – 5 rows with three basket places from inflow to outflow – was introduced. Buckets (15 l) were placed properly (cut off edges carved mildly into the sand) on the soil filter surface to collect the gas. 15 samples, plus three air samples as reference, were taken every week through the septum via syringe (60 ml) and were transferred into glass vials (20 ml). The measurement (CH_4, N_2O) was performed by gas-phase chromatography at Bonn University.

Results and DiscussionConstruction procedure

Regarding planning and construction a close collaboration with the Vietnamese partners proofed successful to get inside information, e.g. about material availability and skilled workers. Due to low altitude difference and little space availability the pilot plant was dimensioned smaller than originally intended.

Separation pre-test

In a pre-test, the capability of two natural filter materials of different structure and thickness, to hold back solids from the brown water, was monitored. Dried rice straw proofed superior compared to rice straw after fungi culture and compressed or shredded water hyacinth.

Table 1: Characteristic of natural filter materials used to separate brown water

Parameter	Unit	RS dry		RS "fungi"		WH pressed		WH shredded	
layer thickness	cm	5	10	5	10	5	10	5	10
DM retention	%	89	83	83	72	83	78	83	78
oDM retention	%	33	33	37	36	43	41	39	50
time till chocking	d	>5	5	3	2	0 - 1	0 - 1	1	1

RS: rice straw, WH: water hyacinth

These approaches got chocked very soon due to their wet and / or sticky material consistency. A 5 cm layer of dried rice straw was better than a 10 cm layer which chocked as well (see Table 1). The 5 cm dried rice straw material showed good results to separate solids from brown water (DM: 1.8 %, oDM: 86 %), and retained 89 % dry mass and 33 % of organic dry mass.

Vermicomposting Procedure and Worm Migration

During the first seven days of operation 30 persons were using the toilets at Hoa An dormitory and 11.3 kg (10 g DM person^{-1} day^{-1}) of wet substrate was assembled in basket A. Later on, only one third of this was collected due to the lower amount of persons using the toilets (9 g DM person^{-1} day^{-1}; Hoa An staff: ~10 persons).
The collected substrate (see Table 2) was pre - digested for one week -in basket A- before it was fed to the worms.

Table 2: Characteristics of residue used for vermicomposting with *Perionyx excavatus* at Hoa An dormitory and references; Edwards *et al.* (1998) used *P. excavatus*, Heck *et al.* (2008) *Dendrobaena veneta*

Parameter	Unit	Hoa An dormitory (faeces)	Edwards *et al.* (1998) (cattle solids)	Heck *et al.* (2008) (faeces)
pH	-	6.1 – 6.4	7.4	5.5 – 7.1
moisture range	%	81 - 85	80 – 87	85 - 95
C/N - ratio	-	10	19	20 - 26
temperature	°C	26 - 33	25 - 30	< 35

For growth and reproduction of *Perionyx excavatus* a substrate with C/N – ratio from 30 to 40:1, pH of about 7.0 and a moisture of 85 % is recommended (Edwards & Bater 1992, Singh *et al.* 2006).

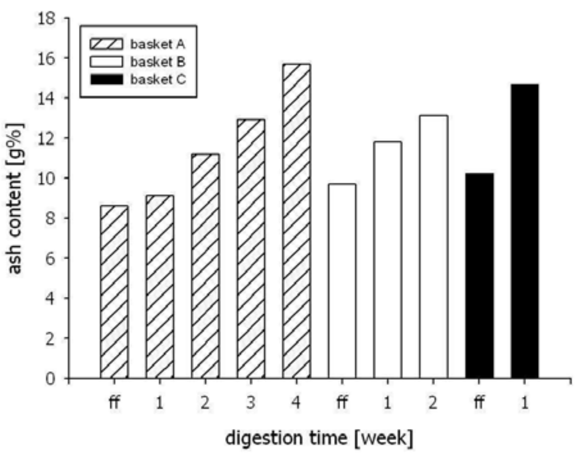

Figure 4: Process of mineralization and decomposition on the basis of ash content for all experimental runs (A, B, C), *ff: fresh faeces*

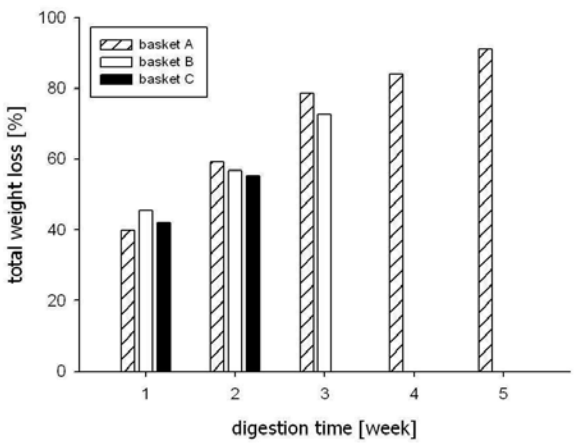

Figure 5: Total weight loss per week and basket in percentage of the initial weight

Compared to results of Heck (2008), who used faecal matter separated from blackwater (faeces + urine), the initial substrate fed to the worms contained less nutrients with a C/N – ratio of only 10:1 but is suitable according to pH and moisture range.
The ash content, an important parameter indicating decomposition and mineralization (Atiyeh *et al.* 2000), increased with time in all experimental runs (A, B, C; see Figure 4). After two weeks, the weight loss was 50 – 60 % and after five weeks of composting 90 % of the total weight was lost. After 5 weeks, 1 kg (A) of fresh compost with a DM content of 23 % had been produced out of one week´s brown water of 30 persons.

The worm biomass increased by 52 % from 210 g to 320 g. The worm distribution was 22 %, 41 % and 37 % for basket A, B and C. Earthworm maturity is shown in Table 3.

Table 3: Characteristics of *Perionyx excavatus* raised on urine-free faeces for 35 days

Parameter	Unit	A [initiation]	B [migration]	C [migration]
maturity	-	young worms	adult worms (at most with clitella)	young / adult worms
hatchlings	-	(++)	(-)	(+)
cocoons	-	(++)	(-)	(+)
worm length*	cm	1.3	>5.0	3.4
worm weight*	mg	46	150	92

(++): many hatchlings & cocoons; (+): few hatchlings & cocoons; (-): scattered cocoons & hatchlings
** mean of 10 and 50 worms, measured two times each*

Brown Water Treatment

The brown water inflow - measured with 3.5 l $person^{-1}$ day^{-1} - is characterized by a high organic load and moderate nutrient contents for total nitrogen (N_{tot}), phosphorous (P) and potassium (K). Using the rice straw layer, about one third of the organic matter and 50 % of N_{tot} is hold back in the solid fraction. Less retention for P and K was recorded here although P is mainly found as calcium phosphate particles (Fraústo da Silva & Williams 1997) whereas K is mainly found as dissolved ions (Jönsson *et al.* 2004). The concentration of both nutrients declines slightly during the settling process due to adsorption and sedimentation and is significantly lower in the outflow of the horizontal soil filter.

Table 4: Characteristic of brown water at different sampling points

Parameter	Unit	toilet inflow	sedimentation	composter	soil filter	fish pond
pH*	-	7.25	7.31 (+/- 0.33)	7.57 (+/- 0.16)	7.42 (+/- 0.07)	6.92 (+/- 0.54)
electric conductivity	[mS cm-1]	2.92	2.35 (+/- 0.44)	2.29 (+/- 0.23)	0.35 (+/- 0.21)	0.55 (+/- 0.02)
total nitrogen	[mg l^{-1}]	1540	801 (+/- 138)	783 (+/- 263)	15 (+/- 1)	15 (+/- 5)
ortho-phosphate	[mg l^{-1}]	72	45 (+/- 5)	63 (+/- 21)	1 (+/- 0.16)	0.48 (+/- 0.22)
potassium	[mg l^{-1}]	491	409 (+/- 197)	575 (+/- 163)	6 (+/- 5)	7 (+/- 5)

In the soil filter K is directly plant available as well as ammonium and nitrate. The calcium phosphates dissolve and become plant - available (Jönnson *et al.* 2004). However, the data shown in Table 4 were taken within the starting phase and the nutrient concentration was lowered due to dilution effects during the rainy season. Therefore more research is necessary.

Greenhouse Gas Emissions

Figure 7 shows the emission rates from different points of the soil filter. As expected, the highest emissions were measured close to the inflow.

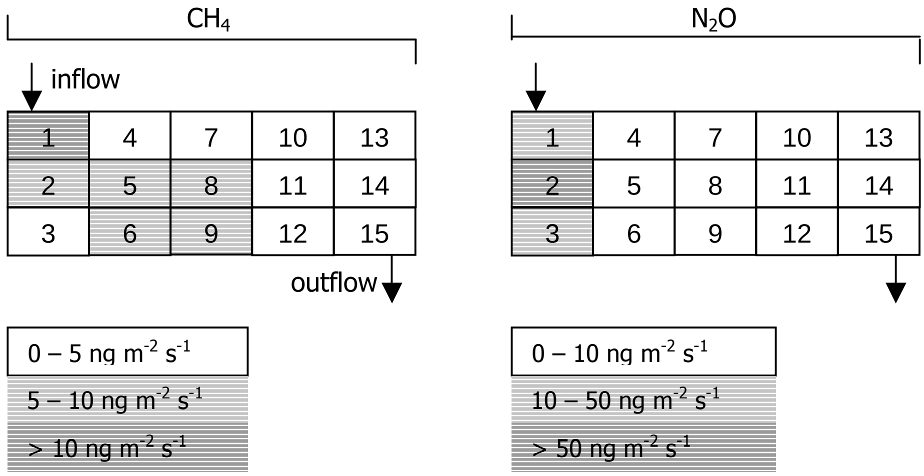

Figure 7: Methane gas and nitrous oxide emissions from the soil filter

With a maximum of 11 ng m^{-2} s^{-1} the emission of methane gas can be classified as negligible. The N_2O - emissions from the soil filter (at most 58 ng m^{-2} s^{-1}) are lower compared to the emissions from sewers (up to 1050 ng m^{-2} s^{-1}) and open land (below 120 ng m^{-2} s^{-1}) determined by Clemens (1998). Due to these first data, greenhouse gas emissions from soil filters may play a minor role in the overall balance.

Conclusion

First runs at the installed brown water treatment system were successful and showed promising results.

The dimensioning and a 4 week composting cycle work well for up to 20 persons. If necessary, additional space underneath the composting basin can be used for further composting and storage.

Recycling of suspended solids can be improved by installing an additional container for collection into the settling tank.

Gained worms may be returned to the vermicomposting process or used for further application or as protein source for animal husbandry (chicken, pig; hygienic risk research!).

Further deep going studies should be carried out.

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II-6: Influence of Different Substrates on Vermicompost Production by two Worm Species

Dao Thi Hong Xuyen[5], Duong Minh[5], Ute Arnold[1] and Joachim Clemens[1]
[1] INRES – Plant Nutrition, University of Bonn, Germany
[5] Dept. of Plant Protection- College of Agriculture & Applied Biology, Cantho University

Keywords: Vermicompost, biogas sludge, earthworm, Trichoderma, cress test, water-hyacinth

Introduction

The trend in agricultural production is reaching towards sustainable agriculture. The application of organic fertilisers combined with beneficial microbes to improve soil fertilities and prevent soilborne diseases proved a high efficiency for land cultivation.

Earthworms (*Oligochaeta*) are regarded as one of the most important creatures that can improve agro-ecosystems although this had been subject to controversy for many centuries (Darwin 1882). Several thousand species are described worldwide, including well-known ones like *Perionyx excavatus, Eisenia foetida, Eisenia andrei, Eudrilus eugeniae, Drawida modesta*, etc. Of these species, *Perionyx excavatus* (Vietnamese name: "Trun Que") is growing popularly in Asian countries, such as Philippines, India, Australia, etc. for biowaste control. The presence of earthworms does not only affect to soil microbial communities (Gunadi *et al.* 2001), but will also produce vermicompost by consuming biowaste from topsoil (Ismail 1994 a,b,c; Edwards & Bohlen 1996). In other ways, the growth of this creature depends on the quality and quantity of biowastes in soil layer (Edwards 1983, Holmin 1983, Safwat & Daniel 1996).

Earthworms are able to live on various kind of organic material although they prefer animal waste with a lot of nitrogen, its best C/N ratio beeing 16 to 18:1 (Buch 1986). The salvage of biowastes and agricultural byproducts by earthworms will help to increase the useful microorganisms and decrease the environmental pollution. The feces of earthworms (vermicompost) are excellent organic fertilisers for the crop cultivation and the activities of microorganic communities (Dickerson 2004).

On the other hand, the vermicompost also supplies antagonistic microorganism to prevent soil born diseases of crops caused by *Pythium, Verticillium* and *Rhizoctonia* (Chaoui *et al.* 2002). *Trichoderma* species (saprophyte fungi) is an antagonist for many agents of soil born diseases of crops such as *Phytophthora* spp., *Fusarium* spp., *Rhizoctonia solani*, *Pythium* spp., *Meloidogyne* nematode, etc (Pham Van Kim 2002, Hoitink & Boehm 1999, Duong Minh *et al.* 2001, Pham Van Du & Diep Dong Tung 2002, Sheela *et al.* 1995, Hoynes *et al.* 1999, Sharon *et al.* 2001).

Within this study, the efficiency of two worms species in converting different waste substrates will be examined. The idea of this study is further to combine waste treatment with the antagonistic microorganism (*Trichoderma* species) helping to produce excellent organic fertilisers for crop production.

Material and Methods

In the pretest, two worm species "Que" (*Perinonyx excavatus*) and "Com" (a local species) were raised in six different feeding substrates: biogas sludge only (B), biogas sludge combined with kitchen waste, rice straw, sugarcane bagasse, water hyacinth and orchard weed straw (each ratio 1:1). Before and after 2 weeks (1) number, size and weight of earthworms (adult, young) (2) the fresh / dry weight and volume of substrates, (3) the spore density of *Trichoderma* was evaluated.

The four treatments with highest vermicompost / worm production were selected for the main experiment where the two earthworm species were raised in biogas sludge, biogas sludge combined with kitchen waste, with water hyacinth and with orchard weed straw (ratio 1:1).

First, the raw substrates were fermented with *Trichoderma* (50 g m^{-3}, 10^9 spores g^{-1}). After 2 - 3 weeks of composting, the semi - composts were supplied to a 50 worm stock. For the first two weeks 1 kg $week^{-1}$, then 1.5 kg $week^{-1}$ of substrate was supplied.

The experiment was carried out in a randomized complete block design. The plastic pots were put in the shadow, set on an iron frame and covered with fine net to avoid worm escape and to prevent predators, like ants, lizards (see Fig 1).

The following data were collected in the beginning and every 4 weeks for 4 months: (1) Number, size and weight of adult and young earthworms (fresh and dry) before and after 1, 2, 3 and 4 months of raising, (2) Fresh and dry matter of substrates and vermicomposts, (3) Chemical parameters pH, EC, NO^-_3-N, NH^+_4 -N, total N and, P (plant available), K total, microelements: Cu, Zn, Mn, Pb, Cd and organic matter, (4) Microbiological analysis of hygienic relevant parameters.

For chemical analysis of the fed substrates, 10 g of samples per pot were collected every 2 weeks randomly, 4 replications were mixed to one sample and 2 samples of 4 weeks were combined to one final sample. For fresh and dry matter, one sample in 4 months was analysed: Total N (by Kjeldahl method); by spectrophotometer for NO^-_3 - N and NH^+_4 – N. For other elements, just one sample of 4 months was analysed by spectrophotometer: available phosphorus, total K, Cu 324.8, Zn, Mn; for Pb, Cd by atomic absorption implement (model Hitachi 5000); pH, EC and organic matter.

For chemical analysis of vermicompost one sample of all replications was taken at the end of the experiment for analysis of organic matter, N, P, K, microelements and heavy metals of all treatments at the end of experiment (4 treatments x 4 replications x 2 earthworm varieties).

For chemical analysis of worms, a number of earthworms of 4 replications were mixed into one and 10 worms per sample were collected.

A cress test was conducted to find out about the compost maturity and its influence on the germination and growth of garden cress. The vermicomposts were filled into a plastic tray (1,000 g per tray, 30 x 50 cm) and compacted lightly. Cress seeds were sowed, 200 grains per tray and pushed lightly. The 25 plastic trays were arranged in randomized block design in the net house in 5 replications. The collected data included: (1) The percentage of germination and emergence after 5 days (2) The growth of seedlings after 10 days: Plant and maximum root height, fresh and dry weight of root and seedlings, (3) The growth score of cress seedling ("Einheitserde" method) for evaluation the inhibition of each composting, (4) The cfu of *Trichoderma* in composting, (5) Analysis of pH and EC of vermicomposts at the end of experiment.

Results and discussion

Pretest of six substrates supplied to two earthworm species

In the pretest, development of *Perionyx excavatus* was best in biogas sludge where their number doubled within two weeks. In B + water hyacinth and B + kitchen waste the number of worms increased from 50 to over 70. B + weed straw were slightly better than B + rice straw and B + sugarcane bagasse.

The amount of "Com" worm was about the same after 2 weeks, in the different treatments. 49 - 54 worms (young and adult) were counted. Lowest volume and dry weight of vermicomposts of the two worm species were recorded in biogas sludge treatment.

Figure 1: Net house of Campus 2, CTU.

Development of earthworms in different substrates

The population of "Que" increased rapidly in all substrates. Best results were achieved in B+kitchen waste, followed by B+water-hyacinth. The treatments showed significant differences from month 3 on (see Fig. 2).

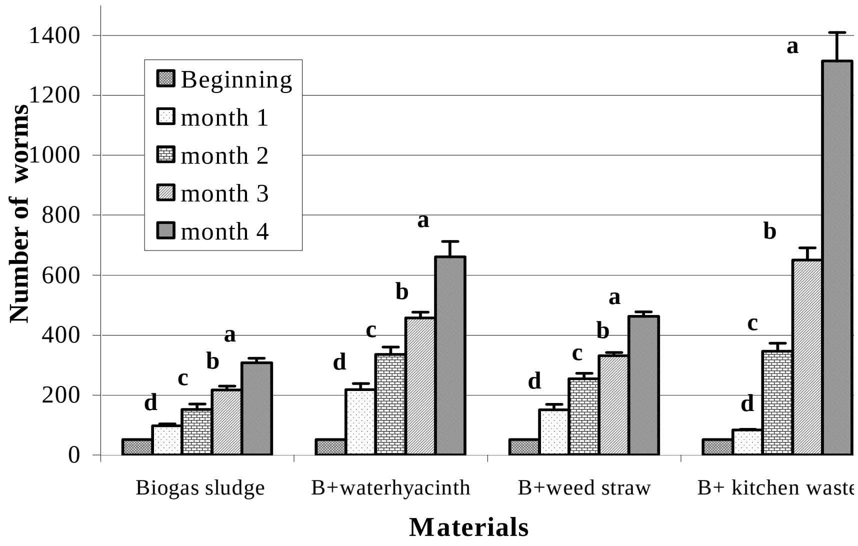

Figure 2: *Perionyx excavatus* individuals grown in different substrates within 4 months

Furthermore the size of the worms increased slightly during the cultivation period in all treatments. Biggest sizes were reached in B + kitchen waste where worm size increased from 13.6 cm to 18.8 cm in average. This development resulted in an increase of total biomass in all treatments (Fig. 3). Highest increase could be noticed in B+kitchen waste (from 27.7 g to 375 g), followed by B + water hyacinth. Biomass in B + weed straw was 4 - fold higher than in the beginning and even in biogas sludge, worm biomass doubled.

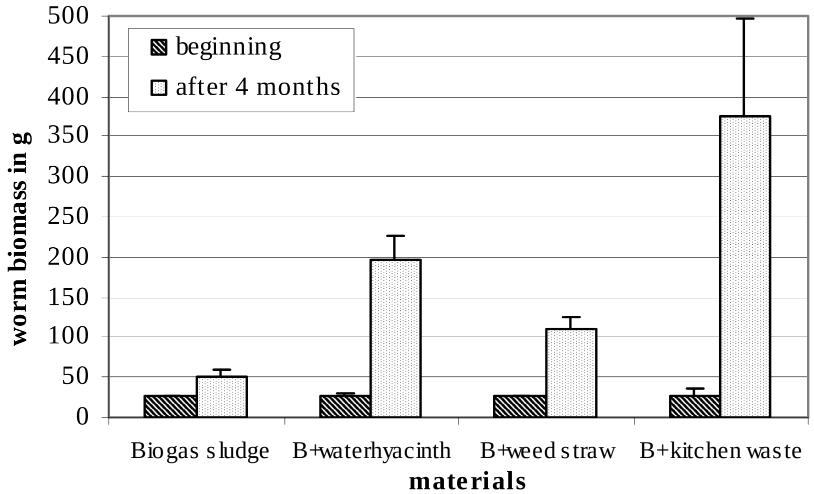

Figure 3: Living biomass of *Perionyx excavatus* grown in different substrates for 4 months

For the other worm species, the worm size increased slightly in three treatments, highest increase was reached in B + weed straw with 16 % (from 21.1 to 24.5 cm). No increase could be noticed in the Biogas sludge treatment.

Nevertheless, the number of "Com" worms was reduced during the 4 months experiment, reaching final values of 40 (B + weed straw) to 20 (B) worms.

This led to a decrease of worm biomass. Reduction to about half of the initial values were found in B + weed straw (48 %) and B + water hyacinth (44 %), less than one third of worm biomass could be recovered in B + kitchen waste (32 %) and Biogas sludge (26 %).
It had been noticed that the "Com" worms tried to escape out of the cultivation pots especially during day time form 3 to 4 pm. This "escaping effect" had not been noticed for *Perionyx excavatus*. As the second is usually inhabiting the upper layer (subsurface layer), whereas the natural habitat of "Com" is the deeper soil, it was probably more adapted to the high temperatures during the dry season in the experimental pots.

Development of Trichoderma

The cfu (colony forming unit) of *Trichoderma* in substrates varied from 2.0 to 2.88 x 10^5 g^{-1} of substrate. In vermicomposts, the cfu ranged from 2.69 - 3.8 x 10^5 g^{-1}. In general, *Trichoderma* was higher in vermicomposts of "Que" than "Com" probably due to the better growth of the first. Highest cfu were achieved in B + water hyacinth and B + weed straw vermicomposts of "Que", from 2nd to 4th month.

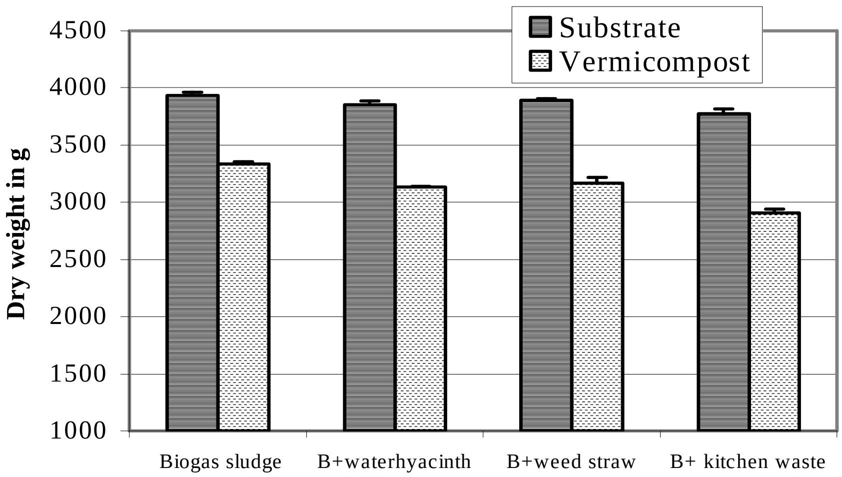

Figure 4: Dry weight of substrates and vermicomposts of *Perionyx excavatus* after 4 months

Fresh and Dry weight of vermicompost

The fresh weight of vermicomoposts was almost the same whereas the dry weight of vermicomposts showed significant differences between the treatments. The dry weight of vermicompost in B + kitchen waste was lower than others.
After 4 months there was a difference between the dry weight of substrates and vermicomposts of *Perionyx excavatus*. The dry weight of vermicompost of B+kitchen-waste was lowest, its reduction was 23 %.

Chemical parameters of substrates and vermicompost

In the substrates supplied to the worms from month 1 to month 4, lowest nitrogen concentrations were determined in B + water hyacinth (1.4 %) and highest in biogas sludge and B + kitchen waste (1.6 %). Total nitrogen in the different vermicomposts was slightly lower but similar in all treatments.

During the vermicomposting process, NH_4^+ decreased whereas NO^-_3 concentrations increased. In total N_{min} was higher in the vermicomposts than in substrates.

The concentration of several other parameters, P, PO_4^{3-}, K and Pb was higher in vermicomposts than in initial substrates, due to the activity of worms and microorganisms, increasing aerobic conditions and because of the reduced dry weight of vermicomposts. Other parameters, pH, EC, organic matter and Cd showed nearly the same values in substrates and vermicomposts.

The total nitrogen mass, however, was higher in substrates than in vermicomposts. The nitrogen mass of substrates and worms together was reduced about one quarter due to microbial activity and losses to the air.

Microbiological analysis of hygienic relevant parameters

In the analysed substrates and vermicomposts *Salmonella and E. coli* could not be detected. Helminth eggs appeared in both, substrates and vermicomposts with lower values in the second. The coliforms were observed in densities of 10^2 to 10^4 (1.3 x 10^4 for B + kitchen waste).

Cress Test

The results showed good germination for all vermicomposts. Germination was lowest for biogas sludge + kitchen waste (75 %). All other had germination indices equal to alluvial soil.

Cress grown on vermicompost of biogas sludge and biogas sludge + orchard weed got the maximum length of root and stem of cress and the highest fresh and dry weights.

Conclusions

Treatment of biogas sludge can be done successfully by worms, with and without co-substrates. All tested substrates were accepted. Biogas sludge + kitchen waste and biogas sludge + water hyacinth provided better conditions and achieved highest populations of "Que" (*Perionyx excavatus)*.

The two earthworm species developed differently: "Que" grew well and increased the population in all treatments. "Com" decreased its population due to unfavourable conditions too different to its natural habitat in the deeper layer of soils.

The cfu of *Trichoderma* was higher in vermicomposts than in substrates and did not change during composting. Higher densities were found in vermicomposts of B + orchard weed and B + water hyacinth.

All vermicomposts showed good results (score 1 - 2) on germination and growth in the cress test and are therefore suitable for growing plants.

Due to present results of hygienic parameters, vermicompost is not recommended to any food crop eaten raw. It may be supplied to any other crop, though.

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List of Abbreviations:	
CTU	CanTho University
E.coli	Escherichia coli
EC	Electrical Conductivity
B	Biogas sludge

Chapter III: Anaerobic Treatment of Black and Brown Water

III-1: Small scale biogas digesters in the Mekong Delta

Julia Nuber[1] and Tran Khuu Tien[4]
[1] INRES-Plant Nutrition, University of Bonn, j.nuber@uni-bonn.de
[4] College of Environment and Natural Resources, Can Tho University, Vietnam tktien@ctu.edu.vn

Keywords: plastic biogas digester, concrete biogas digester, methane yield, sedimentation

Introduction

Integrated farming systems in the Mekong Delta are operating small scale biogas plants. It is common for farmers to clean cow barns and pigsties by hosing down the animals with water several times per day. The waste water is treated in biogas plants, the effluent is used to fertilize the gardens and fish ponds and the biogas is used as energy source for cooking.

There were programs and projects in Vietnam to introduce and to set up biogas plants in rural areas, but there is a lack of information about the biogas production and the efficiency under real farm conditions. There is a need for research on technical and operational issues (Bui 2002, Duong and Le 2002). In this study 19 biogas plants around Can Tho City were surveyed to monitor the operating parameters and the biogas yields and to suggest ways to improve their operation.

Material and Methods

Biogas digesters

Two different types of biogas plants were observed within the study. The fixed dome digester (FD) is built out of bricks. It consists of the fermenter and a displacement tank (Figure 1).

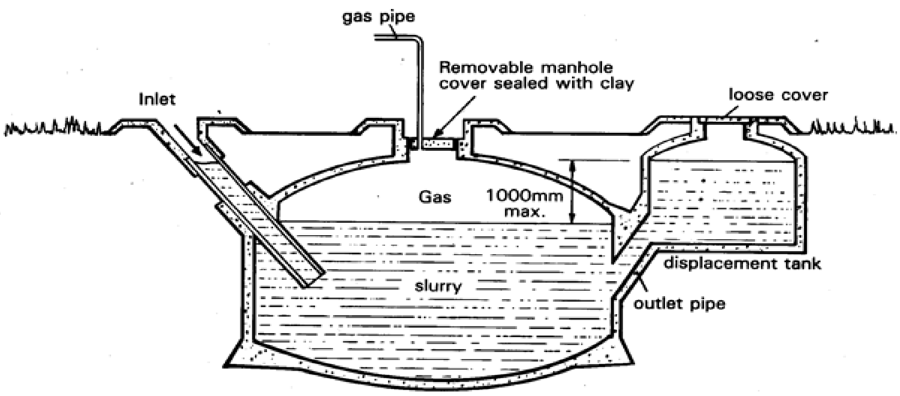

Figure 1: Fixed dome biogas digester (FAO, 1986)

It is completely filled with slurry, and as soon as gas begins to form, it is collected under the dome and forces the level of the slurry down (up to about 1 m). The costs for a fixed dome digester are according to the fermenter size around 500 USD or more (Wienecke 2005).
The plastic biogas digester (PBD) is based on the use of a tubular polyethylene foil as fermenter (Figure 2). The biogas is collected in an external gas storage, which is also a polyethylene tube. A simple reservoir filled with water acts as pressure valve. The PBD is a low-cost digester technology. The investment costs are only a tenth of the investment costs of the fixed dome digesters.

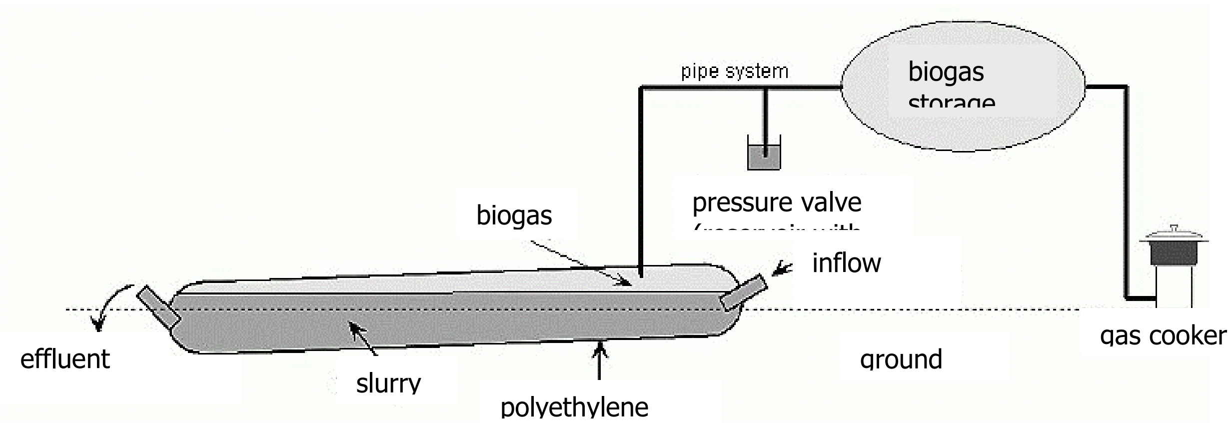

Figure 2: Plastic biogas digester (modified according to Kehlbach, 2007)

In this study nine fixed dome biogas systems and ten plastic biogas digesters were surveyed to investigate their operation. All of these biogas plants were operating with waste water from pigsties.

Sampling

At the biogas plants, samples were taken during the cleaning procedure in the morning. These slurry samples were collected at the biogas digester inflow. For a representative sample, 0.5 litre of the inflow were collected every 20 seconds and transferred into a 40 litre bucket. Before taking samples for analysis, the material in the bucket was carefully stirred.
For gas samples, three 10 l – gasbags were connected to the gas pipe system close to the fermenter. Then the time was measured until each bag was full. At the FD digesters the biogas in the gas dome was released into 150 l – gasbags before the biogas production was monitored.

Analyses

To analyse the amount of inflow into the biogas plants, the water amount used for cleaning was determined by an installed water flow meter.
The gas quality was analysed with a ANSYCO GA 94 infrared gas analyser. To specify the gas amount in the gasbags the gas was cooled to eliminate the water content and then measured with a RITTER gas counter. The results were converted to normal conditions.

To analyse the dry matter content the samples were dried at 105°C for 24 hours. Afterwards the samples were incinerated at 550°C for 4 hours to analyse the organic matter content.

Results and Discussion

The fixed dome digesters (FD) were all constructed by a company, whereas the plastic biogas digesters (PBD) were set up by the farmers themselves. Two different reactor sizes of FD could be found with 6 and 8 m³. The fermenter sizes of PBD were 5.7 m³, 6.4 m³ and 7.6 m³. The PBD were all made out of the same tubular polyethylene foil which is bought from a roll. The farmers decided the length of the plastic foil depending on the space which was available for the PBD at the farm or depending on the experiences of other farmers.
The volumes of the fermenters were not adapted to the number of pigs or the amount of expected organic substrate (Figure 3). All fermenters were in a range of 5 – 9 m³ and the number of pigs was between 5 and 36.

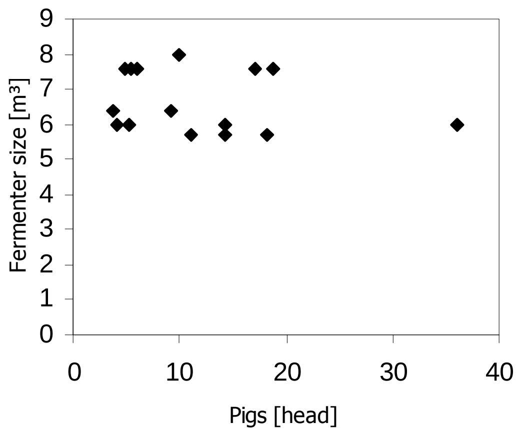

Figure 3: Fermenter size and number of pigs

The hydraulic retention time (HRT) showed a high variability with a mean HRT for FD of 4.8 days (CV: 0.62) and for PBD of 7.05 days (CV: 0.90) (Table 1, Table 2). The HRT didn't correlate with the amount of pigs ($r=0.44$, $p=0.05$). The water amount used per pig and day was in the range of 41.9 – 386 l with a mean value of 163 l.
The mean organic loading rate for FD was 1.58 kg oDM m^{-3} d^{-1} (CV: 0.75) and differed significantly from the mean organic loading rate of PBD with 0.83 kg oDM m^{-3} d^{-1} (CV: 0.53). Since all biogas plants are only fed with waste water from the pigsties, the only organic matter for the biogas production comes from the pig excrements. This, combined with the fact that farmers using a FD are raising more pigs than farmers using PBD, leads to a different organic loading rate.
The daily organic load is rather small compared to German biogas systems, where an organic loading rate of 2.5 kg oDM m^{-3} d^{-1} is recommended (KTBL 2007).
In FD the mean methane yield (247 l N kg^{-1} oDM, CV: 0.68) is not significantly ($p= 0.05$) lower than in PBD (mean 310 l N kg^{-1} oDM, CV: 0.78), but similar to the benchmark of KTBL

(2007) with a methane yield of 240 l N kg^{-1} oDM. Own batch experiments conducted with pig slurry in Can Tho showed methane yields of 214 l N kg^{-1} oDM. There was no correlation between organic dry matter load and methane yield per day (Figure 4).

Table 1: Operating parameters of the surveyed fixed dome systems

Fixed dome	Unit	1	2	3	4	5	6	7	8	9
Number of pig equivalents	-	25.8	16.3	5.50	4.00	5.25	4.13	14.3	36.0	9.88
Water consumption	l pig^{-1} d^{-1}	88	310	133	495	201	260	116	72.7	113
HRT	d	2.66	1.19	10.91	4.04	5.68	5.60	3.64	2.29	7.18
Org. loading rate	kg oDM per m³*d	1.38	3.84	0.46	0.40	1.32	1.39	2.79	2.32	0.35
CH_4 yield	l_N kg^{-1} oDM^{-1}	162	192	437	234	40.0	104	127	513	418

Table 2: Operating parameters of the surveyed plastic biogas digesters

Plastic biogas digester	Unit	1	2	3	4	5	6	7	8	9	10
Number of pig equivalents	-	6.00	17.0	18.8	9.25	14.3	11.0	18.3	4.88	3.75	5.50
Water consumption	l pig^{-1} d^{-1}	180	82.2	129	41.9	206	126	170	386	287	67.6
HRT	d	7.05	5.44	3.14	16.5	1.94	4.10	1.83	4.03	5.95	20.4
Org. loading rate	kg oDM per m³ d	0.58	0.82	0.72	0.41	1.68	0.56	1.47	0.88	0.86	0.31
CH_4 yield	l_N kg^{-1} oDM^{-1}	26.8	151	291	405	87.2	232	464	258	309	882

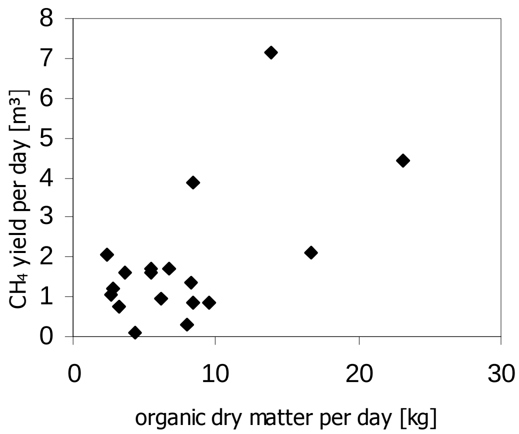

Figure 4: Methane yield per daily organic dry matter load

Three FD fermenters and six PBD fermenters showed methane yields higher than the literature data and those of own experiments. In five plants methane yields were even higher than 400 LN kg^{-1} oDM. The reason for the very high methane yield could be the absence of stirring units. In the fermenters, organic substrates may sediment and contribute for a longer time as compared to HRT to the methane production. This indicates that methane yields cannot be calculated from on site analysis, as the gas production strongly depends on the amount of sediment in the fermenters.

Conclusions and Outlook

Farmers have a basic knowledge about their biogas system, but the results show, that the operation of the biogas systems can be optimized.

The size of the fermenter should be adapted to the number of pigs.

A considerable amount of biogas is produced from the sediment in the fermenters.

To increase the biogas production, water should enter the fermenter at low velocity to optimize sedimentation and avoid sediment transport out of the system. Additionally, farmers may use less water for cleaning the pigsties to increase HRT.

As organic loading is low, farmers could use other organic wastes as additional material to produce biogas. Such a type of co-fermentation could compensate biogas losses when the number of pigs is low and less organic waste from pigs is available.

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List of Abrevations:	
FD	Fixed dome digester
PBD	plastic biogas digester
HRT	Hydraulic retention time
CV	Coefficient of variation
oDM	organic dry matter

III-2: Anaerobic treatment of brown water with long sedimentation time in a pilot biogas plant in Viet Nam

Christoph Ottenheim[1], Nguyen Thi Thu Van[4], Andrea Rechenburg[2], Jürgen Lenz[11], Joachim Clemens[1]
[1] INRES – Plant Nutrition – University of Bonn, Germany, christoph@ottenheim.net
[2] Institute for Hygiene and Public Health, University of Bonn, Germany
[4] College of Environment and Natural Resources, Can Tho University, Vietnam
[11] Bioreact GmbH, Germany, lenz@bioreact.de

Keywords: Vietnam, Can Tho, DeSa/R®, biogas, sedimentation, pathogens, trace elements

Introduction

In times of rising energy consumption, combined with the growing issues of climate change and environmental protection, the need for sustainable use of raw materials is becoming increasingly important. One approach which addresses this problem is the DeSa/R® concept (Decentralized Sanitation and Reuse). The DeSaR concept deals with the separation and utilization of various types of domestic waste water, which differ significantly in the composition and concentration of their main substances (Lens, Piet N. L. 2001). Yellow water is characterized by a high nitrogen and phosphate concentration, while brown water shows a high concentration of organic substances. There is also a significant difference in contamination by pathogenic bacteria. While there is little pathogenic contamination in yellow water, brown water has a much higher burden of pathogenic bacteria (Otterpohl 2002). The aim of the DeSaR concept is to provide maximum extraction of the cleanest possible water, energy production, reuse of nutrients in agriculture, and the separation and decontamination of waste water.

A pilot biogas plant in Can Tho, Vietnam, provides a closer view of the production of biogas from brown water. In contrast to previous experiments, we used minimum recirculation and a longer sedimentation time.

Materials and Methods

Biogas reactor

The utilisation of brown water took place in the "two step mesophilic reactor" (Hans Huber AG Berching, Germany), which has an effective working volume of 0.35 m^3. This reactor, operating at around 30°C, features a partition with two chambers (Chamber 1: hydrolysis/Chamber 2: methanogenesis). The brown water is produced in a nearby dormitory on the campus of Can Tho University (Dormitory B23, 100 students). The brown water is collected and stored, and can be pumped from the large collection tank into a smaller tank (V = 0.2 m^3) which is used for feeding the reactor. During the sampling period, 14 l d^{-1} were pumped into the hydrolysis, while the same amount was transferred automatically into the methanogenic part of the fermenter which lies downstream (HRT_{Tot} = 25 d). The material was recirculated regularly twice a day, with a terminal period of sedimentation (> 12 h), before feeding the reactor on the following day.

Sample analysis

Over a period of 77 days, four daily samples (inflow; hydrolysis; methanogenesis; outflow) were taken from the reactor (n_{tot} = 300) and analyzed. The process factors of pH (n = 255), temperature (n = 279) and EC (n = 255) were measured on-site with a digital device, about once a day. The ratio of volatile fatty acids (VFA) and total inorganic carbon (TAC) VFA / TAC quotient (n = 156), important for process control, was determined by Nordmann titration in the laboratory.

Dry matter (DM) and organic dry matter (oDM) were calculated by drying (24 h, 105°C) followed by ashing (5 h, 550°C). As an important parameter for substrate quality in biogas production, the COD (n = 81) was measured in addition to ODM and DM. We used oxidation with potassium dichromate, followed by titration with Fe^{2+} ions. In addition, total nitrogen (n = 31) and ammonium nitrogen (n = 43) values were determined with Kjeldahl apparatuses. The gas amount was measured daily (by Ritter gas counter) and calculated in relation to the elapsed time ([$l\ h^{-1}$]; 77). Gas quality was analysed via infrared analyzer (n = 288) (Ansyco GA94).

Additional hygiene parameters were analyzed: The amount of Enterococcae [CFU ml^{-1}], Salmonellae [pos / neg], Total coliform [MPN 100 ml^{-1}] and Faecal coliform [MPN 100 ml^{-1}] were measured on a regular basis. After 87 days, a fresh brown water sample and a sample from the methanogenic stage were collected and ashed. This ash was analysed by ICP - OES to calculate the concentration of key macro- and micro-elements.

Results and Discussion

Chemical parameters

While the volume of input during the experiment was constant, the quality differed significantly. The differences occurred because the small storage tank could not be ideally mixed, and the substrate matured rapidly over time. This lack of ideal mixture in the small storage tank was also reflected in the significant differences of dry matter content in the brown water. When feeding a lower-concentrated substrate, a dramatic decrease of biogas yield could be observed, followed by a falling VFA / TAC quotient and causing a high variability of other process parameters. This instability in substrate quality led to a high difference in biogas yield, between 1.68 – 121.68 $l\ d^{-1}$ and 0.84 - 21.52 $l\ CH_4\ d^{-1}\ g^{-1}$ oDM, respectively (Table 1).

Table 1: Chemical parameters

Parameter	Unit	Inflow	Hydrolytic stage	Methanogenic stage	Outflow
pH	-	5.6 - 7.29 (6.67)	6.62 - 8.01 (7.15)	6.73 - 7.84 (7.13)	6.37 - 8.04 (7.13)
Temperature	°C	26 - 31.2 (28.7)	25.7 - 31.5 (29.0)	25.8 - 31.5 (28.9)	25.9 - 32.3 (29.2)
EC	mS cm^{-1}	2.01 - 6.06 (4.20)	4.14 - 6.64 (5.83)	3.64 - 6.24 (5.48)	3.93 - 6.25 (5.44)
VFA/TAC	-	0.31 - 2.22 (0.89)	0.059 - 0.217 (0.119)	0.046 - 0.309 (0.129)	0.051 - 0.999 (0.133)
DM	g l^{-1}	3.35 - 29.88 (12.50)	1.44 - 7.56 (2.60)	1.59 - 24.04 (6.57)	0.79 - 1.57 (1.19)
oDM	% DM	75.8 - 92.8 (87.3)	45.64 - 87.81 (62.82)	47.73 - 88.44 (75.40)	19.59 - 54.48 (39.58)
COD	g O_2 l^{-1}	1.89 - 28.42 (10.59)	1.09 - 9.93 (3.72)	1.22 - 21.79 (8.73)	0.30 - 1.41 (0.82)
Total-N	mg l^{-1}	1260 - 1904 (1477)	588 - 1764 (1176)	672 - 1568 (1047)	112 - 1523 (566)
NH_4-N	mg l^{-1}	504 - 1120 (720)	504 - 1596 (812)	532 - 1120 (723)	34 – 939 (544)

(): average

Table 1: Chemical parameters

Parameter	Unit	Value
Gas production rate	l h^{-1}	0.07 - 5.07 (2.64)
CH_4 content	%	46.3 - 66.2 (59.0)
CO_2 content	%	26.2 - 36.1 (31.75)
H_2S content	ppm	2120 - (>)5000 (3978)

The methane yield per day (Figure 1) reflected this problem, too.

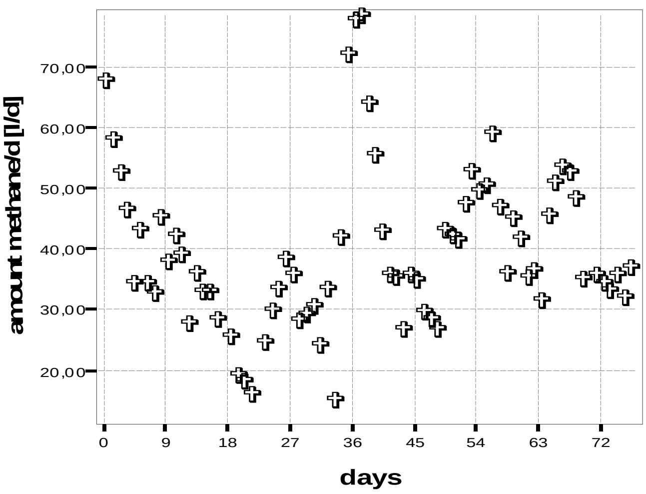

Figure 1: Biogas yield per day over the sampling time

Although the input material varied considerably, the quality of the output was stable: On closer inspection, the mean values of COD (Figure 2), dry matter (Figure 3) and organic dry matter (Figure 4) showed a decrease of 92 %, 90 % and 55 % respectively. The organic dry matter in the outflow was more fluctuant, but this could have been caused by the small amount of mass in the outflow samples.

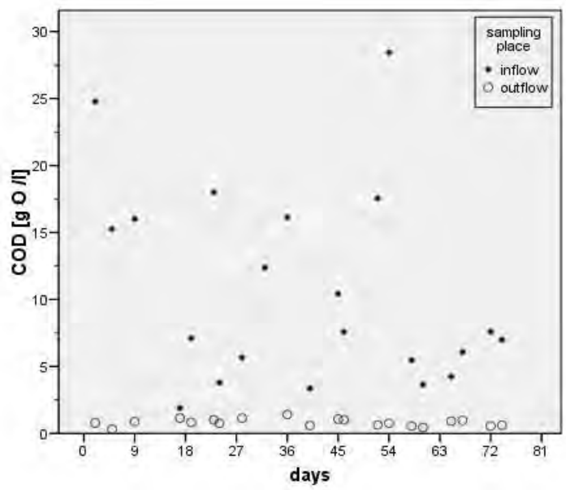

Figure 2: COD in inflow and outflow material

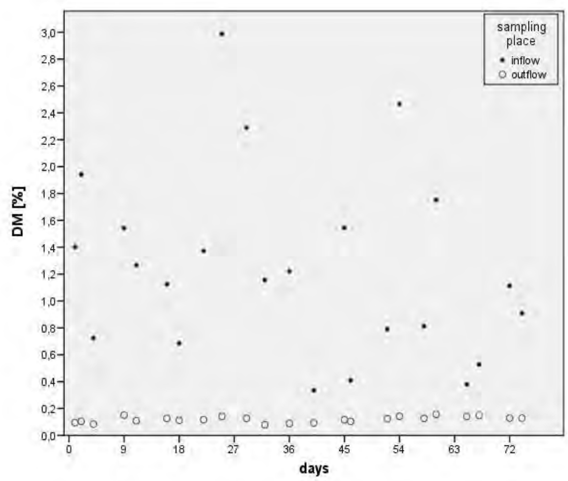

Figure 3: Dry matter in inflow and outflow material

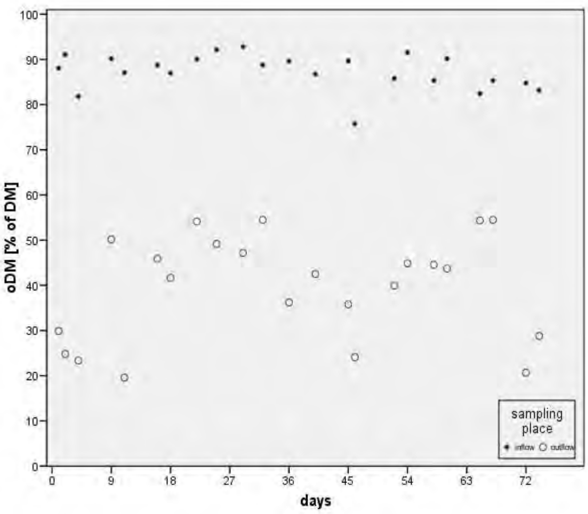

Figure 4: Organic dry matter of DM in inflow and outflow material

Taking a closer look at the nitrogen values, there was a retention of nitrogen. The total nitrogen was lower in the output compared to the input (Figure 5). In the outflow soluble ammonium N was present but only small amounts of organic N were detected (Figure 6, 7) resulting in a theoretical nitrogen retention value of 97 %.

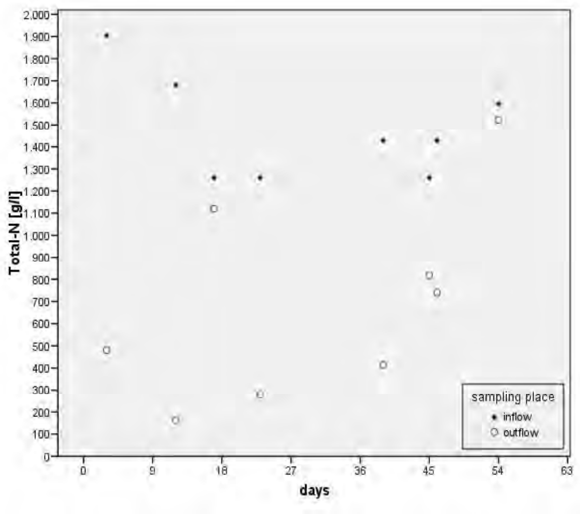

Figure 5: Total nitrogen in inflow and outflow material

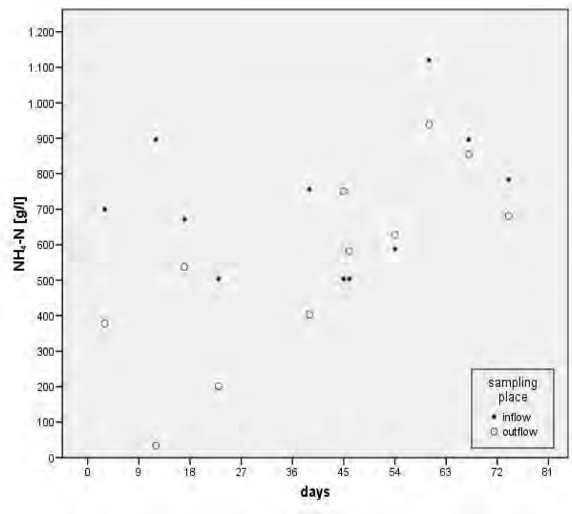

Figure 6: NH_4 nitrogen in inflow and outflow material

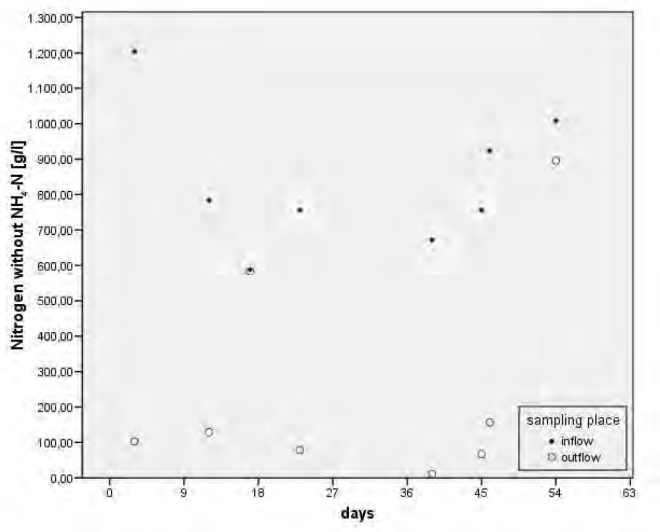

Figure 7: Nitrogen content in inflow and outflow material

Microbial parameters

All hygienic parameters showed significant reduction. From inflow to outflow, the content of Total coliform and Faecal coliform decreased around 2.7 logarithmic scales, while the Enterococcae decreased around 2.9 logarithmic scales. All samples were Salmonella - positive (Table 2).

Table 2: Microbial parameters

Parameter	Unit	Inflow	Hydrolytic step	Methanogenic step	Outflow
Total coliform	CFU 100 ml^{-1}	$2.3x10^6$ - $4.6*10^8$ ($1.68*10^8$)	$2.4x10^5$ - $1.1*10^7$ ($3.13*10^6$)	$2.3x10^4$ - $1.5*10^6$ ($7.07*10^5$)	$4.3x10^4$ - $9.3*10^5$ ($1.91*10^5$)
Faecal coliform	MPN 100 ml^{-1}	$2.3*10^6$ - $4.6*10^8$ ($1*10^8$)	$2.4*10^5$ - $1.1*10^7$ ($2.99*10^6$)	$2.3*10^4$ - $1.5*10^6$ ($6.93*10^5$)	$1.5*10^4$ - $9.3*10^5$ ($1.9*10^5$)
Enterococcae	KBE ml^{-1}	$6.2 * 10^4$ - $1.8*10^6$ ($4.78*10^5$)	$2.425*10^3$ - $1.53*10^4$ ($8.88*10^3$)	$1.15*10^3$ - $1.3*10^4$ ($4.64*10^3$)	$1.15*10^2$ - $6.25*10^2$ ($4.6*10^2$)
Salmonella	+/-	+ (100 %)	+ (100 %)	+ (100 %)	+ (100 %)

Trace elements

The trace elements showed an accumulation through the sedimentation in the reactor. In comparison with the mean values of trace elements of biogas reactors in Germany (data not published), no real lack of trace elements can be observed. Only the aluminium content and zinc content seemed to be high in the pilot plant (Table 3).

Table 3: Trace elements

Element	Reactor substrate [mg*kg TS-1]	Reactor content [mg*kg TS-1]	Bioreact mean values [mg*kg TS-1]	Difference between reactor & mean values [%]
Ca	2,127	23,544	16,134.6	46
K	2,066	12,014	38,017.1	-68
Mg	2,616	57,87	5,109.9	13
Na	1,744	16,569	6,893.4	140
P	10,116	15,380	9,603.1	60
S	1,351	6,227	4,383.8	42
Al	1,875	4,400	1,002.7	339
Ba	32	80	30.8	160
Cu	59	209	86	143
Fe	695	2,618	2,911.1	-10
Mn	238	261	268.1	-2
Si	147	97	1,949.5	-95
Sr	71	104	50.9	104
Zn	462	1,789	231.8	672
B	7.69	25	37.1	-32
Cd	0.46	2	6.6	-71
Cr	2	8	8.9	-11
Li	2	6	13.6	-58
Mo	1.73	9	5.4	69
Ni	4.20	12	10.4	16
Pb	1.12	4	17.8	-75
Sn	1.33	7	17.7	-61
V	1.55	6	6.9	-12

Conclusions

The separated treatment of domestic wastewater can be very valuable. Under anaerobic conditions, biogas is produced from brown water. With a long sedimentation time, the majority of dry matter can be separated from the fluid component of brown water. This leads to a longer hydraulic retention time for the solid parts of brown water, until they are fully degraded or cannot be further degraded under anaerobic conditions. As described, such a sedimentation reactor produces water with lower organic load. In addition, the sedimentation appears to have a positive effect on the pathogenic load of the outflow. The reactor also accumulates trace elements, so there is no lack of trace elements for biogas-producing microorganisms. Through accumulation of nitrogen and trace elements, a good product for agricultural use can also be extracted from brown water.

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List of Abbreviations:	
CFU	colonie forming unit
COD	chemical oxygen demand
d	day
DeSaR	Decentralized Sanitation and Reuse
DM	dry matter
EC	Electric Conductivity
g	gramm
h	hour
HRT_{Tot}	hydraulic retention time
l	liter
MPN	most probable number
n	sample amount
NH4	ammonium nitrogen
oDM	organic dry matter
pH	pondus Hydrogenii
[pos / neg]	[positive/negative]
TAC	total anorganic carbon
Total	total nitrogen
V	volume
VFA	volatile fatty acids

III-3: Biogas Production from Brown Water in a Mesophilic Reactor in CanTho, Vietnam

Joachim Clemens[1], Nguyen T.T. Nhan[4], Nguyen X. Hoang[4], Phan T. Nguyet[4], Julia Nuber[1]
[1] INRES - Plant Nutrition, University of Bonn, Germany, www.ipe.uni-bonn.de
[4] College of Environment and Natural Resources, University of CanTho, Vietnam

Keywords: methane, DeSa/R®, faeces, mesophilic biogas reactor

Introduction

Waste water from households may have considerable amounts of nutrients. Especially the urine fraction has high concentrations of nitrogen (N) and phosphorous (P) and shows rather low contamination with pathogens (Otterpohl & Oldenburg 2000). This is the reason to separate the different waste water origins in the household and to treat the fractions urine, brown water (feces with water) and grey water (water without any flushing water from toilets). If collected separately, in brown water the organic load is high (e.g. at a Berlin test site: 4800 mg COD l^{-1}, Buchholz 2007). The daily load per person is reported between 53 - 150 g COD $person^{-1}$ d^{-1} (Londong 2006, Starkl *et al.* 2005). Additionally, brown water bears the highest hygienic risk. One treatment option for brown water is anaerobic treatment and the production of biogas that can be used as renewable energy source. Here, we studied the biogas production from brown water in a biogas reactor in the South Mekong Delta, CanTho.

Material and Methods

Biogas reactor

The reactor was built by the HANS HUBER AG, Germany. It is part of a treatment concept of urine, grey water and brown water, called DeSa/R®. The reactor has a volume of 350 l and is operated under ambient conditions (temperatures around 30°C). A submersible pump transfers substrate from a brown water storage (6.25 m^3) into a small pretreatment tank (Volume = 200 l). In the pretreatment tank, the content is prepared by adding additional substrates or additives such as enzymes. From here, a daily amount of 20 l d^{-1} was transferred to the biogas reactor, resulting in a hydraulic residence time of 20 days. Substrate was recirculated on a regular basis (20 l every other minute). We report results from an experiment lasting from June-November 2007.

Substrate collection

The new sanitation infrastructure required for the separate discharge and collection of yellow, brown and grey water was installed in the existing dormitory "B23", which accommodates 100 male students in 10 rooms on the grounds of the University of CanTho.

Each bathroom was equipped with one separation toilet and one waterless urinal (manufacturer Gustavsberg, for details see Wohlsager 2007 and Wohlsager *et al.* Chapter III-1).

Analytical methods

To compare the efficiency of the treatment, the COD in the input and output of the reactor was analyzed 16 times during the operation of 178 days. At the same day the dry matter and the organic dry matter contents were analyzed by drying at 105°C (24 hours) and 550°C (6 hours), respectively. Daily, pH in the input material and the temperature in the fermenter were recorded.

The Gas amount was analyzed using a gas counter (Ritter, Bochum, Germany) and for gas quality an infrared device was used (ansyco GA94, Karlsruhe, Germany). Both parameters were analyzed daily. To prevent condensation of water in the infrared analyzer, the gas was cooled prior to its analysis. Gas amount was corrected to normal conditions.

In this paper we present only results of those days, when water samples were analyzed. The data of biogas production shown represent the average between the former and the actual sampling day.

Results and Discussion

The input into the fermenter varied in terms of dry matter and COD, whereas the amount was constant during the experiment. The high variability was due to the operation of the collection tank of the brown water. At the beginning, the substrate was pumped from the middle of the tank into the fermenter. Later on, the solids formed a crust on the surface of the brown water and this more solid fraction was used to feed the biogas reactor.

This resulted in DM concentrations in the input between 5.1 – 47 g l^{-1} and between 2.5 – 28 g l^{-1} in the output, respectively (Figure 1). The average organic dry matter content was 90.1 % (of DM) in the input and 76.6 % in the output. In line with the dry matter, the COD concentration of the input substrate into the fermenter was between 5.1 - 80 g l^{-1}, the output was between 3.4 - 45 g l^{-1}, respectively (Figure 2). At day 90 the COD in the output was higher as compared to the COD in the input. The reason may be the low concentration in the input at that time. Material with a higher concentration as compared to the input was flushed out of the reactor.

The pH tended to be more variable and lower (mean: 7.06, minimum: 6.22, maximum: 8.22) in the input as compared to the output (mean: 7.44, minimum: 7.08, maximum: 7.63). As the input material was stored in a tank with access to ambient air, hydrolysis or even aerobic oxidation may have formed some organic acids that yielded in a somewhat lower pH.

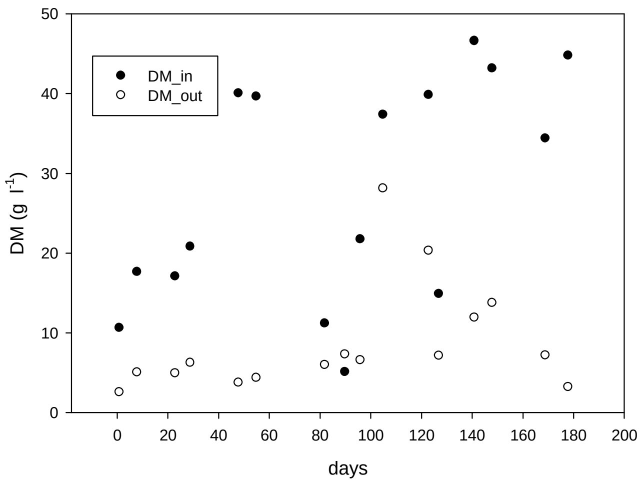

Figure 1: dry matter content in the input and output material

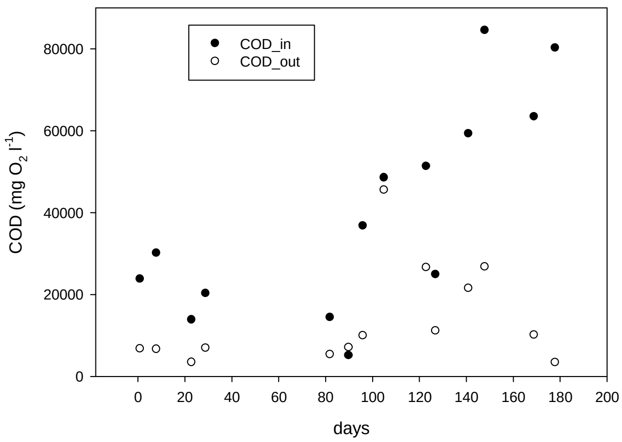

Figure 2: COD in the input and output material

The biogas- and methane production are in line with the input of dry matter or COD. The average biogas production was 132 l d^{-1} (min: 58 l d^{-1}, max: 234 l d^{-1}). With an average methane concentration of 65 % (min: 58 %, max: 70 %) the CH_4 production was on average 86 l CH_4 d^{-1} (min: 37 l CH_4 d^{-1}, max: 150 l CH_4 d^{-1}; Figure 3). The high CH_4 -concentrations are in line with Buchholz, who did experiments with a similar reactor in Germany (Buchholz 2007).

The COD removal calculated by COD data only (CODoutput / CODinput) averaged to 55 %, when all data were taken into account. This is lower as compared to 70 % reported by Buchholz (2007).

The specific gas yields were calculated from the COD removal per day and the daily gas production (Figure 4). They varied considerably around the average of 192 l kg^{-1} COD (CV: 0.37). This gas yield is lower as compared to theoretical calculations based on a continuous input of same amounts of organic material: According to VDI 4630 (2006), the theoretical CH_4-production is 320 l kg^{-1} COD. However for waste water from households, a yield of about 200 l kg^{-1} COD was considered to be more likely as input differs from day to day (gtz

& TBW 1998). Buchholz (2007) reported of specific gas yields of around 230 l CH_4 kg^{-1} COD in his experiments with a similar but thermophilic reactor. In our mesophilic experiments, CH_4 yields were about 15 % lower. But the HRT in the mesophilic reactor was 20 days compared to around seven days in the thermophilic reactor.

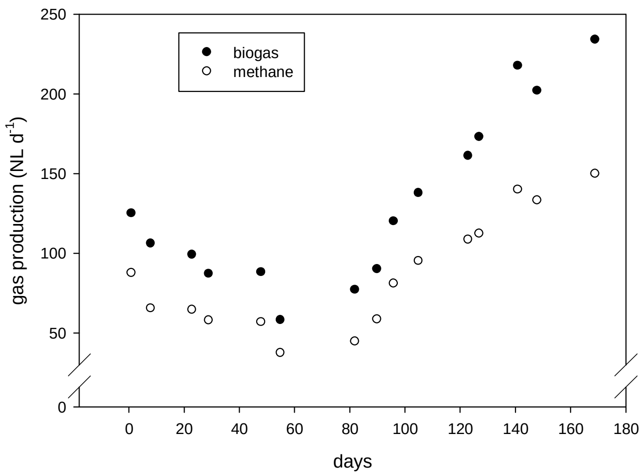

Figure 3: Daily biogas and methane production

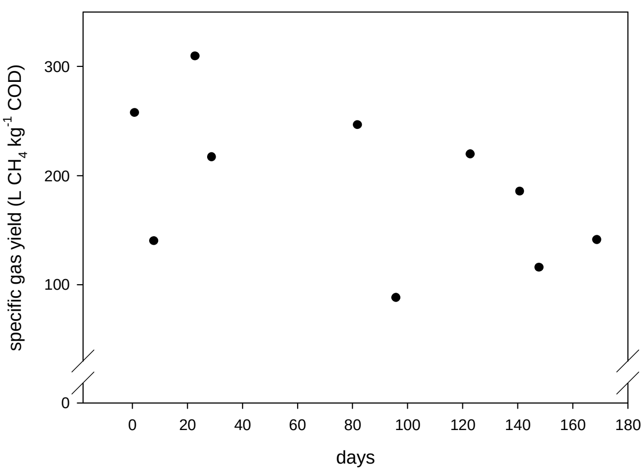

Figure 4: specific CH_4 yield per kg COD

Conclusions

Biogas production with brown water works at lower temperatures than optimum mesophilic conditions. Although COD reduction is rather efficient, the high COD concentration in the output requires an additional treatment of the brown water.

Pathogens should be monitored in future experiments to study their elimination rate.

A mass balance of COD seems to be easier via the gaseous losses. If biogas production is recorded continuously, it helps to avoid sampling and analytical errors.

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List of Abrevations:	
COD	Chemical oxygen demand
N	Nitrogen
P	Phosphorus
DM	Dry matter
oDM	organic dry matter

III-4: Process Control and First Results of the Biogas Plant in Hoa An

Matthias Plöchl[10] and Julia Nuber[1]
[10] BioenergieBeratungBornim GmbH, Potsdam, Germany, mp@b3-bornim.de
[1] INRES – Plant Nutrition, University Bonn, Germany, j.nuber@uni-bonn.de

Keywords: batch digestion tests; continuous-flow digestion tests; feedstock, biogas potential

Introduction

The biogas plant in Hoa An has been built to demonstrate anaerobic digestion of a large range of feedstock: agricultural wastes, residues from crop processing, organic waste from food and feed, and of course, faeces and urine from animal husbandry and human dwellings. A further objective, of course, would be the provision of a new energy source especially in rural areas.

In a first instance the digester should be suitable for taking up the faeces from approx. 200 pigs and probably from more and other animals like buffalo, goat and poultry. But it was also supposed to include other wastes and residues like rice straw, weed, and residues from crop processing. Therefore the concept of two-stage digesters was adapted for the local conditions and the supposed feedstock.

Batch digestion tests have been conducted to assess the biogas formation potential of the supposed feedstock. A consequence from this test was the lay-out of the first-stage hydrolysis basin which is dimensioned according to the values of rice straw. Although the biogas plant runs currently on pig faeces only, due to actual availability of feedstock, further experiments will be conducted in order to assess possible alterations of operation mode.

Material and Methods

First Batch Digestion Tests of Feedstock

Samples were taken from pig and cattle, which were available on Campus II of Can Tho University while Hoa An was still under construction. In addition to animal faeces rice straw and water hyacinth were supposed as feedstock for the biogas plant. Hereof samples were also taken at Campus II of Can Tho University. These samples were analysed according to the standards of proximate feed analysis (Tab. 1) and were investigated for their methane production potential.

The batch digestion tests are conducted in an apparatus which consists of 2 l polyethylene bottles connected to gas meters and a water bath to maintain temperature during the test period (Fig. 1). In the beginning of the experiment the bottles are filled with 1500 ml inoculum – containing the bacteria necessary for the process – and with aproximately 100 mg fresh matter (FM) of the material to be investigated. The amount of material for investigation is mixed with the inoculum in the ration 1:2 on organic dry matter (ODM) basis.

The sample is kept under mesophilic (~35°C) conditions for 28 to 35 days. During that time period the gas is collected in the gas meter and analysed daily for quantity and quality (gas composition).

Table 1: Characterisation of feedstock for biogas plant Hoa An

Feedstock	pH value	DM g kg^{-1} FM	ODM g kg^{-1} FM	N_{total} g kg^{-1} FM	$N\text{-}NH_4$ g kg^{-1} FM	org. Acids g kg^{-1} FM
Pig faeces	6.8	283	212	10.5	1.06	11.9
Cattle faeces	7.7	197	164	4.2	0.32	3.0
Rice straw	8.4	867	747	11.7	0.07	0.8
Rice hull	6.8	857	839	4.2	0.02	0.1
Water hiacynth	4.8	70	56	3.8	0.47	3.7

Figure 1: batch digestion test apparatus: in front polyethylene bottles in a water bath, in the rear gas meters with red-coloured water as obstructing liquid

Continuous-flow digestion tests

Continuous-flow installations enable one to conduct anaerobic digestion tests in the laboratory very similar to those taking place in a large-scale biogas plant. The installation consists of a double - wall container of approximately 10 l volume, a gas bag, a stirrer and a control unit (Fig. 2). The double-wall facilitates the maintenance of mesophilic (~35°C) conditions. The digesters have openings for the daily charging and discharging with feedstock and digestate, respectively. The biogas is collected in a gas bag which is emptied regularly for quantitative and qualitative analyses. The digester is also equipped with a stirrer for frequent mixing of the contents.

If the output of one digester is used for feeding a second digester we can simulate a two-step process. If hydrolysis occurs mainly in the first digester and methane formation in the second we simulate a two-stage process.

Figure 2: Continuous-flow digestion installation consisting of 10 l double-wall containers equipped with gas bags and stirrers

Biogas Plant at Hoa An

The biogas plant in Hoa An is a two-stage biogas plant with a cubic digester of 50 m³ volume and an open-top hydrolysis basis of 10 m³ volume (see Fig. 5, Chapter I-1). In addition to the leachate from the hydrolysis process the digester is fed with pig faeces and slurry. The hydrolysis unit will be fed with rice straw and other fibrous feedstock. The hydrolysis basin is equipped with ten baskets of approximately 0.6 m³ volume each. Two of these baskets will be charged every day. If charging is done from Monday to Friday the material will remain for seven days in the hydrolysis unit. Slurry from the digester is used to flush the hydrolysis basin and to transfer the leachate to the digester. The produced biogas is collected in a 50 m³ gas storage. The gas will be combusted in a combined heat and power unit to deliver electricity and heat.

Results and Discussion

Batch digestion tests demonstrated that faeces from pigs and cattle, rice straw and especially water hyacinth are suitable materials for digestion (Tab. 2). Rice hull only generates little biogas (Fig. 3) especially compared to its large fraction of organic dry matter, which is supposedly mainly crude fibre.

Table 2: Methane yield of selected feedstock

Feedstock	ODM g kg^{-1} FM	org. Acids g kg^{-1} FM	methane l_N kg^{-1} FM	methane l_N kg^{-1} ODM	methane %
Pig faeces	212	11.9	66	311	63
Cattle faeces	164	3.0	43	260	60
Rice straw	747	0.8	177	239	53
Rice hull	839	0.1	24	28	62
Water hiacynth	56	3.7	26	462	61

The biogas plant in Hoa An has first been run with pig faeces as feedstock and diluted cattle slurry as inoculum. Although the measurement of the gas volume is difficult, the water content of the gas seems to be an obstacle for the functionality of the gas meter, but the velocity of filling the gas storage indicates an acceptable biogas production. This can also be proved by the methane content of the biogas, which achieved rather soon a value of more than 60 % (Fig. 4).

In November the man hole of the digester had to be opened to install a new basket. This opening led to a considerable flux of air into the digester but as can be seen not to a break down of the digestion process. This also demonstrates that anaerobic digestion is able to produce its own environmental conditions.

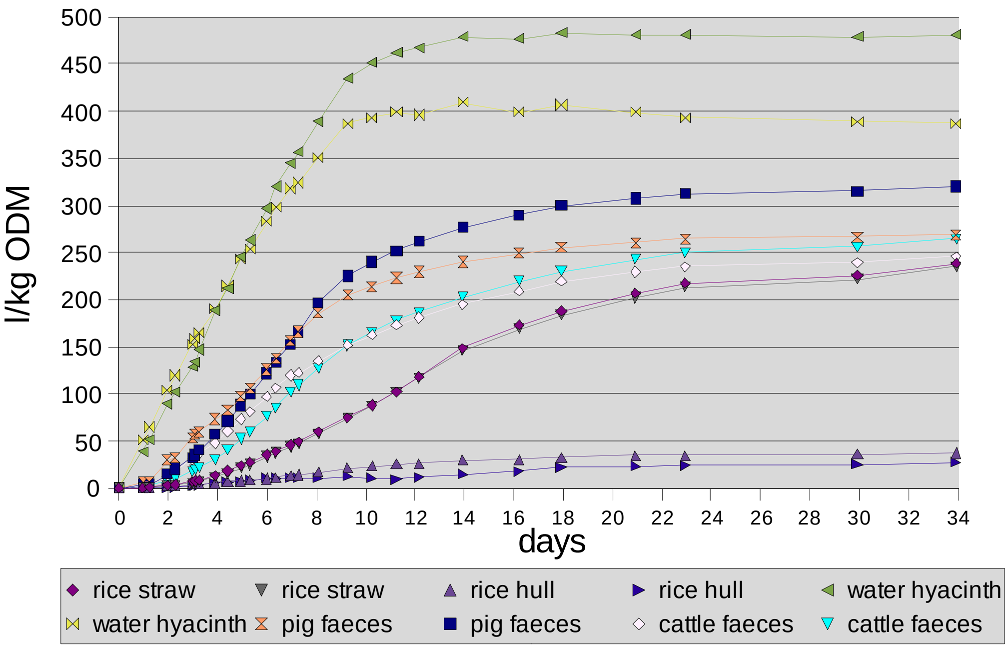

Figure 3: methane sums of feedstock investigated from batch digestion tests

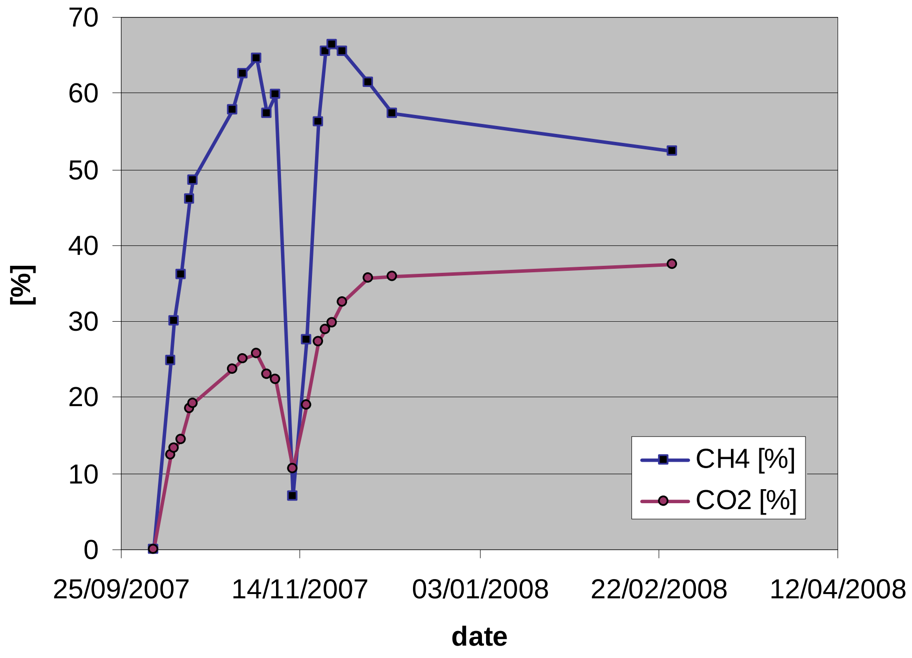

Figure 4: Percentage of methane and carbon dioxide in the biogas from end of September 2007 to the end of February 2008

Conclusions and Outlook

The biogas plant in Hoa An is working well. From April on a student is going to take over the supervision of the biogas plant and to start with the continuous feeding of the hydrolysis unit. In addition, the continuous-flow digestion tests will be conducted at lab-scale in order to assess modifications of the operation mode. We are also going to include a drying of the gas, thus the volume of biogas produced can be measured. We also hope that the CHP can be installed quite soon and the provision of electricity and heat will be available as planned.

List of Abbreviations:	
DM	dry matter
ODM	organic dry matter
WM	fresh matter
$N\text{-}NH_4$	ammonium nitrogen
org. acids	volatile organic acids (fatty acids)

III-5: Effects of different plants and their replacement levels to pig manure on in vitro biogas production by using syringe and flask systems

Truong Thanh Trung[5], Nguyen Van Thu[5] and Joachim Clemens[1]
[1] INRES - Plant Nutrition, University of Bonn, Germany, a.clemens@uni-bonn.de
[5] Dept. of Animal Sciences, Fac. of Agric. & Appl. Biology, Can Tho University, Vietnam

Keywords: Biogas and methane production, plant material, pig manure, syringe, flask

Introduction

During anaerobic digestion, organic matter is converted to carbon dioxide and methane i.e. biogas, by microorganisms in an oxygen-free environment. Beside the animal and human waste, plant material can also be used to produce biogas (Jacques 1997). Crop residues such as maize stalks, rice straw, cotton stalks, wheat straw and water hyacinth enriched with partially digested cattle dung enhanced the gas production in the range of 10 - 80 % (El Shinnawi *et al.* 1989). However studies on plant resources for biogas production are still limited in the Mekong delta of Vietnam. Rice straw is produced in large quantities in this region (about 18 million tons annually), while the anaerobic digestion of rice straw was feasible (Zhang 1999). The possibility of converting water hyacinth into biogas has been an area of major interest for many years due to large amounts of them being present in the canals and rivers in the region. Flask systems are widely used for evaluating biogas production and quality in laboratory experiments, however the use of syringes for this purpose is limited. Therefore the objectives of this study were to investigate the biogas production of rice straw, water hyacinth and para grass (*Brachiaria mutica*) at different levels replacing pig manure as the main substrate by in vitro experiments of syringe as compared to the flasks.

Materials and methods

The study was carried out at the Department of Animal Sciences, Faculty of Agriculture and Applied Biology, Can Tho University, Vietnam. In the experiment of syringes, a factorial design was used. The first factor was the plant material including rice straw, water hyacinth and para grass (Brachiaria mutica). The second factor was replacement levels of plants to pig manure including 10, 20, 30, 40 and 50 % (DM basis) with three replications. In the experiment of flasks, corresponding to each treatment of the experiment of the syringe system, one 5 liter - flask was used. The experimental period lasted for 60 days. Pig manure was collected from the pig farm of Can Tho University. The rice straw, water hyacinth and para grass were collected and dried under sun shine and chopped into small pieces (about 5 mm). They were put into the flasks for the experiment, whereas they were ground to 1 mm size for the syringe experiment. The plant materials and pig manure were analyzed for dry mater (DM), organic matter (OM), crude protein (CP), crude fiber (CF), nitrogen free extraction (NFE) and ash by using the methods of AOAC (1990), and neutral detergent fiber (NDF) and acid detergent fiber (ADF) according to Van Soest and Robertson (1991).

The pig sludge in the flasks incubated at day 80 was extracted for using as inoculum resources. The buffer and medium solutions were prepared according to methods of Menke and Steingass (1988). The ratio of medium solution and sludge was 5:1 (v:g). The dry matter content of the slurry for both syringe and flask experiments was 15 %. For the syringe experiment, the clip was opened and the syringe's plunger was pushed gently, so that air was removed after having added all the substrates. In the flasks we used nitrogen to remove the air. The Geotechnical instrument GA94 (Germany) was used to analyze the components and the volume of the biogas in the flasks, while the methane and carbon dioxide concentrations of the biogas in the syringes were determined by NaOH 1M by two syringes according to Fievez *et al.* (2005). The data from the syringe experiment was analyzed by analysis of variance using the ANOVA of General Linear Model, while the Tukey test was used to compare the mean data values of the two experiments (Minitab 2000).

Results and Discussion

Experiment 1

Table 1 describes the chemical composition of pig manure and plant materials used in Exp 1. The dry matter and crude protein of pig manure were 34.2 and 7.28 %, respectively. The dry matter result of pig manure used in Exp 1 was higher than a result of San Thy (2005), 32.1 %. The NDF and ADF of rice straw and para grass were higher than those of water hyacinth and pig manure. The NFE of rice straw was lower than that of water hyacinth and para grass (39.9, 44.6 and 50.4 %, respectively).

Table 1: The chemical composition (%DM) of pig manure and plant materials used in Exp. 1.

Items	DM	OM	CP	NDF	ADF	Ash	CF	EE	NFE
Water hyacinth	8.10	82.0	11.5	58.1	30.4	18.0	20.0	3.90	44.6
Rice straw	83.6	86.7	5.20	67.2	38.6	13.3	31.6	5.00	39.9
Para grass	20.3	89.2	9.45	69.0	34.3	10.8	30.1	3.70	50.4
Pig manure	34.2	84.7	7.28	38.7	22.8	15.3	12.2		

DM: dry matter, OM: organic matter, CP: crude protein, NDF: neutral detergent fiber, ADF: acid detergent fiber, CF: crude fiber, EE: ether extraction, NFE:.

Table 2: The change of pH values of fermented slurry over incubation days in Exp. 1

Incubation time (day)							
Item	0	1	2	6	10	15	60
Rice straw	7.60	6.90	6.90	6.40	6.70	7.20	7.50
Water hyacinth	7.00	6.90	6.60	6.30	7.20	7.20	7.70
Para grass	7.00	6.50	6.40	6.00	6.00	5.90	6.00

pH values

The pH value of fermented sludge changed during the incubation time (Table 2). At the beginning, the pH value was favourable for fermentation (pH = 6-8). From the day 0-6, the pH value dropped slightly for all treatments. On day 10, the pH value of rice straw and water hyacinth began to increase to 6.7 and 7.2 while that of rice straw maintained the same pattern (6.00).This result was described in the biogas industry (Kuijstermans *et al.* 2007): the pH values drop from 7.5 to 5.5 during the first seven days of incubation. Yadvika *et al.* (2004) reported that pH is an important parameter affecting the growth of microbes during anaerobic fermentation. An optimum pH for digestion should be kept within a desired range of 6.8–7.2.

Biogas production

Table 3: The biogas yield (m^3 kg OM^{-1}) of different plant materials and replacement levels at different incubation times in Exp. 1.

Item	Material (M)			% Replacement (R)					P		
Incub. time (day)	R	WH	PG	10	20	30	40	50	M	R	M*R
14	0.081a	0.060b	0.054b	0.048a	0.051a	0.068b	0.075bc	0.083c	***	***	***
28	0.128a	0.102b	0.058c	0.052a	0.064a	0.113b	0.114b	0.138c	***	***	***
37	0.154a	0.127b	0.060c	0.055a	0.078b	0.134c	0.143c	0.158d	***	***	***
60	0.194a	0.155b	0.063c	0.058a	0.086b	0.168c	0.182cd	0.194d	***	***	***

R: rice straw, WH: water hyacinth , PG: para grass, M: material, R: % replacement.

The different letter a, b, c, d in the same row showed the significant difference values at a level of 5%

The biogas production in syringes was shown in Table 3. The results showed that biogas production of rice straw was significantly ($P < 0.05$) higher than that of water hyacinth and para grass at different incubation times. The biogas production significantly increased ($P < 0.05$) by increasing replacement levels of plantmaterial to the pig manure (from 0.058 increasing up to 0.194 m^3 kg^{-1} OM). Increasing replacement of plant material levels to pig manure enhanced nutrients which bacteria could use to produce biogas.

Table 4: The methane yield (m^3 kg^{-1} OM) and methane concentration (%) of different plant materials and replacement levels at the day 60 in Exp. 1.

	Material (M)			% Replacement (R)					P		
Item	R	WH	PG	10	20	30	40	50	M	R	M*R
$\%CH_4$	58.3a	46.8b	43.6c	41.3a	43.9b	56.0c	56.7c	49.9d	***	***	***
VCH_4	0.079a	0.136b	0.027c	0.024a	0.042a	0.103b	0.119b	0.113b	***	***	***

R: rice straw, WH: water hyacinth, PG: para grass, M: material, R: %replacement.

The different letter a, b, c, d in the same row showed the significant difference values at a level of 5 %

The results in Table 4 indicate that the methane concentration and yield on day 60 were significantly different ($P < 0.05$) among the treatments. The methane yield of water hyacinth had the highest value (0.136 m^3 kg^{-1} OM). The methane concentration of rice straw was significantly higher than that of water hyacinth and para grass. Results reported by Komatsu (2005) indicated that addition of rice straw increased methane production by 66 - 82 % in mesophilic digesters and by 37 - 63 % in thermophilic digester. In the present experiment, the replacement levels of 40 plant materials had the highest value of methane concentration and yield (56.7 % and 0.119 m^3 kg^{-1} OM, respectively). The interaction between different materials and replacement levels was also significantly different ($P < 0.05$).

Experiment 2

Table 5: The biogas yield (m^3 kg^{-1} OM) of different plants materials and replacement levels at different incubation time in Exp 2

Item	Material (M)			% Replacement (R)				
Incubation time (day)	R	WH	PG	10	20	30	40	50
14	0.105	0.105	0.065	0.068	0.068	0.095	0.116	0.111
28	0.229	0.209	0.065	0.107	0.149	0.181	0.206	0.195
37	0.262	0.280	0.065	0.160	0.165	0.105	0.234	0.247
60	0.296	0.323	0.087	0.197	0.181	0.225	0.270	0.304

R: rice straw, WH: water hyacinth, PG: para grass, M: material, R: %replacement.

Table 5 shows that the biogas production for rice straw, water hyacinth and para grass on day 60 were 0.296, 0.323 and 0.0867 m^3 kg^{-1} OM, respectively. A result of Schmidt (2005) showed that the biogas yield of cut grass was 0.125 m^3 kg^{-1}. Kossmann *et al.* (1999) reported that biogas yields for rice straw and water hyacinth at the end of a 10 - 20 day retention time at a temperature of 30°C were 0.17 - 0.28 and 0.375 m^3 kg^{-1} OM, respectively. The methane concentration of rice straw and water hyacinth on day 37 reached 61.6 and 58.2 %, respectively, while that of para grass was 16.6 % (Table 6). At different replacement levels, on day 37 the methane concentration had similar values for all treatments from 42.2 to 49.6 %.

Table 6: The methane concentration (%) of different plant materials and replacement levels at different incubation times in Exp 2.

Item	Material (M)			% Replacement (R)				
Incubation time (day)	R	WH	PG	10	20	30	40	50
14	32.0	31.9	16.6	16.5	25.3	28.1	34.2	30.2
28	58.9	51.8	16.6	28.4	43.2	45.7	50.9	44.0
37	61.6	58.2	16.6	43.2	46.5	45.8	49.6	42.2
60	59.7	56.0	24.0	55.5	47.3	42.9	47.1	40.0

R: rice straw, WH: water hyacinth, PG: para grass, M: material, R: %replacement.

Table 7 shows that the methane production was higher for the water hyacinth and rice straw treatment and this was the highest value for the 50 % replacement by materials.

Table 7: The methane yield ($m^3\ kg^{-1}$ OM) of different plant materials and replacement levels at different incubation times in Exp 2.

Item	Material (M)			% Replacement (R)				
Incubation time (day)	R	WH	PG	10	20	30	40	50
14	0.035	0.036	0.011	0.011	0.018	0.029	0.040	0.037
28	0.108	0.099	0.011	0.03	0.065	0.082	0.096	0.088
37	0.128	0.138	0.011	0.060	0.075	0.097	0.113	0.117
60	0.149	0.161	0.019	0.082	0.085	0.108	0.130	0.143

R: rice straw, WH: water hyacinth, PG: para grass, M: material, R: %replacement.

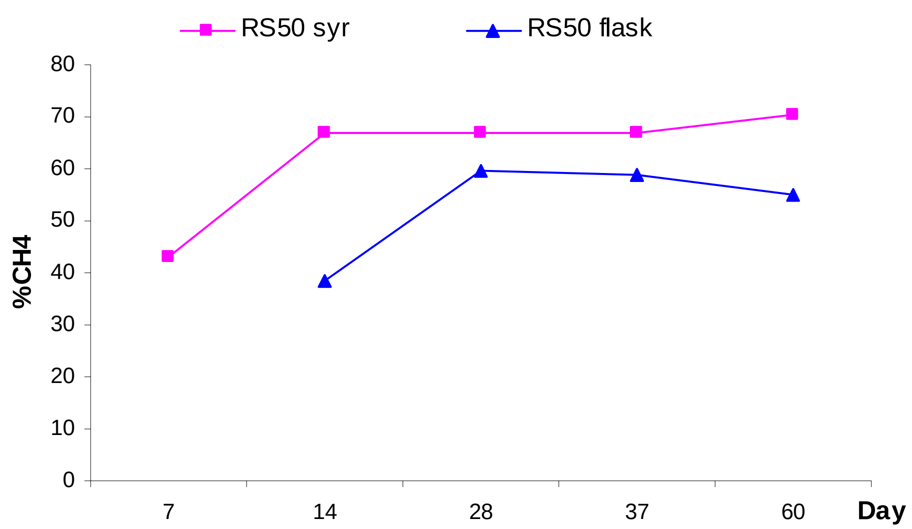

Figure 1: The change of methane concentration of biogas production for syringes and flasks at incubation times

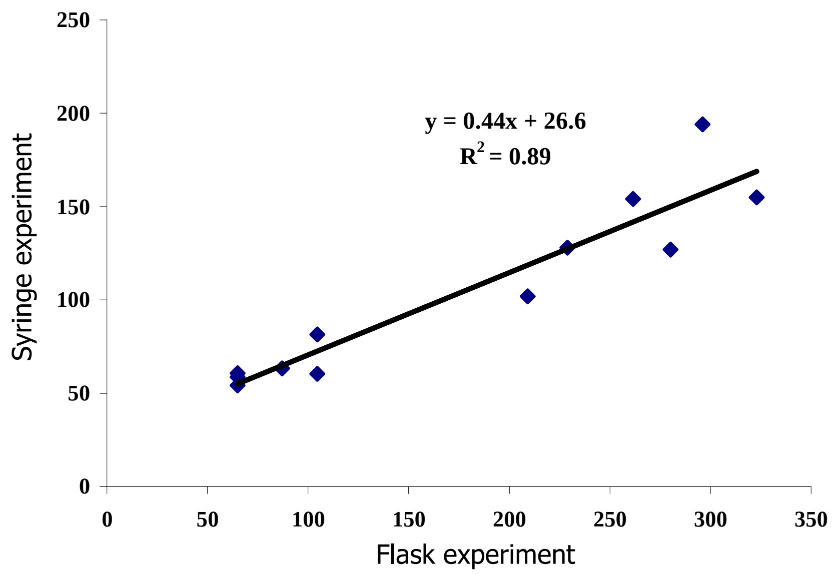

Figure 2: The relationship of biogas yield between syringe and flask systems

Figure 2 also shows that a methane concentration of 60 % can be achieved earlier using the syringes (day 14) than the flasks (day 28).

A close relationship of biogas production between the flask and syringe systems (R^2 = 0.89) was found in the present experiment. Similar results were obtained by Nguyen Van Thu *et al* (2008) with R^2 = 0.86 and SE = 0.038, when investigating biogas production affected by different inoculum sources and levels in both systems.

Conclusion and recommendations

Rice straw and water hyacinth could be used as substrate sources to replace pig manure for biogas production. Rice straw and water hyacinth produced higher biogas yield compared to para grass. The biogas production was enhanced by increasing replacement levels of plant material to pig manure and reached the highest value at 50 % levels. There was a close relationship of biogas production between syringes and flasks, so the method using syringes for in vitro experiments should be standardized to replace the flasks for an application. Experiments of higher than 50 % replacement levels (DM basis) of plant material to pig manure for in vitro biogas production should be considered.

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List of Abbrevations:

DM	dry matter
OM	organic matter
CP	crude protein
CF	crude fibre
NFE	nitrogen free extraction
NDF	netural detergent fibre
ADF	acid detergent fibre
Exp	experiment
EE	ether extraction
R	rice straw
WH	water hyacinth
PG	para grass
SE	standard deviation

III-6: Production and application of enzyme mixtures for increasing biogas yield in the South of Viet Nam

Jürgen Lenz[11]
[11] Bioreact GmbH, Germany, lenz@bioreact.de

Keywords: biogas, enzymes, saccharification, solid-state fermentation, fungi, bioreactor

Introduction

Bioreact GmbH develops new types of complex enzyme mixtures (containing cellulases, xylanases, pectinases, esterases, acetylases etc.) by co-cultivation of fungal strains on plant residuals in a solid-state fermentation process. Enzyme mixtures produced in this way are highly efficient in the degradation of plant material in the course of biogas production in Germany, resulting in enhancement of the specific biogas yield, fluidization of the fermenter content and stablization of the anaerobic fermentation process.

The aim of the present project was to adjust this process of enzyme production to the particular conditions (e.g. available substrates, climate), present in the South of Viet Nam. Furthermore, a solid-state bioreactor prototype was developed for the production of small amounts of enzyme mixtures at the University of Can Tho. Using this bioreactor, an enzyme mixture produced in Viet Nam showed systematic effects on the degradation of pig manure and rice straw during batch tests of biogas production from these substrates on the lab scale, which were carried out by the 'AG Stoffflüsse' (University of Bonn). An experiment on the pilot scale in the DeSaR® - biogas process did not lead to clear results.

Material and Methods

Identification of appropriate fungal strains and substrates

For indentification of appropriate fungi, 11 strains were cultivated in 500-ml-Erlenmeyer flasks on rape meal (50 % moisture content) at 30°C under sterile conditions. Fungal growth was observed during cultivation and various hydrolytic enzyme activities were measured after 6 days of cultivation. Eyzyme activities were determined photometrically in aqueous extracts using the method of König *et al.* (2002). The two best performing fungal strains were cultivated on 5 different substrates as well as on some binary combinations (1:1 WW:WW), afterwards. Screening for the most suitable substrate was carried out as mentioned above.

Identification of appropriate bioreactor designs and fermentation protocol

Three lab-scale solid-state bioreactor types were investigated with respect to their applicability for cultivation of the best combination of micro-organisms and substrate achieved so far: screw-type, tubular-type and tray-type. Micro-organisms were grown for several days in these bioreactors and process performance was again assessed by visual characterization of fungal growth and determination of enzymatic activities after the fermentation. The focus was on moisture control, here.

Using the tray-type bioreactor, a fermentation protocol to be applied in Viet Nam was developed by performing fermentations under different conditions: volume densities and air flow rates. Now, the focus was on the control of maximum temperature during processing. These studies were complemented by computer simulations.

Saccharification and biogas production at lab-scale

The potential of the fermentation product produced in the optimal way for saccharification of substrates was investigated by adding small samples of the fermentation product (4 g DM) to 8 g DM of substrate in 100 ml total volume. After 24 h of incubation at 30°C the amount of reducing sugars was determined photometrically using the di-nitro-salicylic-acid method. Control experiments were performed using heat inactivated enzyme preparations.

Hydrolysates were filtered and used for investigation of biogas production. For that, 100 ml of hydrolysate were added to 200 ml of liquid manure and incubated at 37°C for 24 h under gentle stirring. The produced biogas was collected and measured in upward-downward oriented and flooded graduated cylinders.

Investigation of stability of enzyme mixtures

To measure stability of enzyme mixtures, samples were incubated in the presence of different agents (see Results and Discussion) and the enzymatic activities were determined afterwards as described before. Alternatively, mixtures were dried in a drying chamber.

Production of enzyme mixtures in Viet Nam using a bioreactor prototype

Enzyme mixtures were produced in a prototype of a solid-state bioreactor (developed by Bioreact GmbH) at the University of Can Tho, mainly following the protocol developed earlier, but using a local strain of *A. nig*. The process was cooled by a thermostate (suited for the application in tropical areas) and a water bath together with using radiator coils mounted at the bottom of the bioreactor. Aeration was performed through small holes in the lower back wall of the bioreactor body and a fan, integrated into the upper back wall, was used for air outflow. 4 trays were arranged in an inclined manner within the bioreactor to facilitate air flow between the trays (see Figure 1). Samples of an enzyme mixture produced in Can Tho were tested for their effect on biogas production from pig liquid manure and rice straw by the 'AG Stoffflüsse' (University of Bonn) as well as in the DeSa/R® - pilot plant.

Figure 1: Bioreactor prototype

Results and Discussion

Identification of appropriate fungal strains and substrates

Table 1 shows the results of screening of the 11 fungal strains for their applicability for enzyme production in Viet Nam.

Table 1: Relative activities of various hydrolases after cultivation of 11 fungal strains on rape meal

	FDA	Cel	Xyl	Amy	Pec	Pst	β-Glu	α-Gal	β-Xyl	Σ
N. int.	0.59	0.67	0.19	0.07	0.00	0.16	1.00	0.14	0.31	**3.13**
A. nig.	1.00	1.00	0.33	0.06	1.00	0.25	0.55	0.78	1.00	**5.97**
A. tub	0.91	0.47	1.00	0.04	0.77	1.00	0.36	1.00	0.89	**6.44**
A. ory	0.05	0.07	0.03	1.00	0.31	0.33	0.65	0.21	0.02	**2.67**
T. vir	0.10	0.01	0.05	0.02	0.26	0.78	0.27	0.19	0.11	**1.79**
T. har	0.05	0.03	0.11	0.01	0.71	0.34	0.45	0.45	0.32	**2.47**
F. oxy	0.04	0.09	0.03	0.10	0.00	0.00	0.62	0.09	0.14	**1.11**
P. chrA	0.01	0.03	0.01	0.05	0.00	0.05	0.86	0.25	0.02	**1.28**
P. chrB	0.03	0.07	0.06	0.03	0.00	0.12	0.49	0.08	0.03	**0.91**
E. amA	0.09	0.24	0.07	0.00	0.00	0.54	0.18	0.15	0.09	**1.36**
E. amB	0.00	0.04	0.00	0.19	0.14	0.00	0.03	0.21	0.01	**0.62**

FDA = Hydrolysis of fluorescein-di-acetate, Cel = cellulase, Xyl = xylanase, Amy = amylase, Pec = pectinase, Pst = pectinesterase, β-Glu = β-glucosidase, α-Gal = α-galactosidase, β-Xyl = β-xylosidase

From analysis of the enzyme spectra shown in Table 1 it turned out, that *A. nig.* and *A. tub.* produced the highest levels of hydrolytic acitivity during cultivation at the conditions described above. Both strains also grew well at 30°C. Accordingly, these strains were used for further investigation.

Table 2: Relative activities of various hydrolases after cultivation of *A. nig.* and *A. tub.* on 5 substrates and some binary combinations (1:1 WW:WW)

		SM	SF	SC	SM/M	SF/M	SC/M	SM/R	SF/R	SC/R	SM/SF	SM/SC	SF/SC
	G	++	++	++	+	+	+	+	+	+	++	+	++
	FDA	1.00	0.37	0.05	0.43	0.30	0.23	0.40	0.12	0.20	0.84	0.75	0.68
	Cel	0.79	0.40	0.07	0.44	0.36	0.26	0.62	0.25	0.74	1.00	0.95	0.50
A.t.	**Xyl**	1.00	0.19	0.52	0.14	0.08	0.08	0.35	0.09	0.18	0.32	0.45	0.21
	Pec	0.24	0.21	0.14	0.02	1.00	0.02	0.20	0.14	0.13	0.28	0.27	0.24
	Est	0.23	0.04	0.26	0.00	0.01	0.01	0.18	0.07	0.06	0.34	1.00	0.51
	Σ	**3.26**	**1.21**	**1.04**	**1.03**	**1.75**	**0.60**	**1.75**	**0.67**	**1.31**	**2.78**	**3.42**	**2.14**
	G	++	++	++								++	
	FDA	1.00	0.69	0.46								0.79	
	Cel	1.00	0.24	0.39								0.65	
A.n.	**Xyl**	0.51	0.15	0.34								1.00	
	Pec	1.00	0.12	0.27								0.59	
	Est	0.45	0.10	0.42								1.00	
	Σ	**3.96**	**1.30**	**1.88**								**4.03**	

SM = soy meal, SF = soy flakes, SC = soy cake, M = maize, R = rice, G = growth

Table 2 shows the results of cultivation of *A. nig.* and *A. tub.* on 5 different substrates as well as some binary combinations as described above. Both strains grew well on all substrates and substrate combinations. However, enzyme acitivities developed best on soy meal and a mixture of soy meal and soy cake. Due to the simplicity of using only one substrate, soy meal was selected for further experiments.

Identification of appropriate bioreactor designs and fermentation protocol

A mixed culture of *A. nig.* and *A. tub.* was cultivated in different bioreactor types as described in Material and Methods. From these types, the tray type bioreactor turned out to be most suited for cultivation of fungi in Viet Nam due to offering the lowest risk of contamination as a result of moisture accumulation. Moisture could be controlled most suitably within this bioreactor type.
Identification of an efficient fermentation protocol focused on temperature control. For that, temperature development in dependence of substrate: volume density (represented by the number of trays per bioreactor, see Figure 2) and rate of aeration were investigated.

In the wooden test fermenters used for the experiments, a number of 3 trays gave the best results with respect to temperature profiles (this corresponds to about 70 kg of substrate per m^3 bioreactor volume). In addition, aeration rates of 3 l $min^{-1}\cdot m^{-3}$ during the first 2 days and 50 l min^{-1} m^{-3} during another 2 days gave best results with respect to air supply. Following this way, maximum temperature did not exceed 45°C during the process.

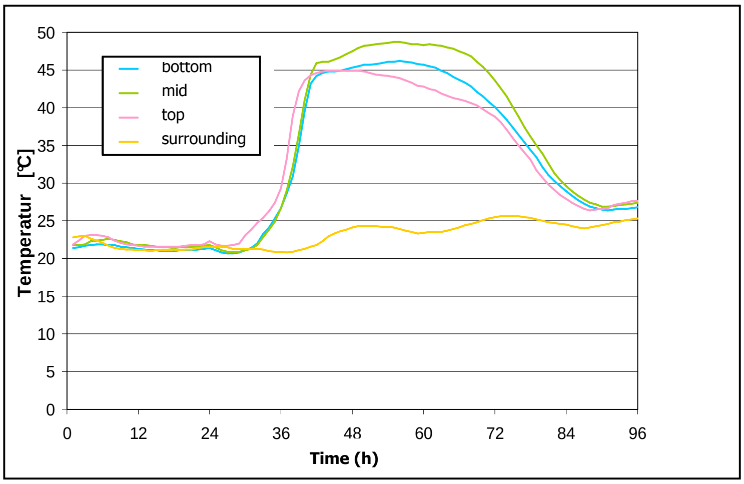

Figure 2: Temperature profile in 3 of 5 trays during fermentation in wooden tray fermenters

Saccharification and biogas production at lab-scale

An enzyme mixture resulting from processing according to the optimal protocol was applied to saccharification of kitchen waste and wheat straw, followed by an investigation of biogas production from the hydrolysates (see Material and Methods). The results are presented in Table 3.

Table 3: Effect of application of an enzyme mixture on saccharification of and biogas yield from kitchen waste and wheat straw

Parameter	Unit	kitchen waste	wheat straw
Additional sugar concentration	mg mm^{-1}	1.9	1.1
Additional biogas yield	mm	140	18
Additional biogas yield	%	26	11

The results in Table 3 show, that in the case of enzymatic treatment of kitchen waste all of the additionally provided sugar was transformed into biogas. This gave an increase in specific biogas yield of 26 %.

This effect was not that clear in the case of straw. However, there was an increase in the specific biogas yield of 11 %. Hence, these experiments showed clear effects of an enzyme mixture produced according to the protocol to be applied in Viet Nam on the degradation and biogas production from two special substrate classes, which were originally intended to be applied in the biogas plants in Can Tho (DeSa/R®, Hans Huber AG) and Hoa An (B^3 GmbH).

Stability of enzyme mixtures

To guarantee enough stability of the enzyme mixtures produced in the South of Viet Nam to carry out the pilot experiments under the climate conditions there, different agents were applied and the evolution of enzyme activities over time was observed. The chemicals and substances tested were: glycerine, propionic acid, a starch containing agent, a ligno-cellulose containing agent, rape meal and sugar beat pulp. However, none of them gave satisfactory results. Hence, drying was investigated, too, and the decrease of moisture in a chamber at 35°C is shown in Figure 3. Under these conditions, there was only little loss in enzyme activities during drying.

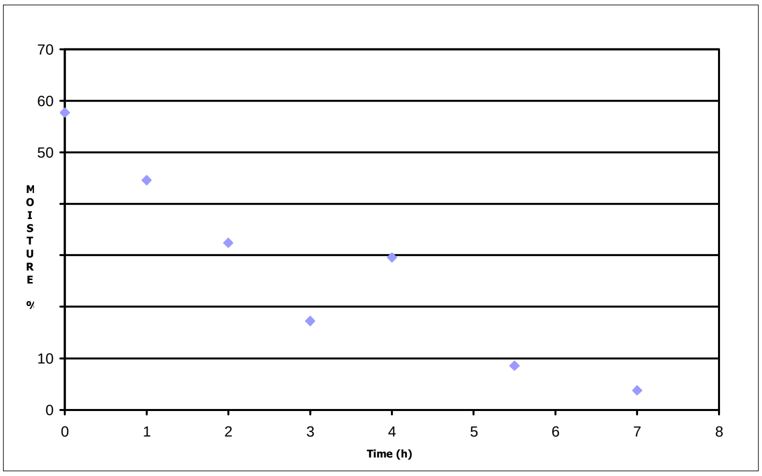

Figure 3: Drying profile of enzyme mixture in a dry chamber at 35°C

Production of enzyme mixture in Viet Nam using a bioreactor prototype

Based on the above results, a bioreactor prototype (see Figure 1) was developed and taken into operation at the University of Can Tho. Using this prototype and a local strain of *A. nig.*, an enzyme mixture was produced at the University of Can Tho and its effect on biogas production from liquid pig manure and rice straw was investigated by the 'AG Stoffflüsse' (University of Bonn, see related papers for more detailed information). Experiments were done as batch tests during 21 days at lab scale. The results showed an increase in the rate of biogas production from both substrates due to enzyme action in the order of 10 - 20 %. However, this increase in biogas production rate was not statistically significant due to scatter between the repetitions. Nevertheless, time courses of cumulative biogas yield with and without active enzyme mixtures were as expected from theoretical considerations, that is, there was a transient deviation in the observed yields.

Test of enzyme mixtures in the DeSa/R®-pilot plant

In addition to that, an enzyme mixture produced by *A. nig.* growing on soy meal together with pulp as an iductor was applied to the DeSa/R®-biogas process running on brown water. At lab-scale, slight saccharification of brown water could be shown using this enzyme mixture. At pilot scale, there seemed to be a visible effect on the absolute biogas yield. However, due to the strong scatter in the COD of the daily input and the lack of continuous monitoring, no significant effect on the specific biogas yield could be detected.

Conclusions and Outlook

The results obtained so far point to the general applicability of enzyme mixtures produced in the South of Vietnam to the optimization of biogas production from waste material as well as for other applications. However, further studies have to be done.

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List of Abbreviations:	
Amy	Amylase
A. nig.	*Aspergillus niger*
A. tub.	*Aspergillus tubingenis*
Cel	Cellulase
COD	Chemical oxygen demand
DM	Dry mass
Est	Esterase
FDA	Fluorescein-di-acetate
G	Growth
M	Maize
Pec	Pectinase
Pst	Pectinesterase
R	Rice
SC	Soy cake
SF	Soy flakes
SM	Soy meal
WW	Wet weight
Xyl	Xylanase
α-Gal	α-Galactase
β-Glu	β-Glucosidase
β-Xyl	β-Xylosidase
Σ	Sum

III-7: Effect of different inoculum sources on in vitro biogas production by using syringe and flask systems

Nguyen Van Thu[5], Truong Thanh Trung[5] and Joachim Clemens[1]
[1] INRES – Plant Nutrition, University of Bonn, Germany, a.clemens@uni-bonn.de
[5] Dept. of Animal Sciences, Cantho University, Vietnam, nvthu@ctu.edu.vn

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Introduction

The polyethylene tube bio-digesters have been widely used in Vietnam to alleviate pollution from wastes and supply fuel for cooking. They are made of local materials with a low cost (around 50 USD per unit) which have supported the use of farmers in both peri-urban areas and villages and their effluent has been used for cultivating fish and water plants, and fertilising fruit trees and vegetables to improve the production (Thu 1999). Livestock manure contains a portion of organic solids, which are fats, carbohydrates, proteins and other nutrients that are available as food and energy for the growth and reproduction of anaerobic bacteria (Charles *et al.* 1993). Yadvika *et al.* (2004) reported that strains of some bacteria and fungi have also been found to enhance gas production by stimulating the activity of particular enzymes. The composition of methanogenic communities present in anaerobic reactors has been studied mostly for laboratory scale digesters, including up-flow anaerobic sludge blanket reactor granules and mixture reactors treating municipal solid waste or wastewater sludge. The Influence of environmental conditions on methanogenic compositions in anaerobic biogas reactors has been reported (Karakashev *et al.* 2004). The in vitro studies of biogas have been important for leading the innovative and productive research and real applications. In the in vitro biogas production studies with the flasks, the methane proportion was low in the first stage due to the slow development of methane bacteria. It takes around 40 days to achieve the normal methane production. Different inoculum sources used for substrate digestion resulted in varying degrees of biogas production (De Ferrer *et al.* 2002). Syringe systems were widely and effectively used in in vitro gas production research for evaluating animal feed quality based on nutrient degradation due to shorter time and economical expenses (Thu and Udén 2003), however, they have not been used for in vitro biogas production studies. The aims of this study were, therefore to find the optimum inoculum in terms of both resources and levels for in vitro biogas production studies with substrates from pig manure, and to evaluate whether syringes could be used for the in vitro biogas production.

The hypothesis of the study was that the optimum inoculum source and the syringe system could facilitate the in vitro biogas production research.

Materials and methods

The study included two experiments. These were done in the laboratory E 205 of Dept of Animal husbandry, Faculty of Agriculture, Can tho University. For experiment 1 (Exp 1) 50ml - syringes were used. The experimental design was completely randomized with 4 treatments from different inoculum resources and 3 replications. The treatments were fresh pig manure (FPM), sludge from the reactor of a bio-digester (SR), sludge from the removal tank (SRT) and rumen fluid (RF) of cattle. The buffer and medium solutions were prepared according to methods by Menke and Steingass (1988). The incubation time lasted 86 days and the temperature was controlled by using a water bath at 39°C.

Experiment 2 (Exp 2) was a completely randomized design with six treatments and three replications. It included two small experiments. For experiment 2a, 50 ml - syringes were used, while the 5 liter - flasks were used in expperiment 2b. Both of them were done at the same time and at the same experimental conditions. The treatments were inoculum sources including no inoculum [NC], fresh pig manure [FPM], sludge from the reactor of a bio-digester [SR], sludge from 5 liter - flasks incubated for 60 days with the ratio (g:v) of the sludge and medium (1:5) [SF 1:5], [SF 2:5] and [SF 3:5], respectively. The incubation time was 80 days with an incubation temperature of 39^0C. In experiment 2b (Exp 2b), the treatments of experiment 2a (Exp 2a) were repeated in one 5 liter - flask. For each flask one gas bag was used to collect the produced biogas in order to analyse it for its composition by using the Geotechnical instrument GA 94 from Germany. For both of the two Experiments, the methane and carbon dioxide concentrations in the syringes was determined by using a 1 M NaOH solution and two other syringes according to Fievez *et al.* (2005).

In both experiments data were analyzed by analysis of variance using the ANOVA General Linear Model, while a Tukey test was used to compare the mean data values of the two experiments (Minitab 2000).

Results and discussion

Experiment 1

The results of Experiment 1 are shown in Tables 1, 2 and 3.

The chemical composition of DM, OM and CP of the pig feces used in experiment 1 (see Table 1) was similar to those reported by San Thy *et al.* (2005).

Table 1: Chemical composition of pig feces used in the Exp 1

Item, %DM						
DM	OM	CP	NDF	ADF	CF	Ash
29.9	84.2	7.36	38.6	22.4	13.1	15.8

DM: dry matter, OM: organic matter, CP: crude protein, NDF: neutral detergent fiber, ADF: Acid detergent fiber and CF: crude fiber.

Table 2 shows the biogas production of different inocula at different incubation times. On day 1, there were no significant differences between the treatments. However, there were significant differences ($P < 0.05$) between the treatments on days 26, 66 and 86 with the highest values belonging to the SR treatment (0.058, 0.111, 0.127 $m^3\ kg^{-1}$ OM, respectively). The values of gas production were low and similar for the FPM, SRT and RF treatments on day 86. Particularly the inocula from rumen fluid and pig feces were usually used for in vitro gas production to evaluate feed quality.

Table 2: Gas production ($m^3\ kg^{-1}$ OM) of different inocula over incubation time in Exp 1

Items	Inoculum				
Incubation time (days)	FPM	SR	SRT	RF	P /± SE
1	0.022	0.022	0.019	0.018	0.13/0.79
26	0.058^{ab}	0.062^{a}	0.053^{b}	0.054^{ab}	0.04/1.19
42	0.078	0.109	0.105	0.068	0.07/6.63
66	0.111^{b}	0.162^{a}	0.119^{ab}	0.114^{ab}	0.04/7.04
86	0.127^{b}	0.251^{a}	0.152^{b}	0.126^{b}	0.02/12.2

FPM: fresh pig manure, SR: sludge of reactor of bio-digester, SRT: sludge of removal tank and RF: rumen fluid of cattle

Different letters a and b in the same row showed statistically significant differences at a level of 5%

Table 3 shows the methane yields for the different inocula. The yields obtained on day 86 in the experiment were lower than those reported by Mahnert *et al.* (2005) with the values of 0.20 - 0.35 $m^3\ kg^{-1}$ OM. The methane production was significantly different ($P < 0.05$) among the treatments on day 86 with the highest values being 0.191 $m^3\ kg^{-1}$ OM for the SR treatment (Table 3). The lower values belonged to the treatments of FPM and RF (0.081 and 0.086 $m^3\ kg^{-1}$ OM, respectively).

Table 3: Methane yield ($m^3\ kg^{-1}$ OM) of different inocula at different incubation times in Exp 1

Items	Inoculum				
Incubational time (days)	FPM	SR	SRT	RF	P/± SE
1	0.005	0.005	0.004	0.005	0.07/0.00016
26	0.015^{c}	0.069^{a}	0.044^{b}	0.018^{c}	0.001/0.0019
42	0.041^{b}	0.077^{a}	0.073^{a}	0.028^{b}	0.01/0.0028
66	0.072^{b}	0.109^{a}	0.079^{ab}	0.080^{ab}	0.05/0.0053
86	0.086^{b}	0.191^{a}	0.111^{b}	0.081^{b}	0.01/0.0087

FPM: fresh pig manure, SR: sludge of reactor of bio-digester, SRT: sludge of removal tank and RF: rumen fluid of cattle

Different letters a and b in the same row showed statistically significant differences at a level of 5%

Figure 1 shows that the incubation time for methane concentration reaching 60 % was the lowest for SR treatment (29 days). For SRT, FPM and RF treatments, the incubation periods were 32, 43 and 48 days, respectively. The above results indicated that when inoculum of sludge from the reactor of a bio - digester was used, the biogas production was improved and the incubation period shortened.

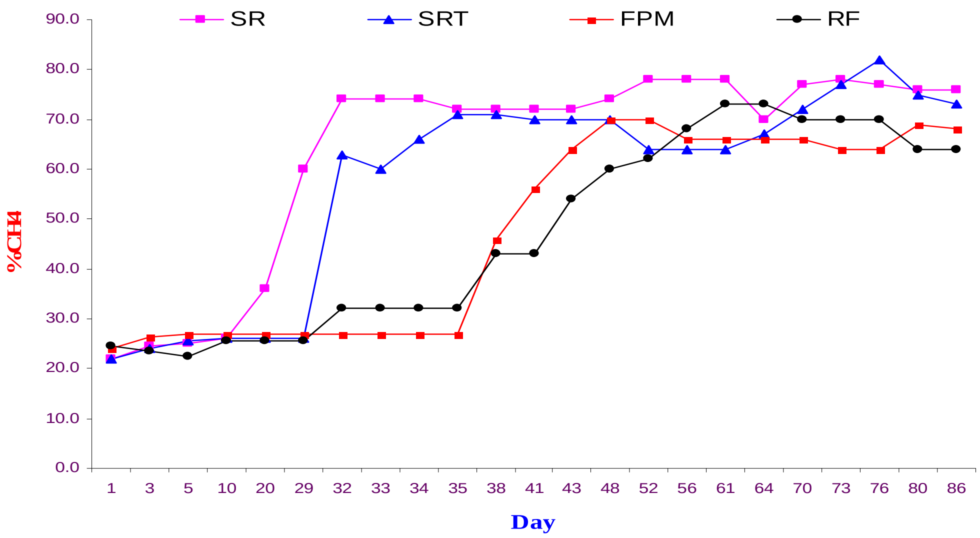

Figure 1: The methane concentration (%) of syringe over incubation times, SR: sludge of reactor of bio-digester, SRT: sludge of removal tank, FPM: fresh pig manure, and RF: rumen fluid of cattle

Experiment 2

In Table 4, nutrients of pig manure in experiment 2 were similar to those of Exp 1 with the CP content being slightly lower than that of experiment 1.

Table 4: Chemical composition of pig feces used in Exp 2

Item, %DM						
DM	OM	CP	NDF	ADF	CF	Ash
35.8	82.4	9.42	39.8	29.1	21.9	17.6

DM: dry matter, OM: organic matter, CP: crude protein, NDF: neutral detergent fiber, CF: crude fiber.

The biogas production of different inoculum at different incubation times in the syringe system is shown in Table 5. The gas production was significantly different ($P < 0.05$) between the treatments with the higher values belonging to the treatments of inoculum extracted from pig sludge incubated for 60 days. The gas production of SF 1:5 treatment was significantly ($P < 0.05$) higher than the others at different incubated days.

Table 5: The gas production (m^3 kg^{-1} OM) of different inocula at different incubation time by syringes system in Exp 2a

Items	Inoculum						
Incub. time (day)	NC	FPM	SR	SF1:5	SF2:5	SF3:5	P /± SE
22	0.054^{a}	0.022^{a}	0.102^{a}	0.372^{b}	0.300^{bc}	0.254^{c}	0.000/±0.018
31	0.116^{a}	0.049^{a}	0.218^{b}	0.399^{c}	0.324^{cd}	0.270^{bd}	0.000/±0.019
50	0.276^{a}	0.270^{a}	0.338^{ab}	0.427^{b}	0.346^{ab}	0.300^{a}	0.004/±0.022
80	0.304^{a}	0.321^{a}	0.354^{ab}	0.447^{b}	0.367^{ab}	0.323^{ab}	0.03/±0.026

NC: no inoculum, FPM: fresh pig manure, SR: sludge of reactor of bio-digester, SF1:5: sludge of flasks incubated for 60 days with the ratio (g:v) of inoculum and medium (1:5), SF2:5: the ratio (g/v) of inoculum and medium (2:5) and SF3:5: the ratio (g/v) of inoculum and medium (3:5).
Different letters a and b show statistically significant differences at a level of 5%

Table 6 also shows that on day 22 of incubation, the methane concentration reached the point of standard biogas (more than 60 %) for all treatments.

Table 6: The methane concentration in biogas production (%) of different inocula at different incubation times by syringes system in Exp 2a

Items	Inoculum						P /± SE
Incub. time (day)	NC	FPM	SR	SF1:5	SF2:5	SF3:5	
22	67.0^{ab}	62.0^{ab}	74.7^{a}	72.0^{ab}	62.0^{b}	63.5^{ab}	0.04/2.85
31	77.7^{a}	79.0^{a}	77.7^{a}	69.0^{b}	62.0^{c}	62.0^{c}	0.000/0.91
50	75.7^{ac}	79.3^{a}	70.7^{abc}	65.3^{bc}	67.0^{c}	62.0^{b}	0.001/1.86
80	68.3^{a}	69.3^{a}	65.7^{ab}	64.3^{ab}	61.7^{b}	52.6^{ab}	0.01/1.37

NC: no inoculum, FPM: fresh pig manure, SR: sludge of reactor of bio-digester, SF1:5: sludge of flasks incubated for 60 days with the ratio (g:v) of inoculum and medium (1:5), SF2:5: the ratio (g/v) of inoculum and medium (2:5) and SF3:5: the ratio (g/v) of inoculum and medium (3:5).
Different letters a and b in the same row show statistically significant differences at a level of 5%

Table 7 shows that the methane yield of the SF 1:5 treatment was significantly higher ($P < 0.05$) than the others on day 22, 31 and 50 but not on day 80 ($P = 0.08$). Kossmann *et al.* (2007) reported that the biogas yield and methane content of pig manure at the end of a 10 - 20 day retention time at a process temperature of roughly 30°C was 0.34 - 0.55 $m^3\ kg^{-1}$ OM and 65 - 70 %, respectively. The biogas yield in this experiment was higher than those reported by Songkasiri (2004) from pig manure in Thailand of 0.217 $m^3\ kg^{-1}$ OM. Thus the syringe system for studying the in vitro biogas production was found to be promising in terms of biogas production and time consumption.

Table 7: The methane production ($m^3\ kg^{-1}$ OM) of different inocula at different incubation times by syringes system in Exp 2a

Items	Inoculum						P /± SE
Incub. time (day)	NC	FPM	SR	SF1:5	SF2:5	SF3:5	
22	0.036^{ac}	0.014^{a}	0.076^{c}	0.268^{b}	0.186^{d}	0.161^{d}	0.001/0.011
31	0.089^{a}	0.039^{a}	0.169^{b}	0.275^{c}	0.201^{b}	0.168^{b}	0.001/0.014
50	0.208^{ab}	0.214^{ab}	0.239^{ab}	0.279^{a}	0.232^{ab}	0.186^{b}	0.03/0.016
80	0.207	0.223	0.233	0.287	0.226	0.202	0.08/0.017

NC: no inoculum, FPM: fresh pig manure, SR: sludge of reactor of bio-digester, SF1:5: sludge of flasks incubated for 60 days with the ratio (g:v) of inoculum and medium (1:5), SF2:5: the ratio (g/v) of inoculum and medium (2:5) and SF3:5: the ratio (g/v) of inoculum and medium (3:5).
Different letters a, b and c in the same row show statistically significant differences at a level of 5%

The results of the flask experiment (Exp 2b) are stated in the following tables 8, 9 and 10.

Table 8: The biogas production of pig feces with different levels of inoculum at different incubation time by flask ($m^3\ kg^{-1}$ OM)

Items	Inoculum						P /± SE
Incub. time (days)	NC	FPM	SR	SF1:5	SF2:5	SF3:5	
22	0.137^{ab}	0.081^{a}	0.112^{ac}	0.351^{b}	0.297^{bc}	0.247^{ab}	0.005/± 0.033
31	0.179	0.187	0.287	0.375	0.346	0.291	0.06 /± 0.036
50	0.376	0.393	0.379	0.406	0.365	0.323	0.58 /±0.031
80	0.376	0.393	0.399	0.427	0.370	0.380	0.87 /±0.034

NC: no inoculum, FPM: fresh pig manure, SR: sludge of reactor of bio-digester, SF1:5: sludge of flasks incubated for 60 days with the ratio (g:v) of inoculum and medium (1:5), SF2:5: the ratio (g/v) of inoculum and medium (2:5) and SF3:5: the ratio (g/v) of inoculum and medium (3:5).
Different letters a, b and c in the same row show statistically significant differences at a level of 5%

Table 9: Methane concentration (%) in biogas of pig feces with different levels of inoculum at different incubation time by flask

Items	Inoculum						P /± SE
Incub. time (days)	NC	FPM	SR	SF1:5	SF2:5	SF3:5	
22	35.7	49.1	36.5	60.2	61.9	62.8	0.07 /± 5.34
31	44.7	56.8	56.2	59.4	62.5	63.1	0.12 /± 2.71
50	59.3^{ab}	67.6^{a}	60.1^{ab}	59.7^{b}	62.4^{ab}	61.7^{ab}	0.05 /± 1.41
80	62.5	67.5	60.9	59.6	62.6	53.5	0.28 /± 3.63

NC: no inoculum, FPM: fresh pig manure, SR: sludge of reactor of bio-digester, SF1:5: sludge of flasks incubated for 60 days with the ratio (g:v) of inoculum and medium (1:5), SF2:5: the ratio (g/v) of inoculum and medium (2:5) and SF3:5: the ratio (g/v) of inoculum and medium (3:5).
Different letters a and b in the same row show statistically significant differences at a level of 5%

The methane concentrations in the biogas were 60.2, 61.9 and 62.8 % for the SF 1:5, SF 2:5 and SF 3:5 treatments, respectively, while the NC, FPM and SR treatments were 35.7, 49.1 and 36.5 %, respectively on day 22. They were lower than the same treatments of Exp 2a with values of 67.0, 62.0, 74.7, 72.0, 62.0 and 63.5 for the NC, FPM, SR, SF 1:5, SF 2:5 and SF 3:5, respectively. The methane production was numerically different between the treatments on day 22 and 31. At day 50 and 80, however, they were similar (Table 10).

Table 10: Methane yield (m³ kg^{-1} OM) of production of pig feces with different levels of inoculum at different incubation time by flask

Items	Inoculum						P /± SE
Incub.time (days)	NC	FPM	SR	SF1:5	SF2:5	SF3:5	
22	0.057^{ab}	0.040^{a}	0.044^{ac}	0.212^{b}	0.185^{bc}	0.156^{ab}	0.008/±0.0 25
31	0.080	0.109	0.163	0.223	0.217	0.184	0.10 /± 0.027
50	0.225	0.265	0.228	0.242	0.228	0.199	0.57 /±0.023
80	0.237	0.265	0.243	0.254	0.232	0.202	0.49 /±0.022

NC: no inoculum, FPM: fresh pig manure, SR: sludge of reactor of bio-digester, SF1:5: sludge of flasks incubated for 60 days with the ratio (g:v) of inoculum and medium (1:5), SF2:5: the ratio (g/v) of inoculum and medium (2:5) and SF3:5: the ratio (g/v) of inoculum and medium (3:5).
Different letters a and b show statistically significant differences at a level of 5%

The results of the flask experiment were similar to those of experiment 2a in which syringes were employed, and were consistent with those reported by Schmidt *et al.* (2005) regarding the methane yield of pig manure, poultry and sewage sludge of 0.30, 0.25 and 0.30 m³ kg^{-1} OM, respectively. In general a methane concentration of 60% was reached earlier in the syringe than in the flask experiment. This is also shown in Figure 2.

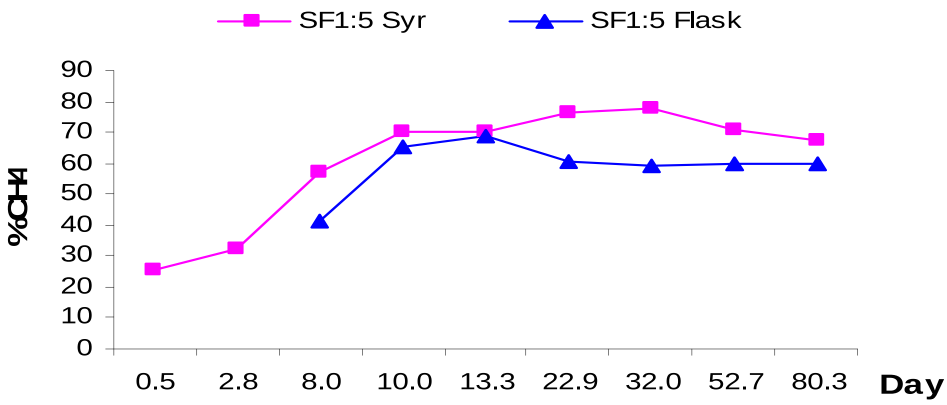

Figure 2: A comparison of CH_4 concentration produced between two systems

There was a close relationship of biogas production by incubated time between the syringe and the flask experiment (R2 = 0.86, SE = 0.038) in Fig 3. Thus the syringes could be promisingly used for the in vitro biogas production research to replace the flasks for saving the cost of time, labor, materials and chemicals.

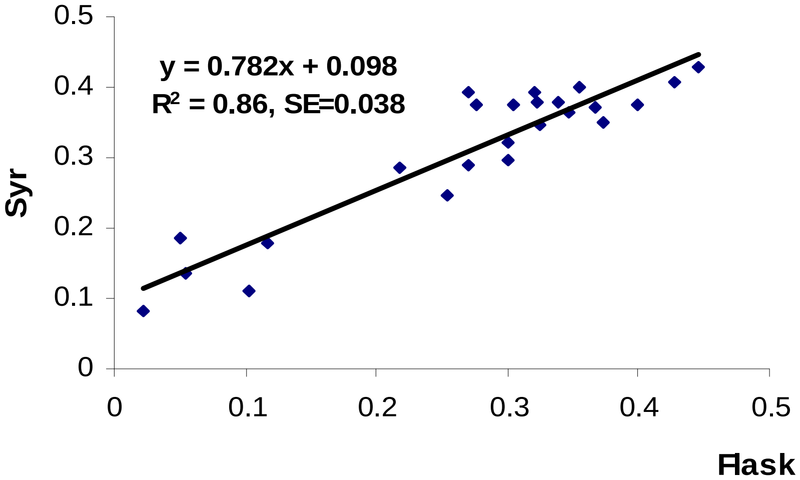

Figure 3: Relationship of biogas production between syringe and flask systems

Conclusions and recommendations

It was concluded that better inoculum sources used for studying in vitro biogas production should be from the sludge of biogas reactors. The inoculum with a ratio of 1:5 (g:v) of sludge incubated for 60 days and medium was optimum for biogas production and quality. The syringes could be promisingly used for the in vitro biogas production. The comprehensive studies of in vitro biogas production by using the syringe system should be considered.

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Chapter IV: Soil Filter and Microbiology

IV-1: Wastewater treatment by vertical soil filter applied at a student dormitory in Can Tho City, Mekong Delta

Thilo Herrmann[16]
[16] Ecolith® Water Technology, 95448 Bayreuth, Germany
herrmann@ecolith.de, www.ecolith.de

Keywords: constructed wetland, grey water, Mekong Delta, sewage treatment, soil filter, sand filter, sanitation, urban drainage, Vietnam, wastewater treatment

Introduction

Urban Drainage

So far municipal wastewater is only barely treated in Vietnam. State-of-the-art urban drainage in the cities of the Mekong Delta is the pre-treatment of the toilet effluent by septic tanks. The effluent of these tanks is diverted to mainly open water courses or to a more or less developed sewer pipe system. Wastewater in residential areas is diverted without any treatment in the same way. Stormwater is mixed with the wastewater effluent and provides a temporarily flushing of sewers, canals and water courses. The tidal effect reaches back into the canals as well as into the pipe drainage system and provides another flushing effect.

Water quality of water courses

The water regime in the rivers of the Mekong Delta is quite different from rivers in Europe. The Mekong is a Monsoon affected river with a naturally high load of suspended soil materials. The ratio of flow to number of inhabitants for the Hau River is probably more than 100 - fold higher compared to the biggest German river, the River Rhine. This means that the effect of wastewater on water quality, discharged into the major rivers in the Mekong Delta, is quite limited compared to any river in Europe. Focusing on municipal (non industrial) wastewater the requirements and goals of wastewater treatment in the Mekong Delta therefore are quite different to those in Europe or the Northern America: The nutrient load of the discharged wastewater, in particular for nitrogen and phosphate, is a negligible parameter.

Within the urban residential areas the situation is quite different. Since the ratio of flow to number of inhabitants is much smaller, the load of wastewater per volume of water in the canals is tremendously increasing: In consequence the water of the small canals is decayed and stinking. The reason for this is oxygen depletion due to decomposition of organic carbon and the oxidation of ammonia (NH_4^+) to nitrate (NO_3^-), both originating from municipal

wastewater. These processes demand more oxygen than is provided in the small water courses. The result is a complete depletion of the available oxygen, what leads to anaerobic processes in that water courses. At the end of that fouling process H_2S is emitted, the well-known stinking gas of the black river in Saigon.
To overcome the problem of putrescent canals, the oxygen consumption of the wastewater has to be reduced. This means in chemical terms, to reduce organic carbon and ammonia input to the rivers and canals by wastewater treatment. The reduction of nutrients is not necessary. In contrast: When providing nitrate NO_3^- instead of ammonia by treatment, without reducing the total nitrogen load, the oxygen supply is enhanced.
When introducing wastewater treatment in the Mekong Delta or another region rich in natural water flow (monsoon affected) the prior goal is the reduction of oxygen demand and pathogens. Oxygen demand can be estimated by determining organic carbon (C_{org}), biological oxygen demand (BOD), chemical oxygen demand (COD) or the specific absorption coefficient at 254 nm (SAC 254 nm) plus ammonia. Pathogens have to be determined by special microbiological methods.

Basic requirements for urban drainage

When introducing (importing) a new technology like urban drainage, it is required to import the whole technological system, not only the material:
The whole technology system comprises the material, the professional knowledge and rules to mount it, to maintain and to repair it in the right way.
The introduction and appliance of the technical knowledge, norms and rules is often forgotten.
Introduction of pipe systems for waste water requires the strict observation of the technical rules to avoid failures in planning and construction:

- Slope of pipes must be at least:

50 mm diameter requires	> 2.0 %
100 mm diameter requires	> 1.0 %
150 mm diameter requires	> 0.7 %
400 mm diameter requires	> 0.25 %

- Avoiding sharp edges
- No use of sharp edged 90° bows, **90° bows are forbidden**
- Use 2 bows of 45° back to back to get a shift of 90°
- T-connections must have a 45° branch, **90° T-connection is forbidden**
- Foresee cleaning ports every 10 m distance from an opening, at least one port after two 90° shifts in direction.

Knowing the rules requires skilled workers: e.g. in Germany a pipe layer worker has completed a 9 year school career and graduates at a professional college for another 4 years. More than 90 percent of all German workers are educated by this minimum education. So far, a worker in Vietnam is not expected to have any professional education.

The further introduction of technical systems will be limited by the availability of skilled craftsmen. Otherwise the operation of technical systems will not be satisfactory.
I strongly recommend not to confine the international exchange on academics, but rather to exchange skilled workers, master craftsmen and teachers for technicians.

Training of the users and staff

Up to now, the existing drainage systems in Can Tho are also used to flow away a big amount of garbage. The experiences at Long An dormitory show that for a student, moving into a house with a sanitary pipe system for the first time in life, some training is necessary about how to use a sanitary system. The pipe system cannot manage the transport of any garbage.
In every wastewater pipe system a blocking can occur. Without construction failures and misuse of the wastewater system a blocking in the pipes is rather seldom. In Germany the main reason for blockages is the ingrowth of roots into pipes outside of a building. Hence a pipe and sewer system in Germany works usually for more than fifty years without any repair. This is cost - efficient.
At the dormitories many blockages have been observed. After 5 years of operation, almost every waste water pipe of the Long An dorm had been damaged or blocked.
The reasons for this are: Failures in planning and construction, misusage by the students, missing knowledge and equipment of the staff to remove the blockages. All this is very costly.
The introduction of regular screenings is much cheaper. The staff should be equipped with pipe-cleaning-twists to prevent damages when cleaning pipes. It is easy to understand that education and training of all stakeholders and concerned persons in the beginning is more important than just to buy and install the pipes.

Separate diversion of stormwater

When introducing waste water treatment additionally to urban drainage, it is a must that all stormwater and rainwater has to be diverted separately from the waste water. So far stormwater usually requires no treatment. But when the bulk of stormwater is mixed with the domestic waste water, the resulting wastewater flow will overcharge every treatment system, independent of the type of treatment.
Up to now the stormwater from the roofs of newly constructed residential buildings is diverted into the same pipes as the waste water. This practice should be banned as soon as possible by a legal order and an information campaign directed to the house-builders and principals.
The main characteristics of the wastewater system at Long An dorm and the expected efficiency is given in Table 1 and 2.

Table 1: Wastewater treatment system at Long An Dormitory

System type Vertical soil filter	Unit	Characteristics
Dimensioning	m² $person^{-1}$	2,5 (german minimum size)
Total area	m²	280
	m² $compartment^{-1}$	70
Total persons	-	200
Total wastewater flow	m³ d^{-1}	30

Table 2: Expected efficiency (dependent on loading rate)

Parameter	Unit	Efficiency
COD $_{homogenized}$ (chemical oxygen demand)	%	>70
COD $_{solute}$ (chemical oxygen demand)	%	>30
TOC (total organic carbon)	%	>70
DOC (dissolved organic carbon)	%	>30
NH_4^+ (ammonium)	%	>95
SS (suspended solids)	%	>95
TN (total nitrogen)		no goal, no efficiency
TP (total phosphorus)		no goal, certain efficiency only during first year of operation expected

Mechanisms within Vertical Soil Filters

- Solids removal by sand filtration and physical sorption at sand grains
- Oxidation of organic carbon to CO_2 and sorption of DOC and subsequent microbial degradation
- Oxidation of ammonia to nitrate by ion-exchange and subsequent microbial oxidation. Efficiency is depending on filter substrate
- Phosphate removal during the first year
- No removal of total nitrogen
- Pathogen removal due to sand filtration and physical sorption at sand grains and competition of pathogens and non-pathogens.

Principles of construction and dimensioning

Collection and distribution of wastewater

The effluent of all toilets is collected separately and conveyed to septic tanks ((1), see Fig. 1). Every four toilets share one septic tank, in total there are five septic tanks for 20 toilets. Every tank is constructed with three chambers. The outflow from all septic tanks is conducted to a collection pit (2), thus containing the pre-treated black water.

In the beginning of construction the storm water of the roof was collected in the same pipe system as the wastewater from showers, lavabos and sinks. Since it is not possible and reasonable to treat the mixture of rainwater and wastewater the gutter of the roof was cut and replaced by a separate pipe system for rainwater only. Now the grey water (effluent from showers, lavabo and sinks) is collected in a separate pipe system and conveyed to another collection pit (3).

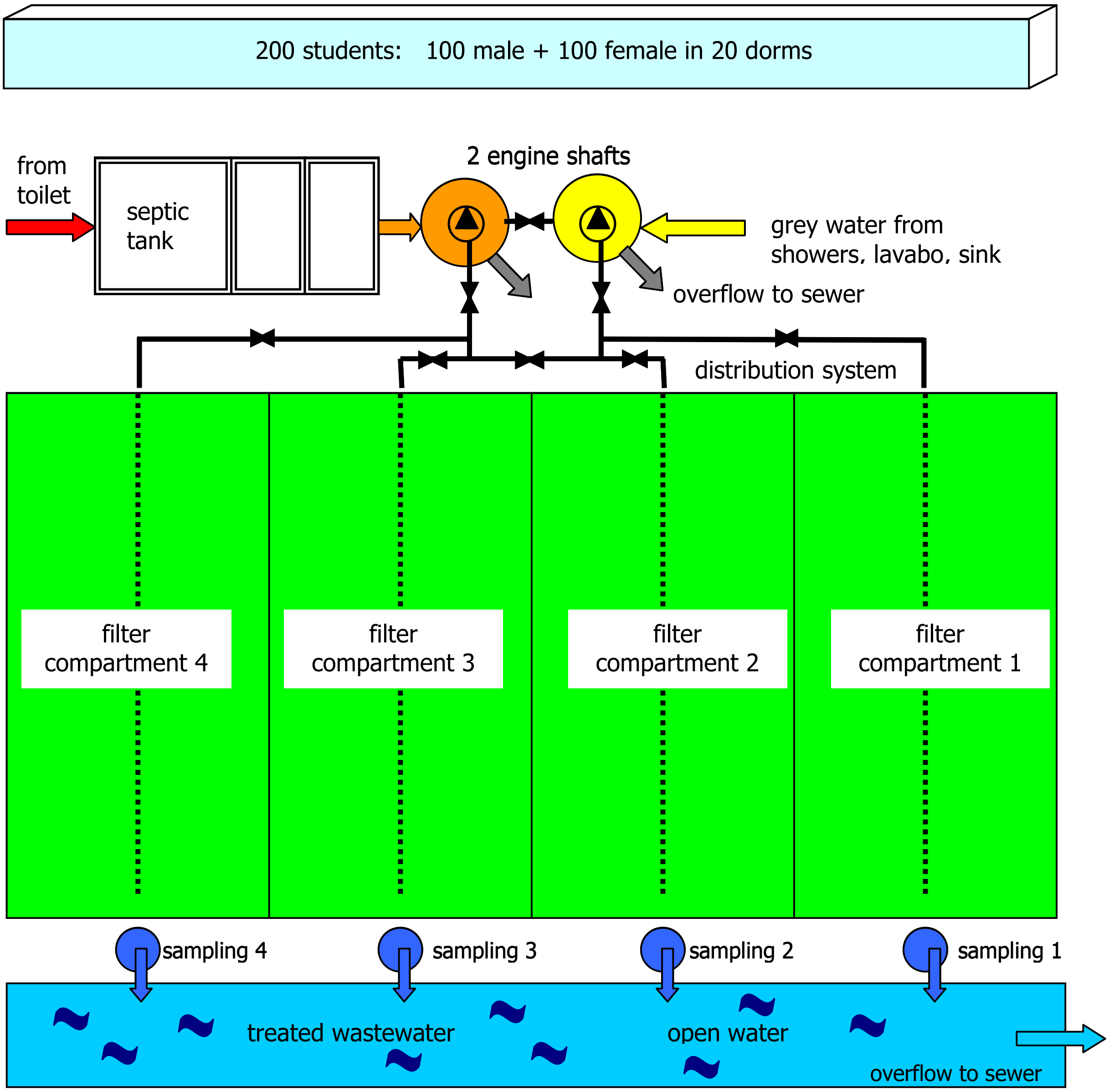

Figure 1: Flow sheet of the vertical soil filter at Can Tho University

The collection pits are used as engine shafts and the wastewater is pumped from there to the distribution system (4). An electronic control unit (5) and valves (6) allow distributing the wastewater to four independent filter compartments. The loading rate onto each filter compartment can be varied according to the requirements of the scientific question. The separation of grey and black water allows conducting experiments during operation for different wastewater types: Black water only, grey water only and the mixture of both. For the case of a cut in electricity the collection pits comprise an overflow (7) outlet, so that the wastewater can drain untreated via the sewer.

Construction of the treatment system

The wastewater is treated mechanically and biologically by a vertical flow soil filter (8). The cross section in Figure 2 shows the water flow: The wastewater is introduced onto the filter surface via distribution pipes (9). The water percolates then by gravity flow through a layer of filter sand (10) towards the filter bottom. A layer of coarse sand (11) prevents the filter sand from penetrating into the subjacent gravel layer (12). The gravel functions as underdrain and collects the cleaned water and conveys it to the central drainage pipe (13). From there the water is discharged into sampling pits (14), where the outflow volume is measured and volume-proportional water samples are taken automatically. The cleansed outflow is drained into an open water canal (15). Here the water can be abstracted for irrigation purposes. The overflow is conveyed in the sewer.

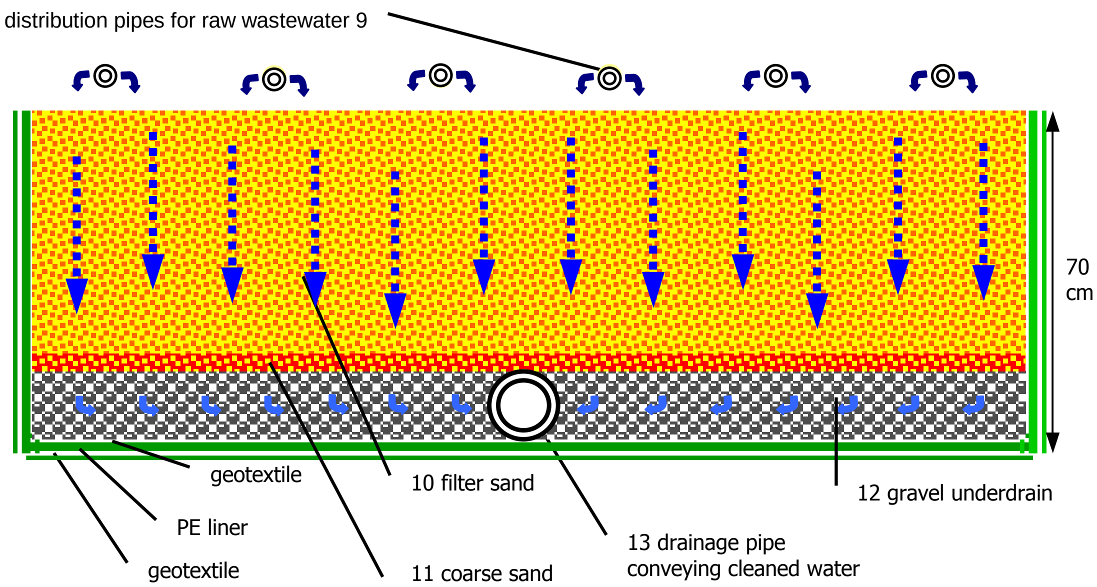

Figure 2: Cross section of a vertical soil filter compartment

The height of sand:

The flow of oxygen into the filter bed is limited by the top surface as the degradation process requires oxygen. Thus, oxygen is one limiting factor of the performance. The flow of oxygen cannot be increased by a deeper filter bed. Therefore, performance will not be enhanced strongly by a deeper filter bed.

The filter surface area:

A specific oxygen demand requires a suitable specific surface area. Since the average carbon and ammonia load of the daily human excreta remain constant, the oxygen demand of domestic wastewater can be expressed by specific filter surface area per person [m^2 $person^{-1}$] or by load of COD per area [mg COD m^{-2} day^{-1}]

Goals of investigation

- Determining the maximum load of wastewater per m² and day separately for grey water and septic tanks effluent
- To find suitable and useful plants which grow under soil filter conditions and provide a product to be harvested. Requirement: The product must not be contaminated with wastewater when consumed
- Investigation of the root system after one year to check possible damage or blocking of the drainage by plant roots
- Find out the limiting factors when loading rate is increased until malfunction of the filter system

Selected plants for first planting

Melaleuca, banana, sugar cane, bamboo, lemon, orange, pomelo, mango, elephant grass, *Cyperus alternifolius*, lemon grass, vetiver grass, several other grass species

Main application of soil filters

Domestic wastewater from 1 up to 20.000 persons
Note:
The toilet discharge is preferably pre-treated in 3 - chamber septic tanks.
Grey water (non-toilet wastewater) has to be free of garbage and rough solids. Pretreatment by screening with 4 mm mesh size is required.

Possible applications of soil filter systems

- Fish processing industries
- Food processing industries
- Breweries
- Slaughter houses

Note:
Wastewater with high fat content is preferably pre - treated by flotation. Chemical pollutants, such as heavy metals, need specific pre - treatment by flocculation and / or precipitation in accordance to the chemical properties of the pollutants.

IV-2: Screening of plant species and their suitability for use in biofilters or constructed wetlands for wastewater treatment

Christian Brandt[1], Nguyen Xuan Loc[4], Truong Thi Nga[4], Mathias Becker[1]
[1] INRES – Plant Nutrition, University of Bonn, Germany
[4] College of Environment and Natural Resources, Can Tho University, Vietnam

Key words: constructed wetland, biofilter, plant screening, recycling, waste water

Introduction

The positive influence of plants in constructed sand filter systems for wastewater treatment is well known. A dense plant stand provides the physical structure and thus promotes settling and supports the growth of biofilms. Root systems obstruct the water flow and provide substantial quantities of surface area for attachment of micro-organisms and deliver oxygen into the rhizosphere to enhance nitrification and C mineralization processes and reduce the pathogen load (worm eggs and fecal *E. coli*) of the waste water. Apart from such technical and environmental benefits, plant communities in biofilters may fulfill ecological functions (nesting sites for birds and dragon flies) and aesthetical values. Besides the function of plants in biofilters, there is an increased interest in plants and their capacity to absorb nutrients from the waste water that would otherwise contribute to the eutrophication of the environment. The capacity of plants to effectively absorb and thereby remove specific environmentally critical nutrients (mainly nitrate and P) from the wastewater will vary with plant species, plant age and the plants capacity to tolerate the elevated sodium levels generally encountered in wastewater.

A pot trial was conducted in 2006 and 2007 to study the growth response of a range of selected plant species under simulated biofilter conditions in order to select candidate species for the subsequent filter trials. Key criteria for selection were biomass accumulation, nutrient uptake dynamics and the ability to cope with high nutrient and salt loads (electric conductivity of 3 - 4 dS m^{-1}).

Material and Methods

The screening experiments were conducted under greenhouse conditions at the Department of Crop Sciences, College of Agriculture, Can Tho University, Vietnam. Plastic buckets (60x40x30 cm) were filled with sand and irrigated with different nutrient solutions, simulating different qualities of wastewater efflux from septic tanks. The pots were either run under aerobic (field capacity) or under anaerobic (permanently flooded) conditions, depending on the group of plant species to be evaluated.

Plant Material

Thirteen upland and 13 wetland species were selected and comparatively evaluated. The species comprised both, woody / herbaceous food and fodder or energy (biofuel) crops in addition to the standard biofilter reed (*Phragmites vallatoria*). For aerobic screening the following species were selected: *Eleocaris dulcis* (Cyperaceae), *Arachis hypogaea* (Fabaceae), *Glycine max* (Fabacea), *Sesbania sesban* (Fabacea), *Vigna radiata* (Fabacea), *Melaleuca leucadendra* (Myrtaceae), *Melaleuca cajuputi* (Myrtaceae), *Saccharum officinarum* (Poaceae), *Oryza sativa* (Var.1 - saline & acid tolerant) (Poaceae), *Oryza sativa* (Var.2 - saline tolerant) (Poaceae) (the two rice varieties are named as two different species in the context of the experiment), *Vetiveria zizanioides* (Poaceae), *Zea mays* (Poaceae) and *Phragmites vallatoria* (Poaceae). The plant material was gathered from various sites in the Mekong Delta, mainly at the CTU station of Hoa An and the CTU campus area.
For the anaerobic screening, nine emergent wetland species and four species adapted to anaerobic conditions were selected as follows:

- The emergent wetland species:
  Oenanthe javanica (Apiaceae), *Pistia stratiotes* (Araceae), *Enydra fluctuans* (Asteraceae), *Limnocharis flava* (Butomaceae), *Ipomoea aquatica* (Convolvulaceae), *Lemna aequinoctialis* (Lemnaceae), *Jussiaea repens* (Onagraceae), *Eichhornia crassipes* (Pontederiaceae) and *Salvinia cucullata* (Salviniaceae).
- To wetland conditions adapted upland species:
  Melaleuca leucadendron (Myrtaceae), *Melaleuca cajuputi* (Myrtaceae), *Oryza sativa* (Var.1 - saline & acid tolerant, Poaceae) and *Oryza sativa* (Var.2 - saline tolerant, Poaceae). Apart from *Oryza sativa*, which was obtained from the germplasm collection at CTU, the plants were gathered from wetlands in and around Hoa An.

Experimental set-up

The plants were seeded / planted into basins (60 x 40 x 30 cm) filled with a 5 cm layer of gravel and a 15 cm layer of sand. The sand and gravel was purchased from a local building material company, washed, and equally distributed to the basins. For the aerobic set-up, a drainage pipe was placed into the gravel layer. The soil aeration status in the basins was adjusted by a specially designed discharge pipe, to reflect both, 15 cm aerobic and a 15 cm anaerobic sand layer. For the anaerobic set-up, plants were grown under permanently flooded conditions with free water surface of 15 cm depth. In every basin 4 individuals of 3 plant species were used and replicated 4 times.

Nutrient solution

A modified Hoagland nutrient solution (Taiz and Zeiger 2000) was used for both trials. Calcium nitrate $Ca(NO_3)_2x4H_2O$ served as nitrogen source for the aerobic and ammonium sulphate $(NH_4)_2SO_4$ for the anaerobic setup. The concentrations of macro nutrients in the solution were NH_4^+ (10 mM), NO_3^- (10 mM), PO_4^{3-} (2 mM), K^+ (6 mM), Ca^{2+} (5 mM), Mg^{2+} (5 mM) and S^- (3 mM for the aerobic solution / 8 mM for the anaerobic solution). The initial EC for the anaerobic screening was adjusted to 3.3 dS m^{-1} at a pH of 6.67. The EC for the aerobic screening was 1.63 dS m^{-1} at a pH of 6.23. This solution was adjusted to the target EC of 3.5 by adding 1 M NaCl– solution. The added daily amount of nutrient solution was 5 liter per anaerobic and 3 litre per aerobic basin.

Sampling and analyses

Plants were sampled up to a plant age of 8 weeks at biweekly intervals. The biomass of 4 plants per harvest date (one from each replication bucket) was recorded after drying the plant material at 70 °C for 24 h. Ground subsamples of the dried biomass were analyzed for NPK contents, using standard methods at the Advanced Laboratory of Can Tho University.

Results

Of the 13 tested plants species, only seven survived the whole duration of the experiment. Two species survived for 6 weeks (*Sesbania sesban*, *Vigna radiata*), one for 4 weeks (*Eleocaris dulcis*) and one for 2 weeks (*Phragmites vallatoria*). *Melaleuca cajuputi* and *Glycine max* died within the first two weeks of the experiment. Plants thriving well under aerobic conditions were *Arachis hypogaea*, *Melaleuca leucadendron*, *Oryza sativa* (both cultivars), *Saccharum officinarum*, *Vetiveria zizanoides* and *Zea mays*.

Biomass and nutrient uptake of aerobically-grown plants

The largest total biomass accumulation after eight weeks was observed with *Saccharum officinarum* (235 g), followed by *Vetiveria zizanoides* (118 g) and *Zea mays* (112 g). The fastest growth rate was observed with *Oryza sativa* followed by *Arachis hypogaea*, *Saccharum officinarum*, *Zea mays*, *Melaleuca leucadendron*, and *Vetiveria zizanoides*. *Sesbania sesban* grew strongly between the 4th and 6th week but died of unknown reasons before the last sampling.

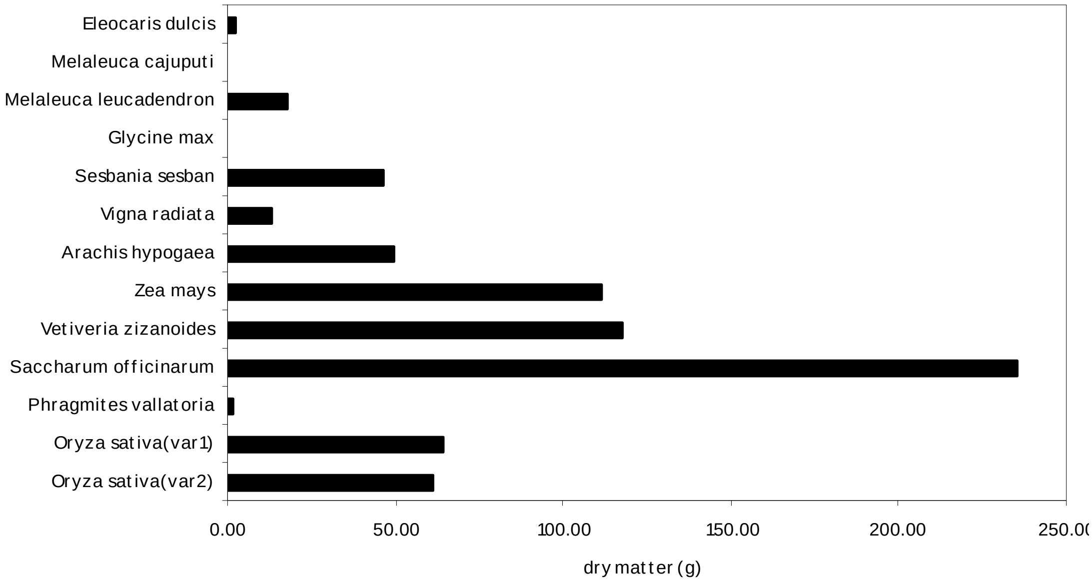

Figure 1: Total dry biomass of 8 week-old plants grown under aerobic conditions

The highest N contents were observed in *Sesbania sesban* (3.3 %) and *Arachis hypogaea* (3.0 %). Nitrogen contents of 2.8 - 2.9 % were determined in *Phragmites vallatoria*, *Vigna radiata* and *Zea mays* (Figure 2). N content tended to decline over time while total N accumulation continued to increase up to 8 weeks of growth, reaching between 1 - 1.5 g per plant in the seven species serving.

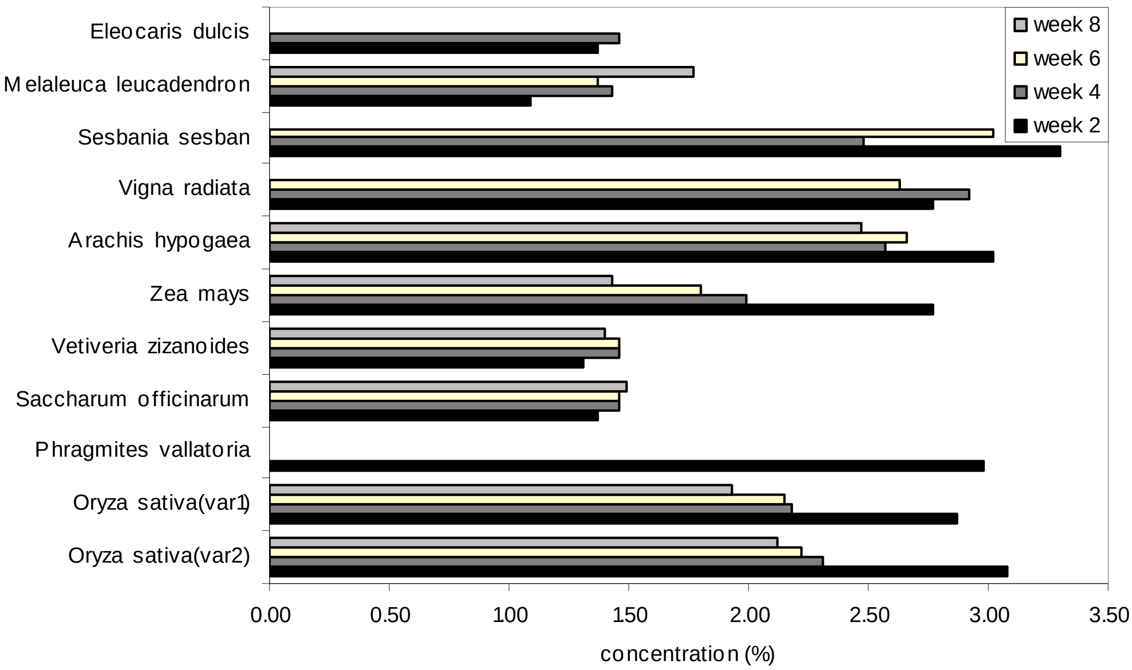

Figure 2: Nitrogen contents in the biomass of 2, 4, 6, and 8 week-old plants grown under aerobic conditions

The P content (Figure 3) was largest in legumes with over 0.4 % and least in grasses. The average P uptake in the biomass at 8 weeks was 0.4 - 0.7 g plant^{-1}.

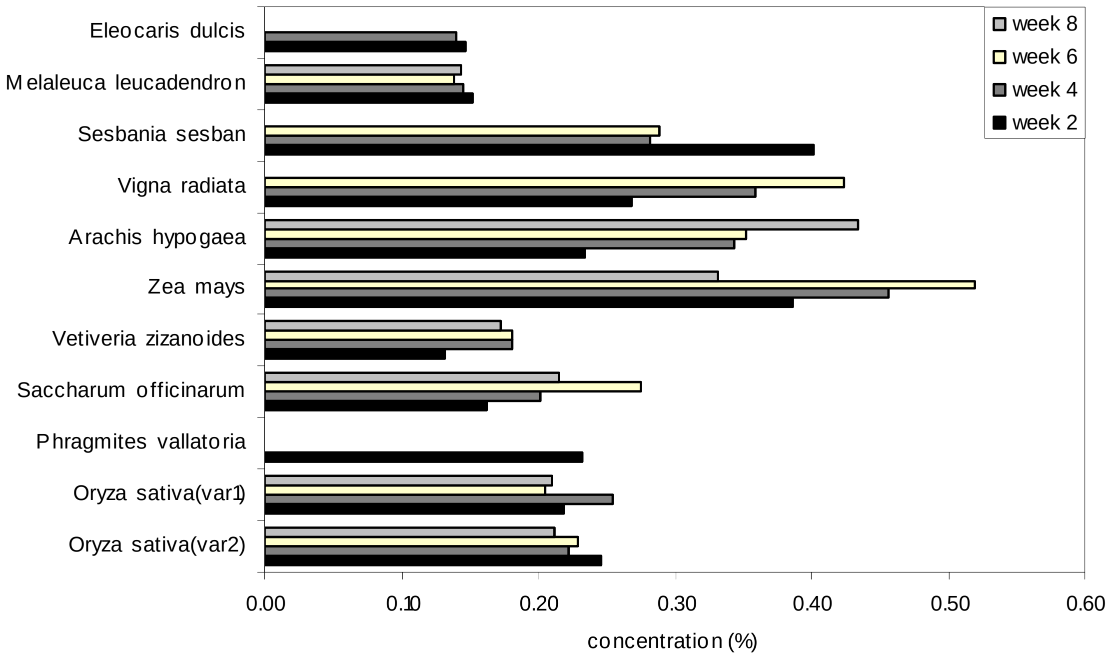

Figure 3: P content in the biomass of 2, 4, 6, and 8 week-old plants grown under aerobic conditions

The highest K concentrations were found in the C 4 grasses and in rice, which showed a K accumulation of >1 g plant^{-1} (data not shown).

Biomass and nutrient uptake of anaerobically-grown plants

Nine out of 13 wetland species reached the end of the trial. *Jussiaea repens*, *Limnocharis flava*, *Oenanthe javanica*, and *Enydra fluctuans* were not adapted to the conditions and died within the first 4 weeks. The largest biomass accumulation was determined in *Oryza sativa* and *Eichhornia crassipes* (Figure 4). The largest nutrient removal / uptake was observed in rice with 1.5 g N, 0.3 g P and 1.3 g K plant^{-1}.

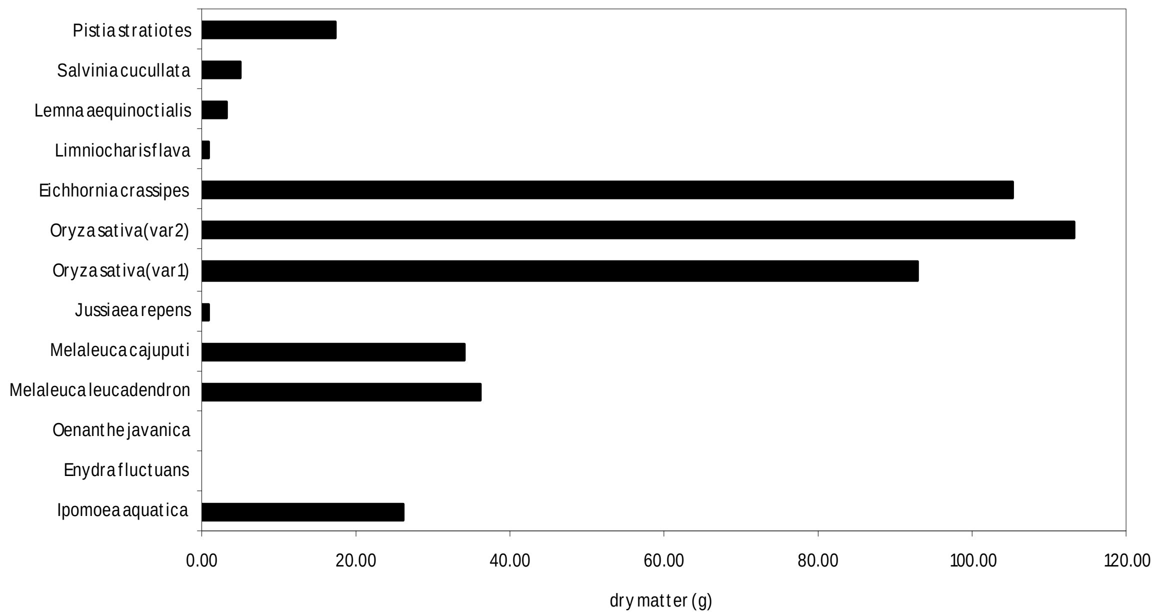

Figure 4: Total dry biomass of 8 week-old plants grown under anaerobic conditions

Conclusion

Under aerobic growth conditions, the largest biomass was accumulated by sugarcane, vetiver and maize, while the largest P and N accumulation was observed in rice and *Sesbania*. Under anaerobic conditions, rice and *Eichhornia* showed largest biomass but only rice was able to accumulate substantial amounts of nutrients. Consequently, species recommended for filter experiments may comprise rice (N accumulation), *Sesbania* (P accumulation), various C 4 grasses (N and K accumulation) and possibly *Phragmites* as the commonly used "standard reference". In addition, *Ricinus communis* has been recommended for constructed wetlands used for bio-fuel production in Brazil and should be included in future evaluations.

IV-3: Physico-chemical changes of wastewater properties in a constructed wetland

Christian Brandt[1], Nguyen Xuan Loc[4], Truong Thi Nga[4], Mathias Becker[1]
[1] INRES – Plant Nutrition, University of Bonn, Germany
[4] College of Environment and Natural Resources, Can Tho University, Vietnam

Key words: constructed wetland, waste water properties, COD, nutrients, *Phragmites* spp., *Pennisetum purpureum*, *Ricinus communis*, *Zea mays*, and *Papyrus* spp.

Introduction

Demographic growth is causing a rapidly increasing pressure on the available water resource and requires new approaches for water resource exploitation and for wastewater treatment. Nearly one billion people have no access to save water for drinking or household activities (Botkin & Keller 2000). A large share of the "unsafe" water has been contaminated by feces and other waste products. This is particularly true for the Mekong Delta, where a majority of the population depends on surface water for a wide range of uses. Releasing untreated wastewater directly to the environment is already affecting the ecosystem and the water quality in the Mekong Delta. Solutions of wastewater treatment are urgently required for environmental protection, planning and a sustainable economic development including tourism.

Biological water purification in constructed wetlands or planted biofilters is a particularly promising option as it is low-cost and has compared to technical water purification approaches the additional potential of removing nutrient elements from the wastewater. Such nutrient loads cause the eutrophication of the environment but can alternatively be absorbed by growing plants for the production of diverse plant-based products. In addition, once established, such planted biofilters are of low cost for operating and maintenance. This type of filter seems particularly appropriate for the Mekong Delta, where a wide range of aquatic plants or emerging, submerged plants are naturally available and where the climatic conditions favor a rapid crop growth and an efficient nutrient removal from wastewater by plants.

To date, little is known about the type of plants that may be used in constructed wetlands or the possible uses of by-products derived from the nutrient-enriched biomass such as handcraft, fertiliser etc.. An experiment has been conducted in view of assessing various plant species concerning their efficiency for nutrient removal their effect on various wastewater parameters in a constructed wetland.

The research was carried out to assess the evolution in space and time of chemical parameters of wastewater during the growing period of a range of tropical plants in a model soil filter systems constructed on the campus at Can Tho University. Changes in selected chemical characteristics of wastewater between the inflow and the outflow of a filter system were comparatively studied during the 3-months growing period of *Phragmites* spp., *Pennisetum purpureum*, *Ricinus communis*, *Zea mays*, and *Papyrus* spp. Dynamic changes in pollutants and pollutant removal in a vertical filter column and in chemical characteristics of the water and the nutrient uptake dynamics of the plants in a horizontal filter were evaluated for further application.

Material and methods

The experiment was conducted from June 1st 2007 to May 31st 2008 at the dormitory of campus II, Can Tho University. Six treatments including five plant species (*Phragmites* spp., *Pennisetum purpureum*, *Ricinus communis*, *Zea mays*, and *Papyrus* spp.) and an unplanted control were arranged in a randomised design using three replications. The plants were grown in single rows at a distance of 15 cm.

At campus II wastewater from the student dormitory (200 persons) was collected in 5 septic tanks. The wastewater was pumped from the outlet of the septic tanks into plastic tanks with 2,000 l volume (182 cm height x 138 cm diameter) and from there it was flushed onto the vertical soil filter system. The vertical filter system consists of 14 plastic tanks with a volume 1000 l each (144.5 cm height x 102 cm diameter). Each tank was filled from the bottom to the top with 15 cm gravel, 60 cm of sand and 10 cm of gravel. The raw wastewater from the septic tanks was loaded into each vertical filter at a rate of 100 mm day^{-1}. The outflow from the vertical system was collected in a 2,000 l tank to supply a horizontal plant filter system. The vertical system had an outflow of 1,100 l day^{-1}. The pre-filtered wastewater was gravity-fed into eighteen 45 l barrels, each placed in front of the horizontal filter lines.

The horizontal system consists of 18 concrete bed rows of 10 m length and with a 5 % slope, each 0.3 m wide and 0.4 m deep. Each row was filled with quartz sand and fed with 45 l of pre-filtered wastewater per day. The outflow was connected to the valve to control the quantity of wastewater leaving the system and to collect water samples. Plants were grown each in a separate row, with 73 plants row^{-1}. *Ricinus communis* and *Zea mays* were planted as 30 day - old seedlings. Young shoots of *Phragmites* spp., *Pennisetum purpureum* and *Papyrus* spp. were transplated at a height of 30 cm. At an estimated evapo-transpiration of 5 – 8 mm day^{-1} (5 – 8 l m^{-2} day^{-1}, FAO), the hydraulic loading rate (HRL) for each row was 45 l day^{-1}. The systems were saturated with tap water during the first 14 days after transplantation.

The water at the inlet and the outlet was monitored at three dates during the 3 - month experimental period for the parameters pH, EC, DO, COD, TN, and TP. Raw wastewater, wastewater after the vertical column and wastewater at the outlet of the horizontal filter system were collected 2 weeks after the start of the experiment (initial sample) and 1 and 2 months thereafter (16-18/01/2008 and 13-15/02/2008).

The efficiency of crop nutrient removal was calculated as percentage remove in comparison the rate at the outlet to the inlet. The plant dry weight was recorded from three plants at transplantation time and after 3 months of growth and analysed for N and P contents. Data were analysed by Independent T-Test and one-Way ANOVA using SPSS software version 13.0.

Results and discussion

Changes in raw waste water parameters

The characteristics of raw wastewater varied little during the first 4 weeks. Thus, the pH was about 7, while EC, COD, TN and TP were 1.2 – 1.4 dS m^{-1}, 129.8 – 188 mg l^{-1}, 106.6 - 149.5 mg l^{-1} and 11.6 - 20.9 mg l^{-1} respectively. DO was very low at 0.3 - 0.43 mg l^{-1}. EC, TN and TP changed significantly during the observation period, reaching 20 - 50 % of the initial values at 8 weeks.

Table 1: Dynamic change and the chemical characteristics of raw wastewater during the experimental period

Parameter	After 1 week	After 2 weeks	After 4 weeks	After 8 weeks (*)
pH	7.2	7.2	7.4	7.0
EC (dS m^{-1})	1.2	1.4	1.2	0.8
DO (mg l^{-1})	0.3	0.3	0.3	0.4
COD (mg l^{-1})	188	129	182	143
TN (mg l^{-1})	115	149	107	59
TP (mg l^{-1})	12	15	21	3

(*) no input for the septic tanks in 14 days due to the return home of all students for their New year holidays. EC: electrical conductivity; DO: dissolved oxygen; TN: total nitrogen (Kjeldahl); TP: total phosphorus.

This phenomenon can be explained due to the change of the wastewater amount, as students went home for holidays during this time.

Characteristics of wastewater after the vertical filter column

The aim of this system was a pre-treatment of wastewater, primarily to mineralize carbon substrates and to oxidize ammonium. To study the percentage remove of this step, outlet samples from the vertical column were collected. The results are shown in Tables 2 and 3. The pH was maintained at ~6.5 and the EC was about 1 dS m^{-1}. However, passage through the vertical filter significantly reduced COD (67 - 113 mg l^{-1}), TN (25 - 47 mg l^{-1}) and TP (0.5 - 2.4 mg l^{-1}), while DO increased to 1 - 3 mg l^{-1}. According to Hue (2006) physical effects can be responsible to decrease COD.

Table 2: Composition of the wastewater after passage through the vertical filter column

Parameter	After 1 week	After 2 weeks	After 4 weeks	After 8 weeks
pH	6.8	6.8	6.9	6.4
EC (dS m^{-1})	1.1	1.0	1.0	0.7
DO (mg l^{-1})	1.0	3.2	1.2	4.17
COD (mg l^{-1})	113.3	67.4	107.8	76.3
TN (mg l^{-1})	32.6	24.9	47.0	16.7
TP (mg l^{-1})	0.8	0.5	2.4	1.6

Table 3: Efficiency of pollutant removal by the vertical filter column

Parameter	After 1 week	After 2 weeks	After 4 weeks	After 8 weeks (*)
EC (%)	8.0	31.2	15.	12.7
COD (%)	39.7	48.1	40.7	46.6
TN (%)	71.7	83.3	55.9	71.8
TP (%)	93.3	96.4	88.7	59.7

(*) no input for the septic tanks during 14 days before

The efficiency of P removal was higher compared to COD and TN during the first 4 weeks with approximately 90 % and around 60 % after 8 weeks. The efficiency to reduce TN was high (> 60 %). There was little change in EC (< 15 %) except after 2 weeks. According to Eddy (1997) the solid pollutants are kept in the spores or on the surface of the filter material. The vertical column had an effect on COD, TN and TP removal. The physical effect of sand keeps the organic matter in the column. Besides, the decomposition of organic matter by micro-organisms caused a decrease in nutrients at the outlet of the vertical column. EPA (832-F-99-007, 1999) stated that the typical pollutant removal efficiency is 33 %, 21 % for TP, TN, respectively in a vertical column.

Table 4: Efficiency of DO increasing of vertical column

Parameter	After 1 week	After 2 weeks	After 4 weeks	After 8 weeks (*)
DO (times)	3.3	10.7	4.1	9.6

(*) no input for the septic tanks during 14 days before

The dissolved oxygen in raw wastewater increased by a factor of up to 10 after passing through the vertical columns (Table 4). Thus, beside the physical filter effect, the wastewater was able to interact with oxygen.

Properties of the wastewater after passage through the horizontal filter

Table 5: Composition of pollutants after horizontal system (unplanted treatment)

Parameter	After 1 week	After 2 weeks	After 4 weeks	After 8 weeks (*)	TCVN 5942-1995 (a)
pH	7.4	8.0	7.6	7.0	6 - 8.5
EC (dSm^{-1})	0.9	0.9	1.0	0.8	-
DO (mg l^{-1})	5.9	6.2	5.6	5.7	2
COD (mg l^{-1})	20.4	10.5	23.0	11.4	< 35
TP (mg l^{-1})	0.0	0.0	0.1	0.2	-

(*) no input for the septic tanks during 14 days before
(a) Vietnamese standard for surface water for other purposes.

The EC after the vertical columns was rather stable during the first 4 weeks (0.9-1.0 dS m^{-1}). This can be explained by the balanced exchange of ions in wastewater and on the sand surface (Eddy 1997). The EC was 0.8 dS m^{-1} after 8 weeks as fever pollutants were added during the 14 days of Tet holiday. COD (10 - 23 mg l^{-1}), DO (5.6 - 6.2 mg l^{-1}) and pH (7 - 8) met the Vietnamese standard for surface water.

Table 6: Efficiency of pollutants removal of horizontal system (unplanted treatment) from the wastewater after vertical column

Parameter	After 1 week	After 2 weeks	After 4 weeks	After 8 weeks (*)
EC (%)	16.5	3.3	0.1	0
COD (%)	82.0	84.4	78.7	85.1
TP (%)	97.4	96.9	96.4	81.0

N.EX: None examination.

(*) no input for the septic tanks during 14 days before

The horizontal system had an effect on pollutants removal of wastewater from the outlet of vertical column on. Data in Table 6 show that efficiency of TP removal within the horizontal system was very high (> 90 %) except for the period after 8 weeks (81 %). The COD depletion was very high (approximately 80 %). The EC was stable after a 2 week operation with wastewater. This means that the pollutants in the sub-flow horizontal system were removed by the filter effect of sand when they passed through (Nhan and Nga 2002). Micro-organisms, attached to the surface of sand particles as biofilm, used the pollutants in wastewater to survive.

The dissolved oxygen in wastewater at the outlet of the horizontal system increased by 2 - 6 times compared to the inlet (Table 7). The oxygen moved downward from the surface to the flows at the bottom and dissolved to them, and caused an increase in dissolved oxygen at the outlet.

Table 7: Efficiency of DO increasing of horizontal system (unplanted treatment) from the wastewater after vertical column

Parameter	After 1 week	After 2 weeks	After 4 weeks	After 8 weeks (*)
DO (times)	5.9	1.9	4.6	1.4

(*) no input for the septic tanks during 14 days before

The water quality in the planted horizontal system outlet (*Pennisetum purpurem*, *Zay mays*, *Pharagmites* spp., *Ricinus communis*, *Papyrus* spp.) was significantly different with the wastewater after vertical columns (used as inlet for the horizontal unit). Most of the observed parameters - pH, DO, COD, NH_4^+, NO_3^- and TP - were significantly different in the wastewater after the vertical columns except for EC. The stable EC can be explained by the balanced exchange of ions in wastewater and on the surface of sand (Eddy 1997). pH increased from 6.9 to > 7.4 in the 4th week sampling period (P1), and from 6.4 to > 7.1 for the 8th week sampling period (P2). The wastewater quality at the inlet of the horizontal system changed when passing the planted horizontal system. DO increased from 1.5 to > 5.6 mg l^{-1} at P1 and 4.2 to > 5.9 mg l^{-1} at P2 and COD decreased from 117 to < 26 mg l^{-1} at P1, and from 76 to < 16 mg l^{-1} at P2. The increase of DO caused an increase of NO_3^- at the outlet (1.8 mg l^{-1} compared to the inlet with 1 mg l^{-1}) and a decrease of NH_4^+ at the inlet (35.3 mg l^{-1} compared to the outlet with < 0.3 mg l^{-1}). The TP also decreased to a low level at the inlet (2.4 mg l^{-1} at P1 and 1.3 mg l^{-1} at P2) and outlet (< 0.1 mg l^{-1} at P1 and

< 0.3 mg l^{-1} at P2). As mentioned most of the pollutants in sub - flow horizontal systems are removed by sand filter effects.

The results in Table 9 show that the water parameters at the outlet of the planted horizontal system were not different from the control (unplanted treatment) except for TP (very low <0.1 mg l^{-1}) and NH_4^+ (low < 0.2 mg l^{-1}) at P1.

Pennisetum purpurem, *Zea mays*, *Pharagmites* spp., *Ricinus communis* and *Papyrus spp.* were not clear in nutrient uptake. On the other hand there were only few nutrients left for 5 plant species.

The data in Table 10 shows that the efficiency to remove pollutants by *Pennisetum purpurem*, *Zea mays*, *Phragmites spp.*, *Ricinus communis* and *Papyrus spp.* was not significantly different from the control (unplanted treatment). The COD removal was 78.6 % at P1 and 85.2 % at P2 in the unplanted treatment and 81 – 84.2 % at P1 and 77.5 % – 92.6 % at P2 in the planted treatment. The TP removal was 78 - 96 % in the unplanted treatment and 70.9 - 97.8 % in planted treatments. However, there was no significant difference in COD and TP removal between unplanted and planted treatment steps. An increase of DO (Table 10) was also not significantly different at P1 and P2 in both treatments.

Conclusion

- The passage of wastewater through the horizontal filter increased DO, while COD, TN and TP were significantly decreased.
- A reduction of COD, TN and TP, reaching the level of the Vietnamese Standard for surface water, was realised with the horizontal filter system
- No significant differences in nutrient removal from wastewater were observed between the different tested palt species.
- Future studies need to evaluate larger nutrient loading rates in the wastewater

Literature

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Table 8: Characteristics of wastewater after passage through the planted filter

Parameter		w.w. after vertical column (**a**)	Planted treatments *Zea mays*	*Papyrus spp.*	*Ricinus communis*	*Phragmites spp.*	*Pennisetum purpureum*
pH	P1	6.86	7.58 ns	7.41 *	7.23 ns	7.36 ns	7.45 *
	P2	6.42	7.11 *	7.23 *	7.01 *	7.10 *	7.61 *
EC (dS m^{-1})	P1	1.0	1.0 ns	1.1 *	1.1 *	1.1 ns	1.0 ns
	P2	0.7	0.8 *	1.0 *	0.9 *	0.9 *	1.0 *
DO (mg l^{-1})	P1	1.23	5.88 *	5.76 *	5.68 *	5.62 *	5.74 *
	P2	4.17	6.02 *	6.31 *	5.94 *	5.80 *	6.49 *
COD (mg l^{-1})	P1	107.79	17.14 *	20.10 *	21.26 *	20.38 *	18.41 *
	P2	76.34	5.91 *	8.19 *	15.03 *	10.47 *	16.95 *
$N\_NO_3^-$ (mg l^{-1})	P1	1.04	2.9 *	3.37 *	6.62 *	3.19 *	1.83 *
	P2	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
$N\text{-}NH_4^+$ (mg l^{-1})	P1	35.29	0.24 *	0.22 *	0.26 *	0.17 *	0.14 *
	P2	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
TP (mg l^{-1})	P1	2.36	0.07 *	0.06 *	0.10 *	0.07 *	0.06 *
	P2	1.25	0.21 *	0.15 *	0.31 *	0.14 *	0.19 *

*(**a**): inlet of horizontal system.*

*ns: non- significantly different, (*) significantly with (**a**) at p<0.05 of horizontal system from wastewater after vertical column*

N.D. non- detected

P1: Sampling at 4 weeks operating with wastewater (16-18/01/2008)

P2: Sampling at 8 weeks operating with wastewater(14)

Table 9: Pollutants removal of horizontal system

Parameter		Unplanted treatment	Planted treatments				
			Zea mays	*Papyrus spp.*	*Ricinus communis*	*Phragmites spp.*	*Pennisetum purpureum*
pH	P1	7.55	7.58 ns	7.41 ns	7.23 ns	7.36 ns	7.45 ns
	P2	6.99	7.11 ns	7.23 ns	7.01 ns	7.10 ns	7.61 *
EC (dS m^{-1})	P1	1.0	1.0 ns	1.1 ns	1.1 *	1.1 ns	1.0 ns
	P2	0.8	0.8 ns	1.0 *	0.9 ns	0.9 ns	1.0 ns
DO (mg l^{-1})	P1	5.62	5.88 ns	5.76 ns	5.68 ns	5.62 ns	5.74 ns
	P2	5.73	6.02 ns	6.31 *	5.94 ns	5.80 ns	6.49 *
COD	P1	23.00	17.14 ns	20.10 ns	21.26 ns	20.38 ns	18.41 ns
(mg l^{-1})	P2	11.39	5.91 ns	8.19 ns	15.03 ns	10.47 ns	16.95 ns
N_NO_3^-	P1	2.39	2.9 ns	3.37 ns	6.62 *	3.19 ns	1.83 ns
(mg l^{-1})	P2	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
N-NH_4^+	P1	1.00	0.24 *	0.22 *	0.26 *	0.17 *	0.14 *
(mg l^{-1})	P2	N.D.	N.	N.D.	N.D.	N.D.	N.D.
TP (mg l^{-1})	P1	0.08	0.07 *	0.06 *	0.10 *	0.07 *	0.06 *
	P2	0.23	0.21 ns	0.15 ns	0.31 ns	0.14 ns	0.19 ns

ns: non- significantly different, (*) significantly different at p<0.05 of planted treatments from unplanted treatment

N.D. non- detected

P1: Sampling at 4 weeks operating with wastewater

P2: Sampling at 8 weeks operating with wastewater

Table 10: Efficiency of pollutants removal of horizontal system

Parameter		Unplanted treatment	Planted treatments *Zea mays*	*Papyrus spp.*	*Ricinus communis*	*Phragmites spp.*	*Pennisetum purpureum*
EC (%)	P1	0.09	0 ns	0 *	0 *	0 ns	0 ns
	P2	0	0.37 ns	0 ns	0 ns	0 ns	0 ns
DO (mg l^{-1})	P1	4.56	4.77 ns	4.67 ns	4.60 ns	4.57 ns	4.66 *
	P2	1.38	1.45 ns	1.52 ns	1.43 ns	1.40 ns	1.55 ns
COD (%)	P1	78.63	84.23 ns	81.29 ns	80.19 ns	81.00 ns	82.84 ns
	P2	85.16	92.57 ns	89.41 ns	80.64 ns	86.70 ns	77.45 ns
TP (%)	P1	96.30	97.28 ns	97.17 ns	96.39 ns	97.50 ns	97.71 ns
	P2	78.36	81.47 ns	86.59 ns	70.88 ns	88.62 ns	82.86 ns
N-NH_4^+ (%)	P1	97.07	99.32 *	99.35 *	99.26 ns	99.52 *	99.86 *
	P2	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.

ns: non- significantly different, (*) significantly different at p<0.05 of planted treatments from unplanted treatment

N.D. non- detetection

Table 11: Efficiency of DO increasing

Parameter		Unplanted treatment	Planted treatments *Zea mays*	*Papyrus spp.*	*Ricinus communis*	*Phragmites spp.*	*Pennisetum purpureum*
DO (mg l^{-1})	P1	4.56	4.77 ns	4.67 ns	4.60 ns	4.57 ns	4.66 *
	P2	1.38	1.45 ns	1.52 ns	1.43 ns	1.40 ns	1.55 ns

ns: non- significantly different, (*) significantly different at p<0.05 of planted treatments with unplanted treatment

IV-4: The role of plant species for wastewater treatment in constructed wetlands in the Mekong Delta

Katrin Hans[1], Jenny Zywietz[1], Mathias Becker[1]
[1] INRES - Plant Nutrition, University of Bonn, Germany
k.hans@uni-bonn.de, jzywietz@uni-bonn.de

Keywords: biofilters, nutrient depletion, wastewater, *Sesbania rostrata*, *Phragmites ssp.*, soil filter

Introduction

Demographic growth is causing an increasing pressure on the fresh water resources in the Mekong Delta. Surface water is the main water source for washing, bathing, cooking and drinking for large parts of the rural population. The uncontrolled release of domestic wastewater into open drains and rivers leads to environmental pollution, water contamination with pathogens and the eutrophication of water bodies (Rechenburg and Herbst 2006). Large wastewater treatment plants are rare and limited to urban and industrial centres (Clemens and Minh 2005). Decentralized small - scale facilities are more appropriate for the rural areas but are usually not affordable by the population.

A low-cost alternative to large - scale technical plants are constructed wetlands. These are man-made complex systems involving water, soil, plants, microorganisms and the environment (Vymazal *et al.* 1998). They use the unique properties of natural wetland ecosystems, which are characterised by a high biological activity and productivity (Kadlec and Wallace 2008) and the ability to transform environmental pollutants into harmless byproducts or essential nutrients. At the same time, these wetlands may serve as natural wildlife habitats.

Constructed wetlands have been used for many decades worldwide and various types have been designed for the treatment of mainly municipal and domestic wastewater. A horizontal subsurface flow (HSSF) wetland is usually a shallow basin filled with soil, sand or gravel. Mechanically pre-filtered wastewater is introduced into the basin and flows horizontally from the inlet to the outlet. The basin may be planted with vegetation tolerant to saturated conditions (flood tolerance) and to a high electrical conductivity of the solution (moderate salinity tolerance). Typically, constructed wetlands are planted with reed grasses (*Phragmites* and *Typha spp.*, Cooper *et al.* 1996). The aerenchyma of these plants provides a good areation of the root zone and the oxygen supply required for the mineralization of organic solutes. At the same time, a dense root system increases the retention time of the water in the filter by slowing down the flow velocity and by providing a medium for microorganisms, forming biofilms in the rhizosphere. In the process, water is depleted of soluble carbon compounds (von Sperling *et al.* 2005). A reduction in the load of plant available nutrients (mainly N and P) is usually minimal as the uptake rates by reed grass are low. A sorption of soluble P onto the mineral filter material does no longer occur once the filter has reached its steady state. A reduction in the concentration of ammonium is mainly due to its oxidation into nitrate rather than a true N elimination (Pell 1991). Thus, the "traditional" constructed wetlands may provide good wastewater sanitation but only a marginal removal of environmentally active nutrient elements.

The tropical climatic conditions of the Mekong Delta provide the opportunity to use fast-growing plant species, other than *Phragmites*, with higher nutrient demand and larger uptake rates for N and P. Additionally, the nutrients removed from the wastewater can be used directly for the production of food, fodder and fuel crops, or indirectly as biofertilisers or compost material for high-value crops. Consequently, such constructed wetlands not only contribute to environmental protection, but also provide agricultural goods and nutrient-rich organic substrates. The effectiveness of such a planted biofilter to remove nutrients is likely to depend on the wastewater-loading rate, the plant species and the filter dimensions. Consequently, we comparatively assessed different plant species at different wastewater loading rates for nutrient uptake dynamics in time (during plant growth) and in space (along the filter system) and for changes in physico-chemical properties of the wastewater. These data will be used to determine the filter dimension required to meet different water quality standards (the Vietnamese TCVN 5942 norm and the EU swimming water standard).

Materials and Methods

A concrete-bed model system of a HSSF wetland with a 5° inclination has been established in 2007 on Campus II of Can Tho University. It is composed of 24 rows of 10 m length and 0.3 m width and a depth of 0.45 m. The filter substrate (sand from the Mekong river) from a previous experiment was removed, mixed and filled again into the filter beds. Eight brick walls were installed in each line to reduce the flow velocity of the water and each filter row was divided into four sections of 2 m length.

Figure 1: Partial view of the planted soil filter system on the campus of

Can Tho University

Three wetland rows each were either planted to two week-old seedlings of *Oryza sativa* (food crop), *Sesbania rostrata* (biofertiliser), or *Phragmites ssp.* (standard reference species) or left unplanted (control treatment). After an adaptation period of 7 days, during which all plants were irrigated with tap water, wastewater was pumped into the wetland at daily loading rates of 40 l (17 l m^{-2} d^{-1}) and 20 l per row (8.5 l m^{-2} d^{-1}) for an experimental duration of 56 days.

Water samples were taken weekly for the determination of pH, EC and temperature (HANNA Multi-metre, Germany). The concentrations of ammonium, nitrate and phosphate in the water of the filter rows were determined photometrically (Merck Spectroquant Photometer) at biweekly intervals. Additionally, the inlet water was monitored daily for nitrate and ortho-phosphate concentrations using Quantofix test strips (Merck) to determine the exact nutrient loading of each row. The COD was measured after six weeks at the in- and outlet by photometrical method.
Aboveground plant biomass samples were taken after 2, 4, 6 and 8 weeks, using composite samples of three plants from each 2 - m section in every row. The plants were oven-dried, weighed and stored for chemical analysis. The total N, P and K contents (micro-Kjeldalhl, Spectrophotometer, and Flame photometer, respectively) as well as the 14 / 15 - N isotope ratio of the nitrogen-fixing *S. rostrata* (Mass spetcrometer) are being determined at the laboratory of INRES - Plant Nutrition at Bonn University.

Results and Discussion

As data are still being processed only preliminary findings are presented here.

Wastewater

As a standard parameter in wastewater treatment, the COD was measured to determine the removal of organic residues within the horizontal wetland. The COD of the black water (before it was induced into a vertical soil filter) was 186 mg l^{-1} and was reduced to 45 mg l^{-1} by the passage through a vertical soil filter.
The COD in the wastewater applied to the horizontal filter rows varied from 45 mg l^{-1} in the full treatment to about 20 mg l^{-1} with the reduced wastewater-loading rate (Figure 2). The COD at the outlet of the horizontal filter ranged from 17 mg l^{-1} (full nutrient load) to about 14 mg l^{-1} (half nutrient load). In some planted wetland rows, the COD decreased to < 10 mg l^{-1}, a value usually found in tap water. Thus, most of the organic material was filtered out or mineralised in the filter system.

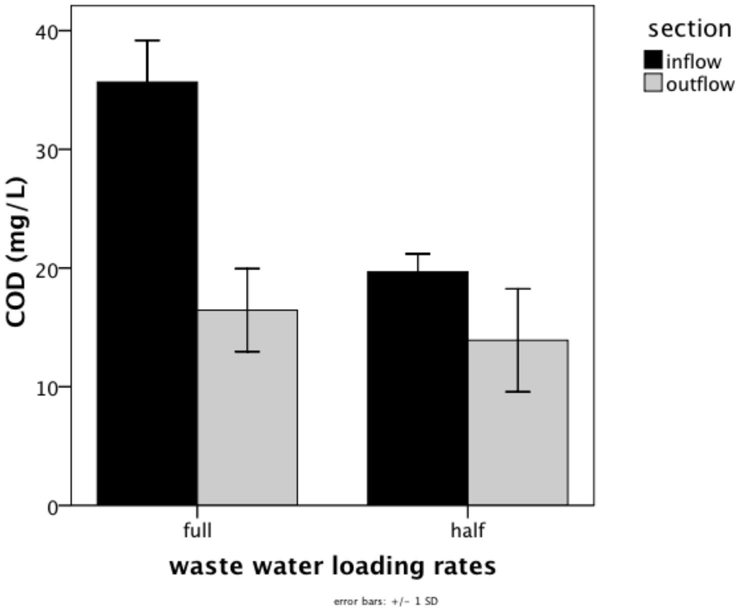

Figure 2: COD depletion between the inflow to outflow in the horizontal filter system as differenciated by the filter loading rate (mean values of of planted and unplanted rows at three replications each).

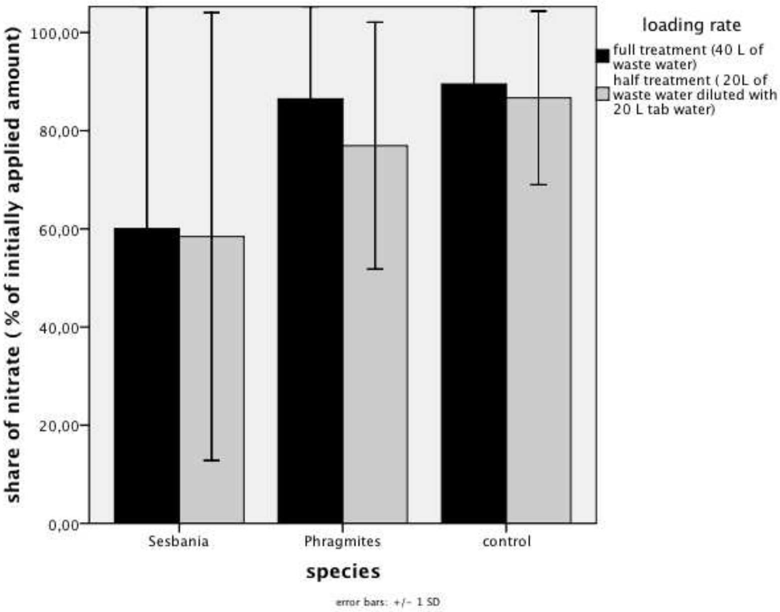

Figure 3: Percentage of nitrate depletion between in- and outflow in the horizontal filter system as differenciated by filter vegetation and wastewater loading rate. Right graph: full load, left graph_half load. Bars present standard errors of the mean (n = 3).

Figure 3 shows that the nitrate concentration in the soil solution decreased during the water's passage through the filter, irrespective of the type of vegetation. Even in the unplanted control, nitrate concentration decreased from the inflow to the outflow by 9 - 110 mg l^{-1}, in the treatment with full nutrient load, and by 6 - 46 mg l^{-1} in the rows treated with half nutrient load. The depletion of nitrate differed between plant species and plant ages.

While the concentration in the filter rows palted to *Sesbania* decreased by 93 % in the full treatment and 87 % in the half treatment, the decline in *Phragmites* variants was only 32 % in the full treatment and 46 % in the half treatment. The control showed the lowest depletion of 23 % in full treatments and depletion in half waste water load with 26 %. Differences in nitrate concentrations in the inflow water may be explained on the one hand by varying numbers of students living in the dormitory, and on the other hand by the rainfall events, contributing to a dilution of the nutrient concentrations.

Plant biomass

The total biomass accumulation differed by plant species and responded to the wastewater-loading rate. Net primary production (NPP - Kadlec and Wallace 2008) of *S. rostrata* reached an average of 3 kg m^{-2}, while *Phragmites ssp.* accumulated only 0.3 kg m^{-2} over the 56 - day growing period (Figure 4).

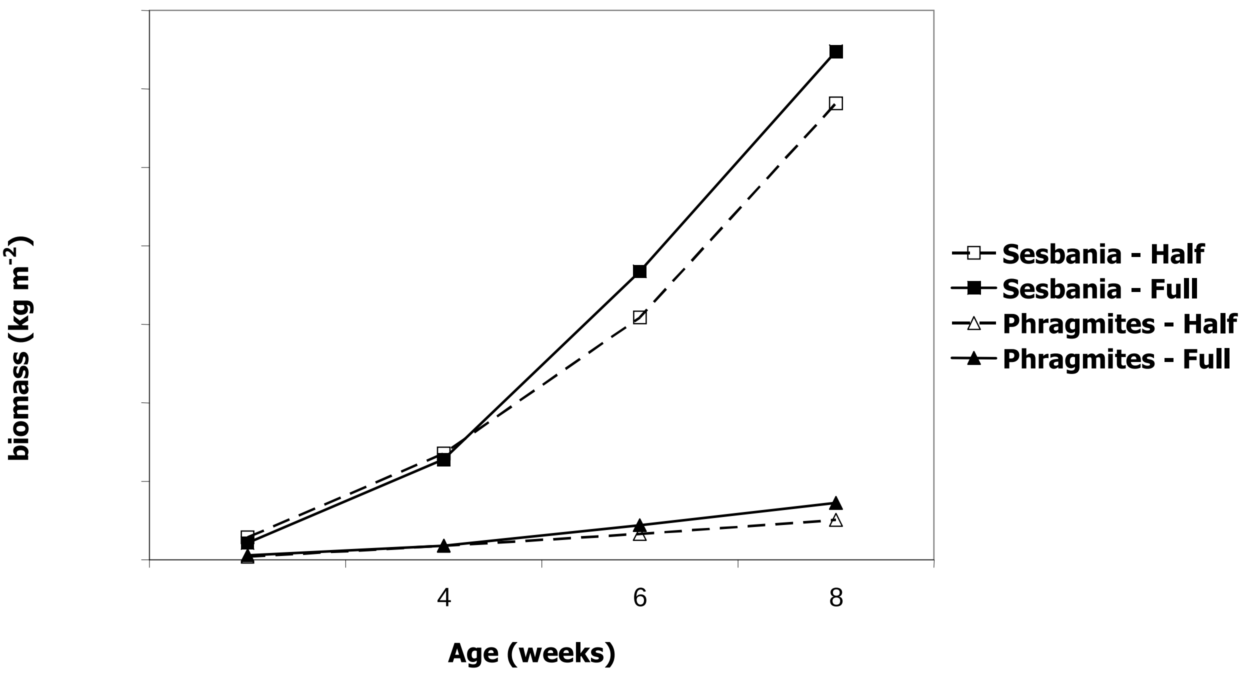

Figure 4: Dynamics of dry biomass accumulation by *Phragmites* and *Sesbania* at two wastewater-loading rates (Half = 8.5 l m^{-2}, Full = 17 l m^{-2}).

Nearly all rice seedlings, except for some individual plants in the lower division of the filter, started to die off after a few days and were completely dead after three weeks, irrespective of the wastewater loading rate. One possible reason for the early death of rice was the young age of the transplants and the fact that the filter substrate was not saturated and the water level could not be reached by the young roots at the early stages of the experiment.

Phragmites showed a weak biomass accumulation in comparison to *S. rostrata*. In typical constructed wetlands, reed grass is grown as a permanent culture so that the plants are able to develop a large root system. In this trial, the growing period was limited to two months and the stem cuttings of *Phragmites* varied in development stage when transplanted. Consequently, the biomass of the individual reed grass plants was highly variable. In contrast, the fast-growing *S. rostrata* performed uniformly. The prevailing growing conditions were obviously more suitable for the legume than for the typical wetland reed grass species.

Conclusion

From the presented preliminary data it may be concluded that planted wetlands can substantially contribute to the cleaning of wastewater. The extent of the cleaning effect depends on loading rates, plant species and plant age. The dynamics of plant nutrient uptake and of solution nutrient depletion will be used to develop a simple model for predicting required filter dimensions for maximal nutrient removal.

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IV-5: Microbiological Aspects of Decentralised Wastewater Reuse

Andrea Rechenburg[2], Susanne Herbst[2], Nguyen Thi Thu Van[4], Vo Thi Yen Phi[4], Julia Nuber[1], Susanne Wohlsager[1], Ute Arnold[1] and Thomas Kistemann[2]
[1] INRES – Plant Nutrition, University of Bonn, Germany
[2] Institute for Hygiene and Public Health, University of Bonn, Germany, andrea.rechenburg@ukb.uni-bonn.de
[4] College of Environment and Natural Resources, University of Can Tho, Vietnam

Keywords: hygiene, pathogen reduction, biogas plant, urine, helminth eggs

Introduction

Progress in access to drinking water as well as to improved sanitation is essential to reduce faecal - orally transmitted diseases. The Millennium Development Goal (MDG) No. 7, Target 10 aims to halve the number of people living without adequate drinking water and sanitation by 2015. In Vietnam, the sanitation coverage increased by 25 % between 1990 and 2004 (United Nations 2006). Nowadays, nationwide programmes to reach the MDG's targets are well established and promote the construction of improved sanitation solutions such as compost toilets, septic tanks and connection to sewerage systems (Socialist Republic of Vietnam 2000). Nevertheless, due to rapid economic development, urbanisation and population growth, there is a massive increase in the need for sanitary infrastructure. In the rural areas of the Mekong Delta an estimated 10 million people live without adequate sanitation (Vietnamese Academy of Social Sciences 2007). Within the integrated Vietnamese farming system (VAC model), untreated excreta from animals and humans (night soil) is utilised. The VAC model practises nutrient recycling by the application of raw excreta as fertiliser in agriculture or as fodder in aquaculture (Anh Tuan 2003). This leads to heavy contamination of the environment with faecal-oral pathogens and parasite eggs occurring in surface water, soils, vegetables and fish (WHO 2006). Furthermore, surface water - being widely used for drinking water purposes - is also contaminated.
As the need for hygienically safe nutrient recycling strategies is evident and the recycling of nutrients in human and animal excreta is traditionally practised, a good starting point for the implementation of sustainable sanitation solutions exists. Hence, biogas plants have been added-on to the VAC model. The benefits of biogas plants are twofold: 1. the production of gas which can be used for cooking and 2. the treatment of faecal matter. So far only animal excreta is being treated in biogas plants, but the treatment of human excreta would also be possible if the pathogen reduction efficacy under local conditions is sufficient to avoid disease transmission. In practice, the effluent from the plants is usually discharged into gardens or ponds.
An even better nutrient source is (human) urine as it contains the nutrients nitrogen, phosphorus and potassium (NPK) and its heavy metal and pathogen content is low.

Pathogens in collected urine can be reduced by adequate storage or further treatment. Within the framework of the interdisciplinary SANSED project, a study on the hygiene quality of the different wastewater treatment types, e.g. different biogas plants, was monitored.

Material and methods

The monitored urine was collected from the student dormitory B23, which was occupied by 100 male students. The samples were taken as 24 h mixed samples at the entrance to the storage tank. Separately, both undiluted urine from the urinals and diluted urine from the separation toilet were sampled (see Wohlsager *et. al.* Chapter III-1). Fresh urine excreted by male students used for the storage experiment in Vietnam was collected directly in plastic containers in the toilets over 1.5 days. Samples from the urine storage tank contained a mixture of urine from the separation toilets and the urinals and were collected within one day. In the storage experiments, this urine was considered to be the diluted material. Samples of the stored urine were taken over a period of eight weeks and the microbiological analysis was done at the beginning, after one month and after two months.

To observe the effect of storage on the persistence of micro-organisms in urine, experiments were also carried out in Germany. Untreated urine (10^5 cfu ml^{-1}) was collected directly in sterile glass bottles. Aliquots of the urine were sterilised and spiked with *Escherichia coli* (10^5 cfu ml^{-1}). Both urine preparations were stored for six weeks at 22°C.

The biogas plants surveyed were operating with waste water from pigsties. The sampling was carried out by the sub - group Nutrient Fluxes (see Nuber *et al.* Chapter II-1). For sampling, a sterilised 1 litre glass bottle was used for both the inflow and the effluent samples. These samples were processed within 1.5 hours. The samples were analysed for the parameters *E. coli*, total coliforms, faecal streptococci, *Salmonella* sp. and helminth eggs according to ISO standards and WHO recommended methods. Additionally, the urine samples were analysed for coliphages with ISO methods.

Results

The persistence of micro-organisms in urine is influenced by the pH value, concentration of ammonia, temperature and dilution (Schönning 2004). In all urine samples analysed neither coliphages nor helminth eggs were detected, but several faecal indicator bacteria were present. The freshly collected urine showed the highest bacterial concentrations for faecal streptococci in all urine samples. In the storage tank and the separation toilet the urine contained a similar concentration of faecal streptococci with 300,000 and 270,000 cfu 100 ml^{-1}, respectively. Urine from the urinals had the lowest faecal streptococci concentrations (3,000 cfu 100 ml^{-1}) compared to the other urine samples.

For *E. coli* and coliform bacteria urine collected from the dormitory storage tank showed a similar level of contamination to the freshly collected urine. These concentrations were 10-fold higher than the concentrations found in samples from the separation toilet and 100-fold higher than the concentrations found in urine at the urinals. *Salmonella* sp. were found in freshly collected urine and in the urine storage tank, but not in urine from the separation toilet or the urinal.

Table 1: Concentration of *E. coli*, total coliform, faecal streptococci, *Salmonella* sp. and total nitrogen in fresh urine, urine from a storage tank, a separation toilet and a urinal

	Unit	Fresh collected urine	Urine storage tank (separation toilet + urinal)	Separation toilet	Urinal
E.coli	cfu/100ml	<100,000	21,000	9,300	200
Coliform bacteria	cfu/100ml	230,000	240,000	93,000	200
Faecal streptococci	cfu/100ml	2,1E+09	300,000	270,000	3,000
Salmonella sp.		positive	positive	negative	negative
N total	mg/l	6,678	2,352	1,778	4,564

To observe the effect of storage on the persistence of micro-organisms in urine, experiments were carried out in Germany and Vietnam. Untreated urine (>10^5 cfu ml^{-1}) and sterile urine spiked with *E. coli* (10^5 cfu ml^{-1}) were stored for six weeks at 22°C. During this time *E. coli* showed only a slight reduction in the untreated urine. The *E. coli* concentration in sterile urine decreased rapidly during the first two days, but then a regrowth exceeding the original concentration was observed. After one week the final concentration reached 10^7 cfu ml^{-1} and slightly decreased to 10^5 cfu ml^{-1} within the next five weeks.

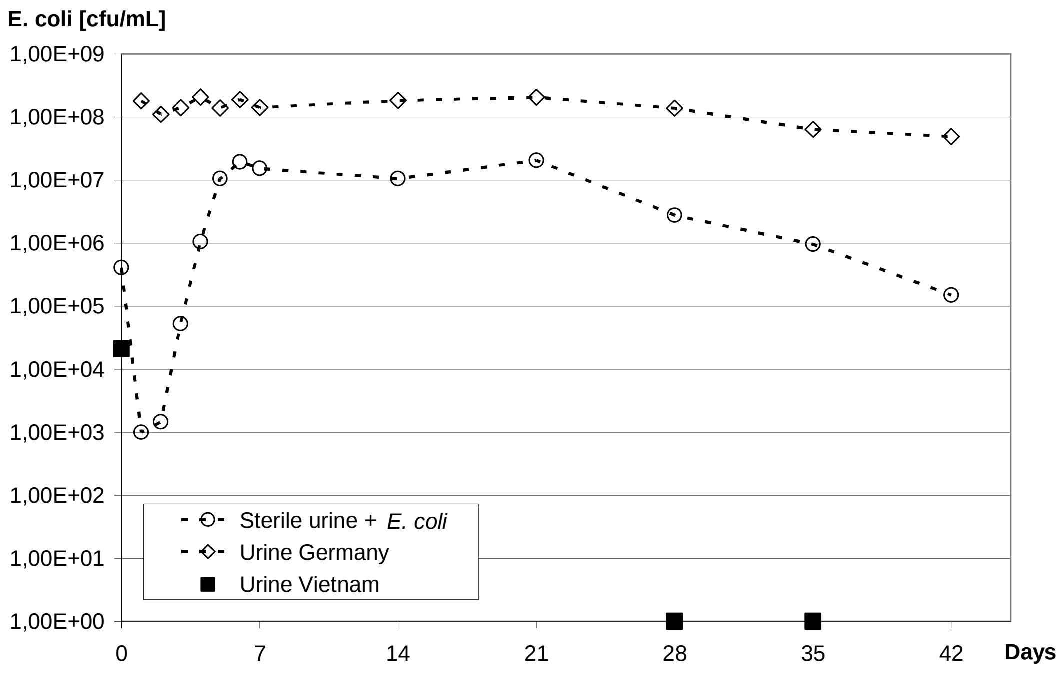

Figure 1: Concentration of *E. coli* in spiked sterile and natural urine in Germany and in Vietnam over a storage period of six weeks

Table 2: Concentration of *E. coli*, total coliform, faecal streptococci and *Salmonella* sp. in diluted and undiluted urine over a storage period of eight weeks

	Storage conditions for diluted urine			
Duration	open	closed	undisturbed	undiluted
	E. coli **(cfu 100 ml^{-1})**			
fresh	<0.1x10^5	<0.1x10^5	<0.1x10^5	2.1x10^4
4 weeks	0	0	-	-
5 weeks	-	-	-	0
8 weeks	0	0	0	-
	Total coliforms **(cfu 100 ml^{-1})**			
fresh	2.3x10^5	2.3x10^5	2.3x10^5	2.4x10^5
4 weeks	0	0	-	-
5 weeks	-	-	-	0
8 weeks	0	0	0	-
	Faecal streptococci **(cfu 100 ml^{-1})**			
fresh	2.1x10^9	2.1x10^9	2.1x10^9	3.0x10^5
4 weeks	1.7x10^4	1.6x10^4	-	-
5 weeks	-	-	-	0
8 weeks	3.8x10^3	1.7x10^3	4.0x10^3	-
	Salmonella sp. **(cfu 100 ml^{-1})**			
fresh	positive	positive	positive	positive
4 weeks	negative	negative	-	-
5 weeks	-	-	-	negative
8 weeks	negative	negative	negative	-

The urine stored in Vietnam at 30°C contained 10^4 cfu ml^{-1} *E. coli* at the beginning of the storage what is substantially lower than the concentrations measured in Germany. After four weeks of storage no *E. coli* were found and no regrowth was observed in the next week. This result is valid for all urine samples. They seem not to be influenced by the type of storage (open, closed, undisturbed, diluted). For total coliforms, the initial concentration in the urine was higher than for *E. coli*, but after four weeks of storage no coliforms could be detected in the samples. The diluted urine was examined after five weeks and did not contain coliforms either.

In comparison to the other indicators, faecal streptococci were found in urine in substantially higher concentrations. During the first four weeks of storage the concentrations decreased by 5 log_{10} units from 10^9 cfu 100 ml^{-1} to 1.7 x 10^4 cfu 100 ml^{-1}. After eight weeks, the concentrations had dropped for another log_{10} unit in all the different storage situations. The diluted urine from the separation toilets contained 3.0 x 10^5 cfu 100 ml^{-1}, being completely undetectable after five weeks of storage. In the undiluted and diluted urine *Salmonella* sp. were present. After a storage period of four and five weeks, respectively, *Salmonella* sp. were inactivated in all samples analysed.

To ensure the hygienic safety of excreta, the treatment in biogas plants was monitored for its efficacy regarding the reduction of pathogens. Both types of plant (plastic and concrete) were monitored for the reduction of pathogens and faecal indicators by comparing the contamination at the inflow and at the outflow of the plants. All indicator bacteria were

slightly reduced in all 20 biogas plants, independent of their type (Table 3), but *Salmonella* sp. were found in the effluent regularly (data not shown), even though this organism was sometimes not present at the inflow.
At the influent of the biogas plants, a median of 45,000 helminth eggs l^{-1} was detected at the concrete plants, whereas a median of 140,000 eggs l^{-1} was found at the plastic plants. The helminth species predominantly identified is *Clonorchis sinensis*, the oriental liver fluke. The reduction in helminth eggs in the biogas plants differed significantly between plastic and concrete biogas plants. Concrete plants reduced helminth eggs by 5.4 $\log_{10}$, whereas plastic plants reduced them only by 0.3 $\log_{10}$ (Table 3).

Table 3: Median reduction of *E. coli*, total coliforms and helminth eggs concrete and plastic biogas plants

	E. coli [MPN 100 ml^{-1}]	**Total coliforms** [MPN 100 ml^{-1}]	**Helminth eggs** [l^{-1}]
		Concrete (n=10)	
Influent	3.3×10^8	3.3×10^8	45,000
Effluent	1.4×10^7	1.9×10^7	0
Log_{10} reduction	1.39	1.24	5.4
		Plastic (n=10)	
Influent	2.1×10^8	2.7×10^8	140,000
Effluent	2.0×10^7	2.3×10^7	75,000
Log_{10} reduction	1.0	1.1	0.3

Discussion

Increased availability of improved sanitation is the priority for the Centre for Rural Water Supply and Environmental Sanitation (CERWASS). The coverage of improved sanitation systems in the Mekong delta is still low, in both, urban and rural areas. Overall more than 58 % of the households dispose faecal matter in fish ponds and there is no doubt that fishpond toilets spread pathogens from faeces easily. Recently, a study by Thien *et al.* (2007) showed that fish raised in the VAC system in the Mekong Delta are often infected with trematodes.

One of the major sources of porcine and human helminth infections in the Mekong delta region is *Clonorchis sinensis*, which finds in fish ponds an ideal habitat and the necessary hosts of water snails, fish and mammals. There is an urgent need to reduce public health risks resulting from this hazardous practice. In particular, in the rural area of Hoa An, where surface water is used for drinking purposes by more than 50 % of the population, the contamination of water should be limited using an integrated control strategy considering water, sanitation and hygiene practices in order to break faecal-oral transmission routes (Eisenberg *et al.* 2007).

It is common practice to hose the excreta from pigsties into biogas plants, where fermentation takes place and methane is produced. In the plastic plants, digestion occurs in large tubes that lie on the ground and the effluent passes into the environment at the end of the system. A probable reason for the difference in the reduction efficacy is the construction of the plants themselves. The concrete plants form a dome, where the helminth eggs and non-motile bacteria sink to the bottom into the sediment. The effluent is discharged from the upper part of the plants therefore preventing helminth eggs from resuspension.

In contrast, the plastic biogas plants keep the sludge inside a long tube. The influent enters the plant at one end of the tube and the effluent is discharged from the opposite end. If the wastewater flow is too strong, already sedimented sludge can become resuspended and leave the plant in the effluent. Indicator bacteria are motile and float in the supernatant water inside the biogas plants and this is likely to be the reason for the slight difference in bacteria reduction efficacy observed in both systems. The fact that *Salmonella* sp. were regularly found in the effluent might be due to the fact that inflow and outflow could only be sampled as a small fraction of total volume. Another reason could be that the pigs, which are the main source of Salmonella from domestic animals, are regularly treated with pharmaceuticals and might not excrete *Salmonella* sp.at the time the samples were taken, even though they excreted the bacteria previously and the Salmonella survived in the biogas sludge in the plant from earlier excreta. The temperature of the effluent water ranged between 27.6 and 31.8°C which does not limit the survival of the faecal indicator bacteria. Compared to European biogas plants the temperatures found in the Vietnamese plants are low and a pathogen die-off inside the plants due to heat inactivation is not likely to occur.

As the main nutrients are excreted via urine, the utilisation of urine in agri- and aquaculture should be favoured. It could be shown that urine is frequently contaminated with faecal indicator bacteria, e.g. *E. coli*. Contamination of the urine occurs during the urination process and in the sanitary system by cross-contamination. But if stored, the urea is transformed to ammonia and hydrogen carbonate and the urine becomes toxic to micro-organisms (Vinneras 2002). A study by Höglund *et al.* (1998) showed a decrease of *E. coli* of up to 90% within one day of storage at 20°C. In the present study, urine stored at 22°C initially showed an even higher decrease of *E. coli* after one day, but a regrowth was observed and *E. coli* survived for more than six weeks. During storage at 30°C in Vietnam no *E. coli*, total coliforms or *Salmonella* spp. were present in the urine after 4 and 8 weeks of storage. It seems that higher temperatures support the die-off processes and result in microbiologically safe urine, if the storage time is appropriate.

Conclusions

Depending on the economic situation and the hydrological conditions, communities in the Mekong Delta of Vietnam rely on surface water as a main water source. Untreated surface water from water channels is frequently used for personal hygiene, laundry, dish-washing and food preparation and large parts of the population in the rural and peri-urban areas of the delta are at high risk of contracting waterborne diseases from surface water.

With more effective operation of biogas plants, the treatment of faeces could result in a reduction in levels of faecal pathogens. In the case of sufficient pathogen reduction, effluent from biogas plants can be discharged into fish ponds and the sludge produced can be applied to fields or orchards. The examination of two biogas plant types - operating in three selected communities in the Mekong Delta - showed differences in pathogen reduction efficacy depending on the type of plant. However, in all plants the retention time was quite short and the bacterial pathogen reduction efficacy was rather low. Hence, improvement of the biogas plants for better pathogen reduction would need to be substantial before it would be possible to recommend the discharge of the biogas effluent to fish ponds and the application of faecal sludge to agricultural land. It is however possible to reduce levels of helminth eggs effectively in concrete plants with a dome, due to deposition in the sludge.

Collected urine contains microbiological contaminants and should be treated depending on the future usage. If used as fertiliser for trees and grains no treatment is necessary, because the crops produced will be processed before consumption. If an application of urine on fruit and vegetables that are consumed raw is intended, the urine should be stored to achieve a die-off of micro-organisms of faecal origin. Otherwise the use of untreated urine might result in a public health risk. Before using urine in aquaculture, storage is necessary as well. The results show that a storage time of 4 weeks is sufficient to obtain a hygienic safe product.
There is circumstantial evidence that the population is aware of the fact that water can transmit diseases although unsafe disposal of faeces and insufficient water storage, handling and treatment practices are widespread. This reveals the need for an integrated approach including the latter aspects as well as safe nutrient recycling strategies and further research on the perception of water and health.

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Chapter V: Application

V-1: Effects of substrate application on maize biomass and exchangeable soil aluminium in problem soils of the Mekong Delta

Christian Brandt[1], T.K. Tinh[4], Mathias Becker[1]
[1] INRES – Plant Nutrition, University of Bonn, Germany
[4] College of Environment and Natural Resources, Can Tho University, Vietnam

Keywords: acid sulphate soil, MAP, soil solution, Vietnam, *Zea mays*

Introduction

The major soil types of the Mekong Delta comprise alluvial soils (40 %), acid sulphate soils (35 %) and grey degraded soils (10 %) (Van Bo *et al.* 2002). All are being used to various degrees for growing upland crops during the dry season (Maclean *et. al.* 2002, Can 2003). All these soils are characterized by element deficiencies and imbalances. Main soil parameters limiting upland crop production are in alluvial soils low soil organic C and N-supply (Dobermann *et. al.* 2002), in acid sulphate soils P deficiency and aluminum toxicity (Tinh *et. al.* 2001), and in gray degraded soils low cation exchange capacity and low K and N content (Mussgnug *et al.* 2006). While mineral fertilisers can correct deficiencies and liming can avoid the pH-related Al toxicity, such approaches are capital-intense and are hence available only to a limited extent to low-input farmers. On the other hand, most farms can avail to various types of farm-grown organic matter and possibly of substrates derived from waste and wastewater treatments (Watanabe 2003). Widely available are pig manure and rice straw compost and biogas sludge. A "new" substrate is magnesium - ammonium – phosphate (MAP) from wastewater filtration plants. These substrates contain variable amounts of plant nutrients and may have a positive effect on the physical structure and chemical properties of the soil (Hue and Lucidine 1999). Of particular interest are the addition of P and N, particularly for alluvial soils, an enhanced water-holding capacity for the degraded soils, and the addition of P and the complexation of toxic aluminum in acid sulphate soils. We tested these substrates in comparison to an unamended control and the commonly applied NPK fertiliser in a pot trial using maize (*Zea mays* L.) as a test crop.

Material and Methods

Samples were collected from the A horizons (0 - 20 cm) of three acid sulphate soils with pH – values of 3.2 (Hoa An), 3.7 (Long My), and 4.2 (Hau Giang), an alluvial soil from Chau Doc (An Giang) and a gray degraded soil from Moc Hoa, (Long An). The soils were dried and ground to pass through a 2 mm sieve. Selected characteristics are presented in Table 1.

Table 1: Selected characteristics of the experimental soils used in the pot experiment

Parameter	Acid sulphate soil (Hoa An)	Acid sulphate soil (Hoa An)	Acid sulphate soil (Long My)	Alluvial soil (Chao Doc)	Degraded soil (Moc Hoa)
Soil type (USDA)	Sulphaquept	Sulphaquept	Sulphaquept	Tropaquept	Plinthaquult
pH (H_2O)	3.2	3.7	4.2	6.9	5.1
org. C (%)	4.33	4.99	3.34	1.03	2.18
Exch. Al^{3+} (mg $100g^{-1}$)	12.4	13.2	11.6	n.a.	1.3
Tot. N (%)			0.30	0.13	0.15
Avail. P (mg kg^{-1})				2.0	4.1
Exch. K (mg kg^{-1})			3.7	1.9	0.6
CEC (cmol kg^{-1})	11.0	12.8	11.7	13.9	3.4

Three organic substrates from decentralized waste and wastewater treatment, commonly applied to field and garden crops in the Mekong Delta were collected from farms in Can Tho province. Magnesium ammonium phosphate (MAP) from decentralized yellow water treatment was included into the trial as a new high potential fertiliser for cash crop production. The organic amendments included biogas sludge, pig manure compost, and mushroom compost. The substrates differed in their N content, C/N ratio, and P and K content (Table 2).

Table 2: Selected characteristics of the organic and inorganic substrates used

Substrate	Moisture cont (%)	Total N (%)	C (%)	C/N ratio	Total P (%)	Avail. P (%)	C/P ratio	Total K (%)
Organic substrates								
Biogas sludge	84.4	1.77	30.6	17.5	2.26	0.29	105.5	0.13
Mushroom compost	11.2		44.9					
Pig manure compost	49.3	1.38	24.8	18.0	2.02	0.25	99.1	0.49
Inorganic substrates								
Magnesium ammonium phosphate		5.71	n.a.	n.a.	12.62	12.62	n.a.	n.a.
Mineral fertilizer (NPK 15:7:7)		14.7	n.a.	n.a.	7.04		n.a.	6.42

Samples of air-dried and ground soil (500 g dry weight) were placed into 500 ml plastic pots and placed into the greenhouse of the College of Agronomy of Cantho University. Fresh biogas sludge, pig manure and mushroom compost were added and carefully mixed into the soil at rates of 10 and 20 Mg ha^{-1}. The MAP and NPK – fertilisers were added at a rate equivalent to 100 kg N ha^{-1}. An unamended soil served as control. The substrates were applied to each soil in three replications. The soils were maintained at 75 - 100 % field capacity by bi-weekly weighing and watering with distilled water.

The experiment consisted of a planted and unplanted setup. Soil solution was extracted from the unplanted pots at 10-day intervals over a period of 40 days by micro-suction roots that were installed in an 8.5 cm diagonal of each pot. The solution was cold-stored for later analysis for pH and soluble and complexed Al (McLean 1965). In two parallel setups, the pots were planted with maize (*Zea mays* L.) and harvested at 20 and 40 days after seeding to determine aboveground dry matter and N and P uptake.

Results

Crop response to substrate application in different soils

Maize dry biomass at 40 days was largest in the degraded (0.8 g plant^{-1}) and the alluvial soil (0.5 g plant^{-1}) and declined to 0.4 g in the moderately acidic acid sulphate soil and to < 0.1 g in the unfavorable acid sulphate soil (Figure 1). The lower biomass in the alluvial as compared to the degraded soil was ascribed mainly to N deficiency as symptoms occurred on older leaves. An application of mineral NPK fertilizer resulted in the largest maize biomass response on the N deficient alluvial soil provided no significant biomass increases in the degraded and the acidic acid sulphate soil.

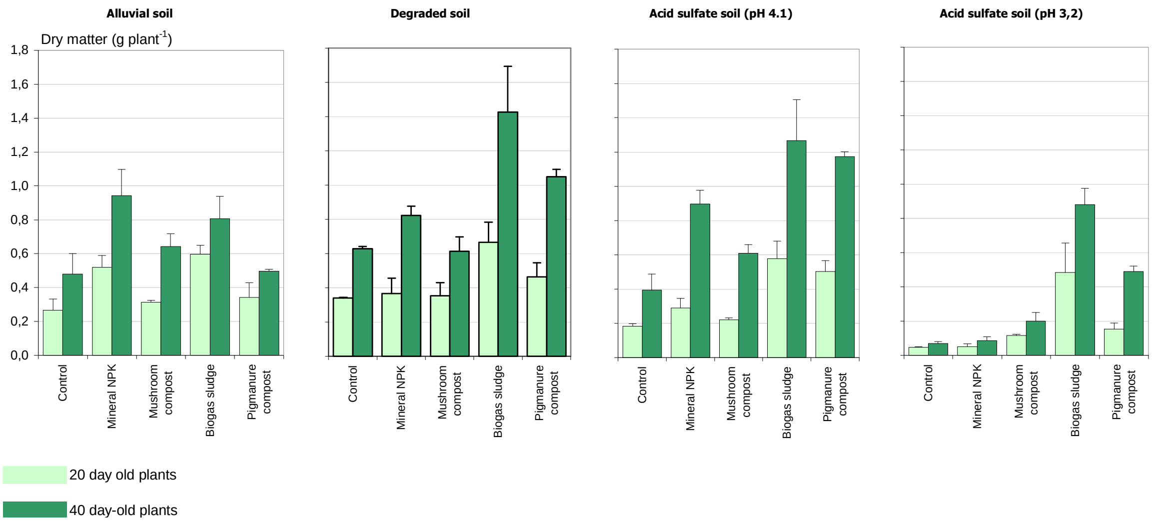

Figure 1: Dry biomass accumulation by 20 and 40 day-old maize plants in four soils and with 5 different fertilizer amendments (pot experiment, greenhouse).

Irrespective of the application rates, organic substrates provided the largest effects in the marginal soils (degraded and acid sulphate soils), with biogas sludge being always superior to pig manure and mushroom compost. The application of MAP provided no significant effects except for the alluvial soil (data not shown). Here, maize response was highly correlated to the amount of applied N, irrespective of the amendment.

Dynamics of soil solution pH after substrate application

A poor growth of maize on acid sulphate soils was assumed which may be related to P deficiency and aluminium toxicity due to a low pH value. Particularly in the acid sulphate soils, the growth differences and the growth response of maize to substrate addition was closely associated with the amount / dynamics of soil solution pH and exchangeable Al^{3+}. The dynamics of soil solution pH during the 40 - day experimental period are presented for four soil types and 5 soil amendments (Figure 2). In the alluvial and degraded soils, the solution pH changed little during the experiment and was largely unaffected by mineral or organic fertilizer application.

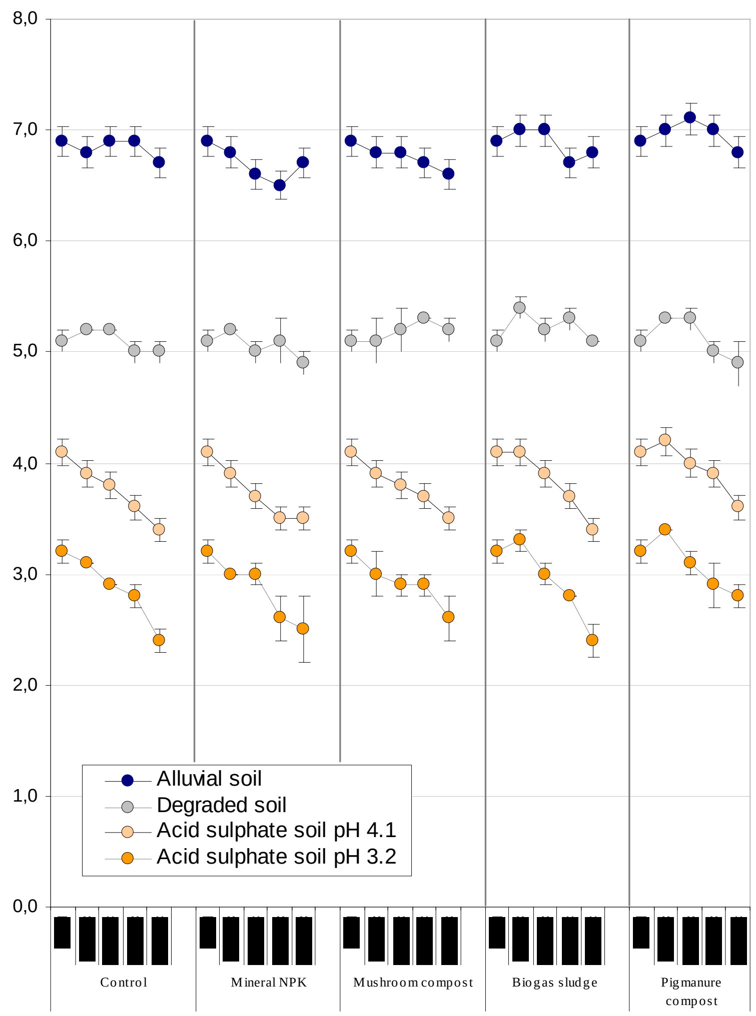

Figure 2: Dynamics of soil solution pH in two acid sulphate soils, a degraded soil and an alluvial soil as affected by soil amendment (control, 100 kg N ha^{-1} as NPK; 20 Mg ha^{-1} as mushroom compost, biogas sludge, pig manure compost)

However, in the case of the two acid sulphate soils the pH values declined with the time of aerobic exposure by up to one unit during the incubation period. Thus, the pH of the moderate acid sulphate soil declined from 4.2 to 3.3 and in the strongly acidic acid sulphate soil from 3.2 to 2.2. Neither mineral fertilizers nor biogas sludge were able to counteract these acidification trends. However, the application of pig manure compost, and to a lesser extent also of mushroom compost, was able to temporarily slow down the acidification of these soils.

Dynamics of soil solution aluminium after substrate application

Soil acidity was strongly correlated with the amounts of exchangeable (Al^{3+}) and total aluminium (data not presented). There was not detectable aluminium in case of the alluvial soil with pH values ranging from 6.8 to 7.1. In the degraded soil (initial pH of 5.2), the slight acidification during the incubation period resulted in an accumulation of up to 1.5 cmol kg^{-1} of exchangeable and of 1.8 cmol kg^{-1} of total Al (Figure 3). In the acid sulphate soils, the duration of aerobic incubation provoked a strong soil acidification, which associated with significant increases in soil solution Al. In the unamended control these reached after 40 days up to 3 cmol kg^{-1} in the moderate and up to 45 cmol kg^{-1} in the strongly acidic acid sulphate soil.

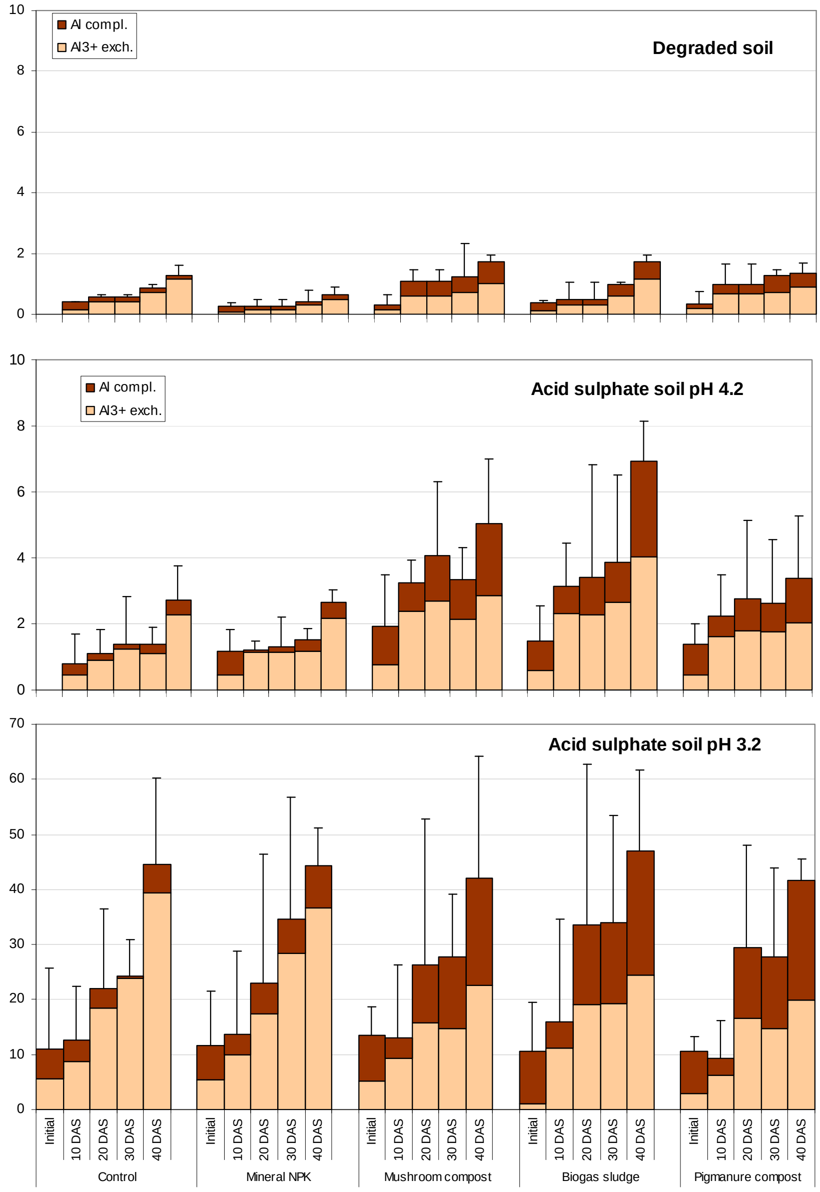

Figure 2: Dynamics of soil exchangeable (Al^{3+}) and complexed (organic) aluminum in two acid sulphate soils and a degraded soil as affected by soil amendments

Neither mineral nor organic amendments could significantly arrest the observed soil acidification trends or the build up of total Al in the solution. However, with all organic substrates, the share of the toxic Al^{3+} was reduced in favour of complex Al. Thus, substrate application (and subsequent mineralization) was able to bind (immobilize) some 40 % (mushroom compost and biogas sludge) or even 50 % (pig manure compost) of the aluminium in complex form. Maize biomass increased as the share of complex Al in the total Al-pool increased.

Conclusion

The different major soil types of the Mekong Delta are differentially suited for the production of upland crops. Similarly, the effectiveness of mineral and organic fertilizers strongly differs by the type of the soil and the fertilizer source. On N - deficient alluvial soils, mineral NPK or MAP and N - rich biogas sludge provide largest crop responses. On degraded soils, the addition of N and K needs to be supplemented by organic carbon. Hence, nutrient-rich organic substrates appear most suited for this soil type. Acid sulphate soils are generally critical for the production of upland crops due to a rapid acidification under aerobic soil conditions. While P application (in mineral or organic form) appears beneficial, only the application of organic substrates can address the problem of aluminum toxicity. The mechanism appears not related to a pH buffering effect but rather in the complexation of toxic Al^{3+}. We may conclude that the observed positive effects of organic substrates from waste and wastewater treatment appear particularly prominent in marginal soils. Particularly in such environments, farmers tend to be resource-poor and hence largely depending on locally or on-farm available substrates to correct soil problems or increase crop production. These data are still preliminary and will require field validation at various sites.

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V-2: Comparative evaluation of diverse organic and mineral substrates on upland crops in three major soil types of the Mekong Delta

Duong Van Ni[7], Nguyen Thi Bach Kim[7], Duong Van Nha[7*], Ly Ngoc Thanh Xuan[7*] and Mathias Becker[1]
[1] INRES – Plant Nutrition, University of Bonn, Germany
[7] Hoa An Biodiversity Research Station, Can Tho University, Vietnam
[7*] An Giang University, Vietnam

Key words: organic substrate, application, acid suphate soil, alluvial soil, degraded soil, maize (Zea mais) mungbean (Vigna radiata), Marigold (Tagetes erecta)

Introduction

The nearly 3 million ha of arable land in the Mekong Delta are dominate by alluvial soils (40 %), acid sulphate soils (35 %) and degraded soil (10 %) (Van Bo *et al.* 2002). All these soils are characterized by element deficiencies and imbalances. Thus, main soil parameters limiting crop production are low soil organic C and N - supplying capacity in the alluvial soils (Dobermann *et. al.* 2002), P deficiency and Fe or Al toxicity in the acid sulphate soils (Tinh *et. al.* 2001), and a low cation exchange capacity and low K and N content in the degraded soils (Mussgnug *et al.* 2006). While rice is the dominant crop during the wet season, these soils are being increasingly used for growing high value upland crops during the dry season (Maclean *et. al.* 2002, Can 2003). Besides the cultivation of food crops like maize (*Zea mais* L.) and mungbean (*Vigna radiata* L.), there is a growing market demand for cut flowers such as Marigold (*Tagetes erecta* L.).

Upland cropping during the dry season is likely to further accelerate the mineralization of soil organic matter and hence to exacerbate the problems of low soil nutrient supply and the physical degradation of the soil structure in the alluvial and degraded soils, while an intermittent soil aeration phase in acid sulphate soils leads to acidification and can result in severe Al toxicity and further exacerbate the problem of P deficiency (Husson *et. al.* 2000). Various types of farm - grown organic matter or mineral substrates are hypothesized to differentially affect soil fertility and the response of the major upland crops (Hue and Lucidine 1999). Widely available in the area are various types of composts from animal manure, biogas or the production of rice mushrooms. "New" substrates derived from decentralized wastewater treatment may comprise magnesium – ammonium – phosphate (MAP) and human urine. We tested these substrates in comparison to an unamended control and the commonly applied NPK fertilizer in trials on the three major soil types in An Giang province using maize, mungbean and marigold as test crops.

Material and Methods

Geographical location and climatic conditions

Field experiments were conducted at three sites in An Giang province in the northern Mekong Delta (10° 10′ 30″ to 10° 37′ 50″ Northern latitute and 104° 47′ 20″ to 105° 35′ 10″ eastern longitute). An Giang province occupies 3,406 km^2 or 1.03 % of the country area. It is characterized by a monsoonal climate with an annual mean temperature of 27°C (maximum 28.3°C, minimum 25.5°C) and an annual rainfall of 1,130 mm, ranging from 700 to 1,800 mm. The rainfall is distributed over a 130 - day period with 88 percent falling from May to November. During this wet season, the rainwater combined with surface water originating from the upper Mekong river catchment cause severe flooding of 1.5 - 2.9 m between August to November.

Experimental soils

According to the provincial soil map, three major and contrasting soil types dominate the area. The experimental sites were selected on these soil types as follows:

- Alluvial soil (Gleyi Dystric Gleysols) located on My An commune, Cho Moi district;
- Acid sulphate soil (Dystri-orthi-endo-orthithionic Fluvisol)] located on Luong An Tra commune, Tri Ton district; and
- Degraded soil (Ochri Dystric Podzoluvisols) located on Chau Lang commune, Tri Ton district.

Plant material

Baby corn (*Zea mais* L.), mungbean (*Vigna radiata* L.) and Marigold (*Tagetes erecta* L.) were selected as test crops for substrate response. Baby corn can be grow all year round but is primarily cultivated during the winter – spring and the spring – summer season. It can grow in almost every soil type but soils rich in organic soil, as well as sandy alluvial soils with a pH of 6-7 are considered most favorable. The immature cobs are harvested by hand 40 to 45 days after planting. Mungbean is mainly cultivated during the dry season (December to April) for 60 - 70 days, where it is grown as a cash crop and is grown in rotation with irrigated lowland rice. Recommended soils for mungbean are alluvial soils with pH 6 - 7. Marigold is grown all year round. The time from germination to blooming ranges from 60 to 70 days. Marigold is used as decoration flower in Vietnamese traditional culture. It provides a good cash income to the farmer and consumes less water than rice and corn.

Fertilizer material

Eight different mineral and organic fertilizer sources were compared with an unfertilized control treatment.

Table 1: Selected physico - chemical parameters of the fertilizer substrates used (data for organic substrates are provided on a dry matter basis).

No.	Type of fertilizer	pH H_2O	OM (%)	NO_3^- (ppm)	NH_4^+ (ppm)	N (%)	P_Olsen (ppm)	$K_{exch,}$ (mg kg^{-1})	Moisture (%)
F_1	Control								
F_2	Mineral N-P-K								
F_3	Mushroom com.	8.2	56	78	47	0.18	511	3,520	14.5
F_4	Biogas sludge	6.8	6	2,480	63	0.26	1,358	451	14.9
F_5	Cow manure	7.3	59	334	51	0.95	992	1,464	14.4
F_6	Vermicompost	4.9	32	16,303	493	0.59	1,302	2,360	15.1
F_7	Goat manure	6.4	34	8,727	107	0.68	1,088	1,197	6.9
F_8	MAP	nd	nd	nd	nd	nd	nd	nd	nd
F_9	Liquid Urine	nd	nd	nd	nd	nd	nd	nd	nd

nd: not determined

Mineral fertilizers were applied at rates equivalent to 100 kg N ha^{-1}, while organic substrates were applied at rates of 10 Mg ha^{-1}. Selected physico-chemical parameters are listed in Tables 1 and 2.

Table 2: Nutrient addition (NPK) by mineral fertilizer or substrate application

No.	Type of fertilizer	Amount of application on field			
		Application rate (Mg ha^{-1})	N (kg ha^{-1})	P (kg ha^{-1})	K (kg ha^{-1})
F_1	Unfertilised control	0	0	0	0
F_2	N-P-K compound	0.05(NPK)+0.05(urea)	31	8	4
F_3	Mushroom compost	10	18	5	35
F_4	Biogas sludge	10	26	14	5
F_5	Cow manure	10	95	10	15
F_6	Vermicompost	10	59	13	24
F_7	Goat manure	10	68	11	12
F_8	MAP	nd	100	nd	nd
F_9	Liquid Urine	nd	100	nd	nd

nd: not determined

Soil and plant analysis

Composite samples of soils taken at the onset and at the end of the experiment, stored at room temperature (32°C) and analyzed for pH, total N, total P, exchangeable K, and total C (Table 3). Plant samples were collected from 2 m^2 areas at 40 and 80 days after planting. The samples were dried at 70°C for 72 hours for dry matter accumulation and for N, P and K determination (Figure 1). All samples were analyzed at the soil laboratory of An Giang University using standard methods.

Treatment application

Nine fertilizer levels and three crops were arranged in a randomized block design using three replications at each of the three study sites (S 1-3 × C 1-3 × F 1-9 × R 1-3 = 243 treatments). The individual plot size was 5 m^2 (1 x 5 m raised beds). The total experimental at each study site was 300 m^2. The raised beds were covered with rice straw after treatment application.

Planting: Baby corn and mungbean were directly seeded into the raised beds at a rate of 3 to 4 seeds per planting hole and thinned to two seedlings per hill after germination. Marigold seedlings were pre-germinated 15 days before transplanting into the filed at a rate of one seedling per hill.

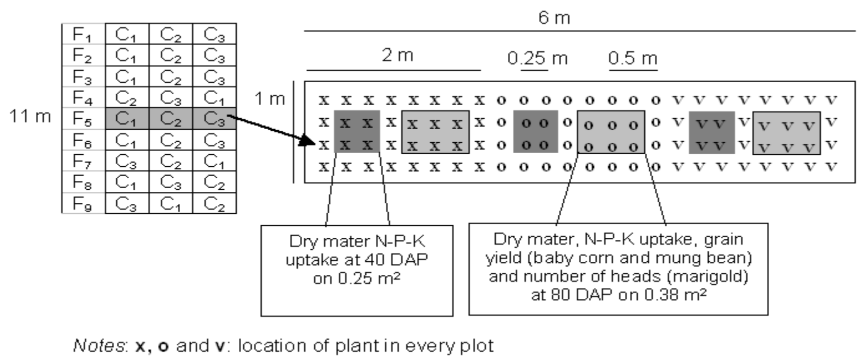

Figure 1: Plant sampling scheme during the field experiments

Table 3: Methods of soil and plant analysis used

No	Parameter	Analysis method
		PLANT
1	N total	Digest with H_2SO_4 - $CuSO_4$ - Se, rate 100 – 10 - 1. Distil micro Kjeldahl
2	P total	Digested with H_2SO_4 - $CuSO_4$ - Se,. Color development of Phosphomolybdate with ascorbic acid, by HPLC
3	K total	Extract by $BaCl_2$ 0,1M, colorimetric by AAS
4	Dry matter	Dry at 65°C until sustainable moisture.
		SOIL
1	N total	Digest with H_2SO_4 - $CuSO_4$ - Se, rate 100 – 10 - 1. Distil micro Kjeldahl
2	P total	Digested with H_2SO_4 - $CuSO_4$ - Se solution. Color development of Phosphomolybdate with ascorbic acid by HPLC
3	K exchange	Extract by $BaCl_2$ 0.1 M, compare color on AAS
4	%C	Walkley - Black method: oxidize by H_2SO_4 strong acid - $K_2Cr_2O_7$ solution. Titrated with $FeSO_4$.
5	PH	Extract by water with rate of soil / water 1:5, measured by pH meter

Fertilizer application: Organic fertilizers (mushroom compost, drained biogas sludge, dried and mixed pig manure, vermicompost and biogas sludge compost), liquid urine and MAP were applied after soil preparation onto the raised beds. Mineral fertilizers were applied as follows:

(1) Mungbean
- Basal application: 0.025 kg (N-P-K 16-16-8)
- First top dressing: 15 - 20 day - old seedings at 0.025 kg (N-P-K 16-16-8) + 0.013 kg (urea)
- Second top dressing: 35 - 40 day - old seedings at 0.013 kg (N-P-K 16-16-8) + 0.009kg (urea)

(2) Baby corn
- Basal application: 0.038 kg (N-P-K 16-16-8)
- First top dressing: 10-15 day-old seedings at 0.013 kg (N-P-K 16-16-8) + 0.007 kg (urea)
- Second top dressing: 20 - 30 day - old seedings at 0.013 kg (N-P-K 16-16-8) + 0.009 kg (urea)
- Third top dressing: 35 - 40 day - old seedings at 0.007 kg (urea)

(3) Marigold
- Basal application: 7 - 10 day - old seedings at 0.013 kg (N-P-K 16-16-8) + 0.004 kg (urea)
- First top dressing: 15 - 20 day - old seedings at 0.013 kg (N-P-K 16-16-8) + 0.004 kg (urea)
- Second top dressing: 25 - 30 day - old seedings at 0.013 kg (N-P-K 16-16-8) + 0.004 kg (urea)
- Third top dressing: 35 - 40 day - old seedings at 0.013 kg (N-P-K 16-16-8) + 0.004 kg (urea)

Crop management: The experiments were weeded and pesticides were applied as required. Irrigation was provided daily in the early morning or late evening. At the Luong An Tra (acid sulphate soil) and Cho Moi (alluvium soil) sites, water was provided by pump irrigation once a day, while at Chau Lang (degraded soil) site, water was supplied twice.

Table 4: Cropping schedule of three experimental sites

Site	Soil type	Begin	End
1. Luong An Tra	Acid Sulfate Soil	27 February 2007	25 May 2007
2. Cho Moi	Alluvial Soil	11 March 2007	10 June 2007
3. Chau Lang	Degraded Soil	28 February 2007	25 May 2007

Crop performance: At the end of experiment (80 days after planting), the biomass and fruit (cob or pod) yield was determined based on 2 m^2 harvest areas. In the case of marigold the number of bloomed flowers was counted.

Statistical analyses

Data were entered into Microsoft Excel and analyzed statistically by SPSS. Mean comparison was done by Duncans Multiple Range Test (DMRT: 0.05).

Results

Crop dry matter accumulation

Irrespective of the crop species, biomass accumulation was generally highest in the degraded and lowest in the acid sulphate soil. The dry matter accumulation by the crops at 40 and 80 days after seeding / transplanting is presented in Tables 5 and 6. Apart for MAP and liquid urine, maize biomass corresponded to the amount of N input in the alluvial soil, indicating that N is most limiting in the alluvial soil. The accumulation of mungbean biomass corresponded mostly to the amount of added P in the alluvial and the acid sulphate soil. Marigold did in most cases not significantly respond to inputs. Sole the balances NPK supply provided by mineral NPK compound and goat manure showed significant effects on biomass accumulation in the alluvial and degraded soil. However, all crop did respond to added C in the degraded soil, indicating that the soil organic matter content and the soil physical effects of substrate application were overriding the nutritional effects.

Yield response to substrate application

The grain yields of maize and mungbean and the flower yield of marigold largely followed the biomass trends. Apart from MAP and cowdung, maize yield response followed the amounts of added N in the alluvial soil, while mungbean yield was related to P inputs in all three soil types (Tabel 7). The largest numbers of marigold flowers were obtained in the acid sulphate soil with the application of aerobic composts. Anaerobic biogas sludge provided significant yield gains in the alluvial while aerobic composts showed largest effects in degraded soils, irrespective of the crop species.

Crop nutrient uptake

The NPK content and crop uptake largely corresponded to the soil nutrient stocks and the nutrient additions by substrates (Table 8). Surprising was however the very large amounts of K removed from the degraded soil and also the generally large K uptake from rice straw compost.

Effects on soil parameters

The effects of substrate application on changes in soil chemical parameters are presented in Table 9. It seems that one single season of treatment application has no major apparent effects on soil parameter changes. Nevertheless, there are interesting trends to be seen: In the alluvial soil, upland cropping (and the associated tillage operations) results in a reduction of organic C, and consequently of total soil N content, irrespective of substrate use. In the degraded soil, on the other hand, any organic substrate contributes to an increasing trend in soil organic C. In both, the alluvial and the acid sulphate soil, the application of organic substrates and of MAP increases the soil pH.

Table 5: Effect of substrate application on dry matter accumulation at 40 days after seeding by maize, mungbean and marigold on three contrasting soils of the Mekong Delta (Field experiment, An Giang Province, Vietnam, 2007)

Type of substrate	Substrate application rate	Nutrient input (kg ha^{-1})			Dry matter accumulation (Mg ha^{-1} at 40 DAS)								
		N	P	K	Alluvial soil			Degraded soil			Acid sulphate soil		
		----- (kg ha^{-1}) -----			Maize	Mungbean	Marigold	Maize	Mungbean	Marigold	Maize	Mungbean	Marigold
Control	none	0	0	0	6,1 ab	2,3 b	2,4 ab	15,6 bc	2,2 a	1,4 b	6,2 a	1,2 d	1,0 b
Mineral NPK	100 kg ha^{-1}	31	8	4	9,0 ab	2,7 ab	2,4 ab	35,4 a	2,9 a	2,0 ab	11,2 a	3,3 a	1,3 ab
Mushroom compost	10 Mg ha^{-1}	18	5	35	7,7 ab	2,7 ab	2,3 ab	20,6 ac	2,5 a	1,5 ab	5,6 a	2,3 ac	1,1 b
Biogas sludge	10 Mg ha^{-1}	26	14	5	8,4 ab	3,3 a	2,6 a	22,7 ac	3,1 a	2,1 ab	5,3 a	2,5 ab	1,6 ab
Cow manure	10 Mg ha^{-1}	95	10	15	6,8 ab	2,7 ab	2,4 ab	31,2 ab	3,2 a	1,8 ab	4,9 a	2,2 bd	1,2 b
Vermicompost	10 Mg ha^{-1}	59	14	24	9,6 a	3,0 ab	2,4 ab	29,4 ab	2,3 a	1,9 ab	10,8 a	2,9 ab	2,0 ab
Goat manure	10 Mg ha^{-1}	68	11	12	10,1 a	2,7 ab	2,6 a	19,2 ac	2,9 a	2,2 a	8,6 a	3,1 ab	1,5 ab
MAP	100 kg ha^{-1}	100	16	0	5,5 b	3,3 a	1,8 b	10,9 c	1,9 a	1,0 b	4,4 a	1,4 cd	0,9 b
Liquid Urine	320 L ha^{-1} (?)	100	10	18	7,9 ab	2,7 ab	2,2 ab	21,4 ac	2,4 a	1,4 ab	6,6 a	2,1 cbd	1,6 ab

Identical letters behind values in a column denote significant differences by Duncand Multiple Range Test (DMRT, 0.05)

Table 6: Effect of substrate application on dry matter accumulation at 80 days after seeding by maize, mungbean and marigold on three contrasting soils of the Mekong Delta (Field experiment, An Giang Province, Vietnam, 2007)

Type of substrate	Substrate application rate	Nutrient input (kg ha^{-1})			Dry matter accumulation (Mg ha^{-1} at 80 DAS)								
		N	P	K	Alluvial soil			Degraded soil			Acid sulphate soil		
		----- (kg ha^{-1}) -----			Maize	Mungbean	Marigold	Maize	Mungbean	Marigold	Maize	Mungbean	Marigold
Unfertilised control	none	0	0	0	13,5 c	5,5 b	7,2 ab	21,4 b	3,6 a	7,0 ab	6,8 d	1,9 d	6,6 bc
N-P-K compound	100 kg ha-1	31	8	4	21,4 a	6,9 ab	7,6 ab	24,8 ab	5,8 a	7,5 ab	13,4 bc	4,3 ab	10,5 ab
Mushroom compost	10 Mg ha-1	18	5	35	12,1 c	7,3 ab	6,2 ac	38,0 a	5,1 a	5,9 b	10,2 bd	3,6 cd	7,4 ac
Biogas sludge	10 Mg ha-1	26	14	5	19,3 ab	8,2 a	6,2 ac	25,0 ab	4,2 a	7,1 ab	11,9 bc	5,9 a	8,5 ab
Cow manure	10 Mg ha-1	95	10	15	12,7 c	6,7 ab	7,9 a	32,3 ab	3,6 a	8,6 ab	8,9 cd	3,7 bc	6,6 bc
Vermicompost	10 Mg ha-1	59	14	24	19,6 ab	6,4 ab	4,4 c	33,6 ab	5,5 a	7,9 ab	19,6 a	5,7 a	9,1 ab
Goat manure	10 Mg ha-1	68	11	12	18,3 ab	6,9 ab	5,4 ac	30,4 ab	5,1 a	10,3 a	14,4 b	4,7 cd	11,2 a
MAP	100 kg ha-1	100	16	0	12,1 c	5,1 b	5,1 bc	20,0 b	3,9 a	4,3 b	9,2 bd	3,8 bd	3,8 c
Liquid Urine	320 L ha^{-1} (?)	100	10	18	15,4 bc	5,4 b	7,2 ab	34,9 ab	3,6 a	4,9 b	11,2 bc	2,8 d	7,9 ab

Identical letters behind values in a column denote significant differences by Duncand Multiple Range Test (DMRT, 0.05)

Table 7: Effect of substrate application on the grain yield of maize and mungbean and number of flower heads of marigold on three contrasting soils of the Mekong Delta (Field experiment, An Giang Province, Vietnam, 2007)

Type of substrate	Substrate application rate	Nutrient input ($kg\ ha^{-1}$) N	P	K	Alluvial soil Maize (Mg ha-1)	Mungbean (Mg ha-1)	Marigold (flowers m-2)	Degraded soil Maize (Mg ha-1)	Mungbean (Mg ha-1)	Marigold (flowers m-2)	Acid sulphate soil Maize (Mg ha-1)	Mungbean (Mg ha-1)	Marigold (flowers m-2)
		----- ($kg\ ha^{-1}$) -----											
Unfertilised control	none	0	0	0	3,57 bc	1,14 cd	296 ab	3,05 b	0,68 b	287 ab	1,47 b	0,28 c	202 d
N-P-K compound	100 kg ha-1	31	8	4	5,22 ab	1,12 cd	334 a	3,06 ab	0,82 ab	319 ab	2,48 ab	0,71 bc	390 b
Mushroom compost	10 Mg ha-1	18	5	35	4,27 ab	1,25 bc	246 bc	3,49 ab	0,99 ab	264 b	2,51 ab	1,13 a	291 bd
Biogas sludge	10 Mg ha-1	26	14	5	5,79 a	1,50 ab	278 ab	3,90 a	0,97 ab	287 ab	1,68 ab	1,14 a	327 ab
Cow manure	10 Mg ha-1	95	10	15	4,67 ab	1,07 cd	286 ab	3,29 ab	0,97 ab	275 ab	2,64 ab	0,88 ab	226 cd
Vermicompost	10 Mg ha-1	59	14	24	4,90 ab	0,97 cd	189 c	3,59 a	1,19 ab	301 ab	2,54 ab	0,55 bc	398 ab
Goat manure	10 Mg ha-1	68	11	12	5,25 ab	1,80 a	243 bc	3,82 a	1,33 a	338 a	2,91 a	1,01 ab	405 ab
MAP	100 kg ha-1	100	16	0	1,52 c	0,80 d	256 ac	1,80 b	0,49 ab	254 b	2,39 ab	0,40 c	280 cd
Liquid Urine	320 L ha^{-1}	100	10	18	5,18 ab	1,04 cd	288 ab	3,51 ab	1,28 ab	295 ab	1,81 ab	0,66 bc	315 ac

Identical letters behind values in a column denote significant differences by Duncan Multiple Range Test (DMRT, 0.05)

Table 8: Effect of substrate application on the NPK content and NPK uptake by maize at harvest on three contrasting soils of the Mekong Delta (field experiment, An Giang Province, Vietnam, 2007)

Type of substrate	Alluvial soil N	P	K	N	P	K	Degraded soil N	P	K	N	P	K	Acid sulphate soil N	P	K	N	P	K
	----- (%) ------			--- $kg\ ha^{-1}$ ----			----- (%) ------			--- $kg\ ha^{-1}$ ----			----- (%) ------			--- $kg\ ha^{-1}$ ----		
Unfertilised control	0,93	0,15	0,57	126	20	77	0,95	0,15	0,98	204	32	210	0,70	0,10	0,80	48	7	55
N-P-K compound	0,95	0,16	0,54	194	33	110	1,02	0,16	0,99	253	40	246	1,12	0,17	0,89	151	23	120
Mushroom compost	1,15	0,11	0,89	139	13	108	0,94	0,16	1,10	357	61	418	1,01	0,20	1,02	103	20	104
Biogas sludge	0,95	0,13	0,59	183	25	114	1,06	0,15	0,95	265	37	238	0,96	0,11	0,83	114	13	99
Cow manure	1,43	0,10	0,77	181	13	98	0,99	0,17	0,93	320	55	301	1,14	0,14	0,87	102	12	78
Vermicompost	0,93	0,13	0,79	183	26	155	1,15	0,13	0,97	386	44	326	1,05	0,11	0,88	185	19	155
Goat manure	1,15	0,10	0,64	210	18	117	1,09	0,16	1,05	331	49	319	0,92	0,11	0,86	132	16	124
MAP	1,15	0,15	0,66	139	18	80	0,96	0,18	0,98	192	36	196	1,34	0,09	0,91	123	8	84
Liquid Urine	0,80	0,11	0,57	124	17	88	1,11	0,11	0,85	388	38	297	0,71	0,10	0,80	80	11	90

Table 9: Effect of substrate and fertilizer application on changes in selected soil parameters after one cropping season (field experiment, An Giang Province, Vietnam 2007)

Alluvial soil	pH water	Org C (%)	total N (g kg^{-1})	avail. P (mg kg^{-1})	exch. K (mg kg^{-1})
Initial Sampling	4,91	3,22	0,91	38	56
After 1 cropping season					
Control	5,03	2,49	0,59	36	26
Mineral NPK compoun	5,05	2,52	0,75	44	23
Mushroom compost	5,39	2,93	0,69	64	32
Biogas sludge	5,66	2,65	0,61	35	34
Cow manure	5,10	2,82	0,69	53	25
Vermicompost	5,57	2,55	0,59	29	32
Goat manure	5,06	2,76	0,77	40	21
MAP	5,33	2,61	0,55	53	32
Liquid Urine	5,36	2,60	0,49	36	27
Degraded soil	pH water	Org C (%)	total N (g kg^{-1})	avail. P (mg kg^{-1})	exch. K (mg kg^{-1})
Initial Sampling	5,1	1,94	0,32	60	64
After 1 cropping season					
Control	5,52	1,85	0,34	47	48
Mineral NPK compoun	5,48	1,91	0,49	63	40
Mushroom compost	5,66	2,37	0,47	51	83
Biogas sludge	5,84	2,05	0,32	58	48
Cow manure	5,87	2,11	0,61	64	56
Vermicompost	5,88	2,21	0,57	64	48
Goat manure	5,88	2,26	0,57	54	52
MAP	6,03	1,96	0,51	54	38
Liquid Urine	5,71	1,89	0,45	58	39
Acid sulphate soil	pH water	Org C (%)	total N (g kg^{-1})	avail. P (mg kg^{-1})	exch. K (mg kg^{-1})
Initial Sampling	3,95	13,8	1,92	13	126
After 1 cropping season					
Control	4,36	14,6	2,04	14	113
Mineral NPK compoun	4,27	15,2	2,01	12	113
Mushroom compost	4,1	14,4	1,78	10	185
Biogas sludge	4,06	13,6	1,72	12	79
Cow manure	4,11	14,8	1,95	12	104
Vermicompost	4,08	13,6	1,97	14	109
Goat manure	4,07	14,9	1,93	11	87
MAP	4,25	14,9	1,86	14	192
Liquid Urine	3,96	13,1	1,65	9	66

Conclusions

From the presented results the following may be concluded:

- Organic recycled substrates can in most cases replace mineral fertilizers.
- The crop response to added inputs varied with substrate, crop species and soil type.
- Anaerobic sludge and generally N-rich substrates provided in general the best effects on crop growth and yield on the alluvial soil, and specifically with maize.
- Aerobic composts provided the largest biomass gains and yield responses in the degraded soil, irrespective of the crop species.
- P-rich substrates with the exception of MAP resulted in the largest crop biomass and yield response in mungbean, and on acid sulphate soils, irrespective of the crop.
- Changes in soil parameters were not apparent after one single cropping season.

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V-3: Short-Term Effects on Soil Properties and Plant Performance of Rambutan (*Nephelium lappaceum L.*) by Amendment of Organic Materials

Vo Thi Guong[5], Vo Van Binh[5], Ute Arnold[1], Georg Guggenberger[9], Mathias Becker[1]
[1] INRES – Plant Nutrition, University of Bonn, Germany
[5] Dep. of Soil science and Land management, College of Agriculture, Can Tho University, VN
vtguong@ctu.edu.vn
[9] Institute of Soil Science, Leibniz University Hannover, Germany

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Introduction

Soil physical and chemical degradation was found in raised beds constructed on former orange orchards. Soil compaction, low soil pH, low base saturation and low contents of organic matter and nutrients are commonly encountered (Vo Thi Guong *et al.* 2005). In the Mekong delta, farmers apply large amounts of inorganic fertilizers to sustain yield levels, but thereby further reduce soil quality.

Organic matter is a key factor determining physical and bio-chemical soil quality as has been shown from long-term studies (Revees 1997). In combination with clay minerals organic matter enhances the hydrophobicity and increases water stability of soil aggregates, therefore providing a better resistance to slaking (Chenu *et al.* 2000). The addition of organic matter over a short-term showed a favorable biological loosening and prevented soil and water losses, thus contributing to soil fertility and maintaining the soil organic matter content (Rosolem *et al.* 2002). An increase in soil organic matter can take several years to be detected as it is an effect on long-term productivity (Werner 1997). The conversion from conventional mineral to organic fertilizers and to lower input rates can improve soil chemical properties and soil fertility. The nutrient cycles may be changed by using crop covers or by the application of organic manures and compost and a reduction or elimination of inorganic fertilizers. These changes improve directly the nutrient supply and indirectly the quality of the soil environment (Sean Clark *et al.* 1998).

Our objectives were to (i) evaluate the effect of four different composts and of green manure on soil physical and chemical properties of raised beds of rambutan orchard and (ii) to study the effects of these organic amendments on fruit yield.

Materials and methods

Experimental design

The experiment was carried out in a rambutan orchard grown on alluvial soils where raised beds have been constructed 16 years ago. A complete randomized block design was applied with four replications. Each plot has a surface area of 25 m^2, consisting of two rambutan plants of 5 years, each.

Experimental treatments were set up using 10 tons dry weight per hectare of biogas sludge compost, vermicompost, compost of sugarcane filter mud and fresh biomass of Ox eye daisy (*Sphagneticola trilobata*). Trichoderma fungi was added to all organic substrates. All organic treatments were complemented by a low dose of inorganic fertilizer (1.5 kg N, 0.4 kg P and 5 kg K per tree and year). The treatment of farmer's practice comprised only inorganic fertilizer with 2.2 kg N, 0.6 kg P and 2 kg K per tree and year). A basal application of 1.5 t ha^{-1} of $CaCO_3$ was applied to all treatments. Nutrient concentrations of organic substrates are presented in Table 1.

Table 1: Nutrient concentrations of applied organic substrates

Parameter	Unit	Biogas Sludge	Vermicompost	Sugarcane Filter Mud	Green Compost (Daisy)	Lime
N	%	1.45	0.60	1.90	1.76	-
P	%	0.55	0.21	2.50	0.36	-
K	%	0.36	0.81	0.34	3.11	-
Ca	%	0.06	0.01	0.34	0.50	36.10
Mg	%	0.27	0.34	0.27	0.22	1.06
C	%	37.07	5.38	29.78	41.38	-

Composite of soil samples (consisting of ten soil cores) of the top 10 cm of each plot were taken at initial stage and 3, 6 and 12 months after application of organic manures to measure some selected physical and chemical soil properties. Top soil of 10 cm depth of raised beds has soil pH of 3.4, average content of 26.6 g C kg^{-1}, 24.8 mg kg^{-1} nitrogen available, 149.1 mg kg^{-1} P available, 0.1 cmol K^+ kg^{-1}, 2.6 cmol kg^{-1} Ca^{2+} exchangeable, 24 % of base and 5.9 ppm exchangeable Zn.

After harvesting of fruits, a second amendment was applied at the same rate of fertilizer and lime. Soil sampling was done six months after application.

Measurement

At harvest, fruit weight per plant was recorded. Soil aggregate stability was determined using wet sieving. The remaining soil samples were air dried, crumbled by hand and sieved through 1 - 2mm aggregate. Soils were stored in plastic boxes at room temperature for analysis.

Soil analysis was carried out at the Soil Science Lab using their standard techniques: total N by Kjeldahl, P available by Olsen method, labile organic N was extracted by 2 N KCl and boiled at 100°C (Gianello và Bremner 1986).

Analysis of all data sets was performed using IRRISTAT software and mean separation was done using Fisher's LSD.

Results

Organic manures changing some soil properties

The changes of soil properties were evaluated in the two top soil layers: 0 - 5cm and 5 - 10 cm 6 months after organic substances had been added. Table 2 shows an increase of NO_3 in the case of biogas sludge and green manure in the top 5 cm. Sugarcane filter mud showed an increase in calcium and in exchangeable zinc in the soil. Soil pH, labile organic nitrogen, organic carbon in soil tended to increase but were not significantly different compared to the inorganic fertilizer plot.

In comparison to layer below (5 - 10 cm), soil pH, soil organic carbon and all others chemical properties were dramatically reduced (data not shown). In general, the top 5 cm, where organic substances, lime and inorganic fertilizer were incorporated, soil pH and soil nutrients were improved obviously compared to underneath layer.

Table 2: Soil properties 6 months after applying organic substrates (0 – 5cm)

Parameter	Unit	Farmer's Practice	Sugarcane Filter Mud	Biogas Sludge	Vermi-compost	Green Compost	CV (%)
pH	-	3.9 a	4.5 a	3.8 a	4.3 a	4.2 a	9.0
NH^{4+}	mg kg^{-1}	17.6 a	28.4 a	29.5 a	18.2 a	27.4 a	36.6
NO_3^-	mg kg^{-1}	80.7 b	424.3 ab	483.7 a	279.8 ab	544.1 a	40.7
OC	g kg^{-1}	38.9 a	52.5 a	55.1 a	48.6 a	50.6 a	20.5
Ca	cmol(+) kg^{-1}	8.5 c	19.3 a	12.8 bc	12.5 bc	15.5 ab	23.6
Zn_{exc}	mg kg^{-1}	8.6 c	15.6 ab	20.2 a	10.6 bc	11.5 bc	24.1

Soil pH, calcium and base saturation

Three months after liming (1.5 t ha^{-1} to every treatment), initial soil pH (~3.5) had not changed. Six months after the amendment, soil pH tended to increase a little (about 4) but returned to the initial level after one year. This result shows that application of a small amount of lime and organic amendment could not improve of soil acidity in the raised beds of a 16 - year old rambutan orchard. However, incorporated lime, sugarcane residue compost and green manure improved significantly the calcium concentration in the top soil 6 months after addition (Figure 1). One year after the amendments, exchangeable calcium was reduced and back to initial values. Initial soil had a low base saturation (24 %). It increased to 68 % after liming and after adding organic and green manure, it increased up to 90 % after 6 months (data not shown). The changed calcium concentration was an important factor contributing to the balance nutrients in soils.

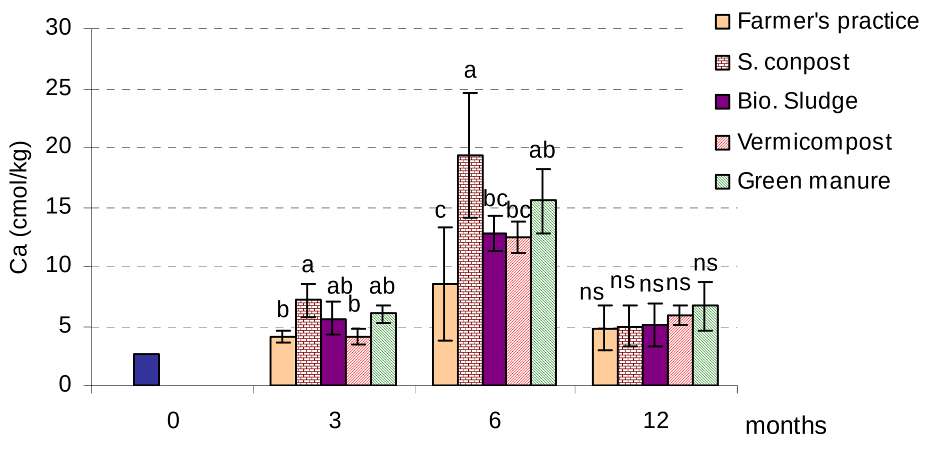

Figure 1: Effect of organic amendment on exchangeable calcium in top soil

Soil organic carbon

In comparison to the farmer’s practice, soil organic carbon was higher with addition of sugarcane compost three months after application treatment. One year after compost application, no difference in organic carbon among the different treatments could be observed. Six months after the second aplication, plots with sugarcane compost and biogas sludge compost showed a significant difference to farmer´s practice. Vermicompost and green manure showed the same tendency but not statistical difference (Figure 2).

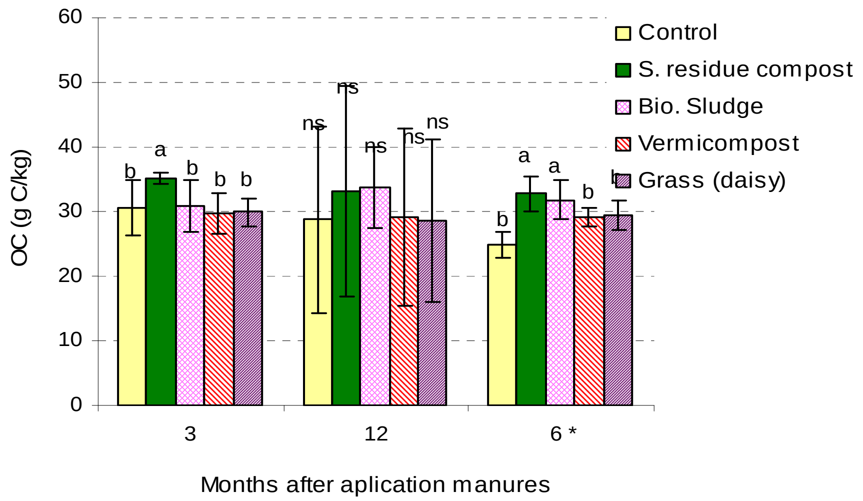

Figure 2: Organic carbon after application of different organic amendments (6*: 6 months after 2nd application)

Available Nutrients in soil

Figure 3 presents the fast available nitrogen, NH_4^+ in the top 10 cm after application of different substrates.

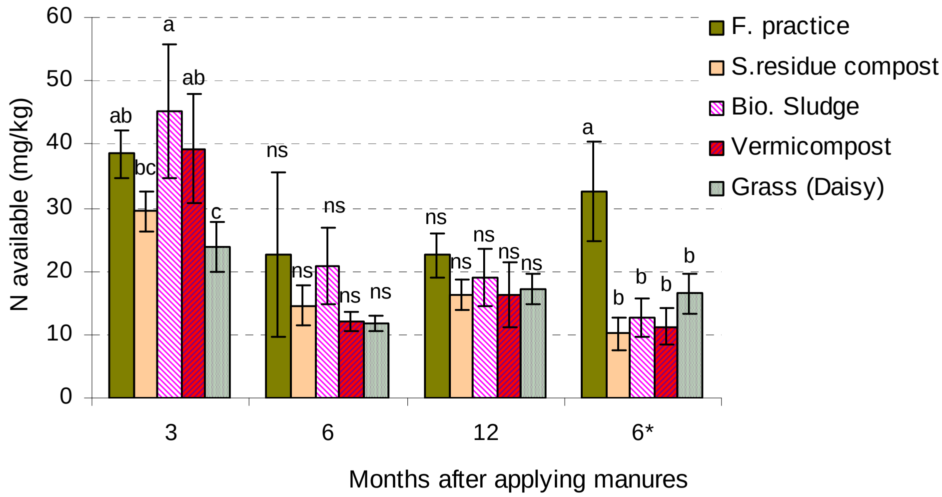

Figure 3: Effects of organic amendment on soil NH_4^+ (6*: 6 months after the second application)

Biogas sludge and vermicompost showed the highest increase in NH_4^+ in the top soil. Six months and one year later, NH_4^+ was reduced and similar NH_4^+ concentrations in the top soil of all treatments could be observed. In the second year, mineral fertiliser led to highest NH_4^+ contents in the top soil. In our study, available nitrogen was mainly affected by addition of inorganic nitrogen fertilizer.

Phosphorous concentrations are shown in Figure 4. These indicate that raised bed soils were rather rich in available phosphorus. Soils were enriched by inorganic fertiliser and by organic manures. One year after organic manure amendment, available P was still about double of P at initial stage.

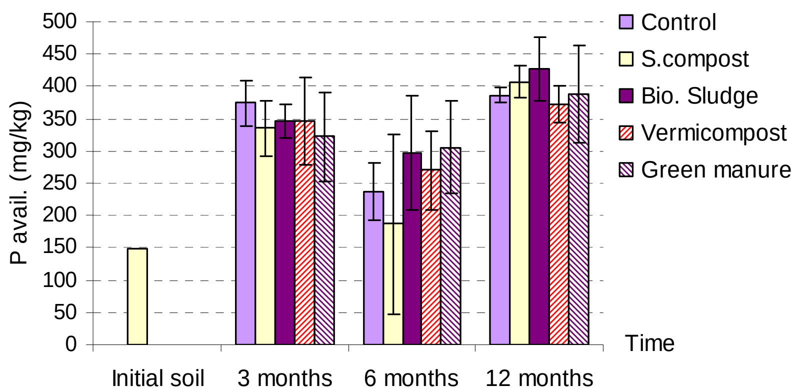

Figure 4: Effects of organic amendment on P_{avail} in top soil

In this study, the micronutrients, Zn was examined. Mineral fertilizer at farmer's practice showed a low level of exchangeable Zn (< 5 mg kg^{-1}). Addition of sugarcane filter cake and biogas sludge resulted in a significant increase in the Zn contend 6 and 12 month after application (Figure 5). Vermicompost and green manure showed little effect on the Zn concentration.

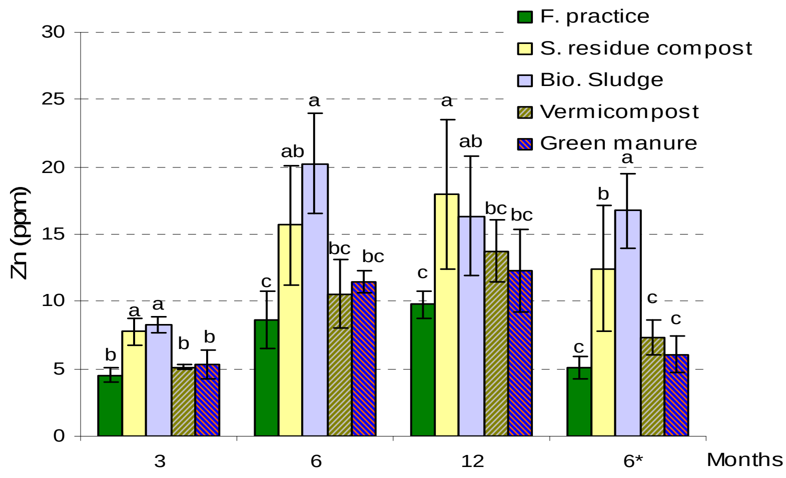

Figure 5: Zn exchangeable in top soil after application of different organic materials

Soil microbial and physical parameters

To evaluate the soil microbial growth, soil respiration was measured by soil incubation for four weeks. Sugarcane filter cake compost, biogas sludge and daisy tended to enhance the soil microbial activity. The effect was clearly after 4 weeks of incubation. Vermicompost showed little CO_2 release after one week in comparison to the inorganic amendment (Figure 6).

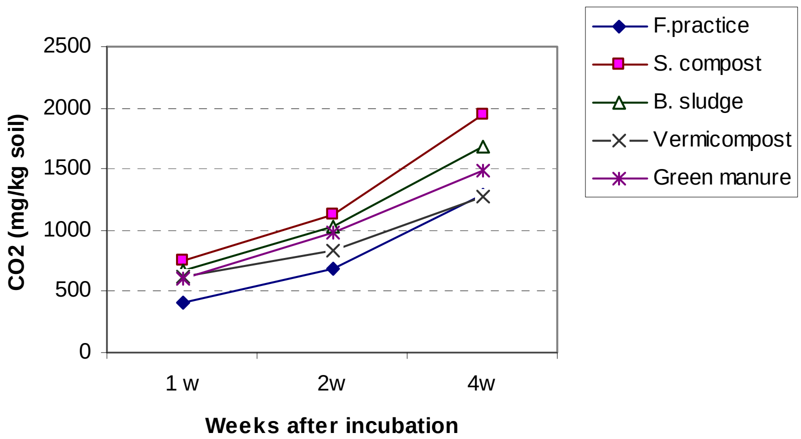

Figure 6: Effect of organic manures, green manure with low input inorganic fertilizers on soil respiration (6 months after application)

Some selected soil physical parameters were determined. Sugarcane filter cake compost, biogas sludge and vermicompost tended to increase soil aggregate stability but there was no statistical difference compared to farmer's practice. For the other soil characteristics such as soil bulk density, water holding capacity, no changes could be detected.

Fruit Yield

The average fruit weight was 50 to 70 kg per plant, with highest for ox eye daisy compost. No significant difference in fruit weight could be observed between the different treatments. The monitored effects of soil parameters did not influence the fruit yield.

Discussion

In our study we found that in organic management, ammonium had a tendency to increase its level but soil nitrate was low compared to farmer's practice. This result was in agreement with the findings of Anne *et al.* (2006). They indicated that nitrate and total soluble nitrogen levels in soil were low in organic management in comparison to conventional management. By using ^{15}N technique, Sorensen (2001) found that about 12 % of organic nitrogen in organic manure was gross mineralized within the first week following application. Due to the high dose of phosphorus and potassium added to every crop, soils showed high concentrations of available phosphorus and exchangeable potassium. In addition, organic composts affected the enrichment of these nutrients in soils: sugarcane filter compost contained highest levels of total P and vermicompost had highest concentration of total K. No significant difference between inorganic and organic amendments on P and K could be observed.

Although with short term organic carbon amended, soil organic matter increased 3-6 months after application compared to farmer's practice. Sugarcane filter cake compost showed a clear effect by increasing about 4 g C kg^{-1} after the first and about 8 g C kg^{-1} after the second addition. Biogas sludge increased about 4.3 g kg^{-1} of soil organic carbon in 10cm in the second batches. The increase of soil organic carbon was found six months after the amendments, but it reduced after one year.

Clemens and Binh (personal communication) found on the same field experiment that the CO_2 emissions were significantly high in raised beds with organic amendments. This result indicates that the carbon turn over of soil organic matter was greatly enhanced in soils. In the study of Stefano *et al.* (2008), slurry application in medium term (11 years), lead to intermediate increase in soil organic matter and changes in biochemical properties. In farmers' practice, cover grass and fallen leaves are removed out of their orchard. Such management way leads to greatly reduce the soil organic matter which resulted in negative effect on the soil health.

Soil pH was low, about 3.5, as a result of continuous cultivation of 16 years without calcium amendment. Through leaching and crop uptake, calcium and perhaps Mg were low. Applying organic fertilizer and lime resulted in a significant increase in exchangeable calcium and based saturation. However, due to the relatively low dose of lime, soil pH still remained low at about 4.5.

Therefore, adding calcium (and magnesium) can play important role to improve yield-limiting factors despite little changes in soil pH. This factor may have influenced plant growth and rambutan fruit yield which did not differ between farmer's practice and organic amendment due to basic liming for all treatments.

Soil aggregate stability index tended to increase by using organic materials. The same tendency was found for soil respiration. Organic soil management lead to greater biological activity than the conventionally managed soils (Mader *et al.* 2002, Anne *et al.* 2006). In the study of Sean Clark *et al.* (1998) they indicated that after eight years of application of organic manures, it resulted in higher soil organic C, soluble P, exchangeable K and soil pH.

In contrast, the physical and chemical soil properties showed little changes. The measurement of these soil parameters were not significantly different between these two types of management, emphasizing that the differences between organic and convention are more gradual, not like black and white (Anne *et al.* 2006). So we expected that the positive effect of organic management on raised beds of orchards will be gradually found in longer term study.

Conclusion

- Differences between organic amendents and sole mineral fertilizer application were relatively small within the first 18 months
- Some biochemical parameters (e.g. soil respiration, organic carbon, Ca and Zn) showed initially higher values in organic than in mineral treatments, but tended to decrease after 12 months.
- No changes in soil physical characteristics could be observed. A high rate of inorganic fertilizer resulted in calcium and zinc imbalance, while organic fertilizers did improve crop performance after 18 months. Long - term studies on soil properties and crop yield will be required.

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V-4: Effects of Substrate Application to Alluvial Soils on Soil Microbial Parameters in a Rambutan (*Nephelium lappaceum*) Orchard

Olga Shibistova[9], Sabine Tischer[9], Vo Van Binh[3], Duong Minh Vien[3], Vo Thi Guong[3], Georg Guggenberger[9]

[5] College of Agriculture and Applied Biological Sciences, Dep. of Soil Science and Land Management, Can Tho University, Vietnam

[9] Institute of Soil Science, Leibniz University Hannover, Germany &
Institute of Agricultural and Nutritional Sciences, Soil Sciences, Martin Luther University Halle-Wittenberg, Germany

Keywords: Alluvial soils, biogas sludge, enzymes, phospholipid fatty acids, microbial activity, microbial biomass, organic substrates, rambutan (*Nephelium lappaceaum*), soil organic matter, sugar cane compost, vermicompost

Introduction

Agricultural and horticultural practices influence the soil environment in many aspects including physical soil parameters, chemical soil parameters, and the soil organic matter status. In the Mekong Delta, horticultural practices, e.g. in rambutan (*Nephelium lappaceum*) orchards, rely on inorganic fertilization together with irrigation. This management system leads to losses of soil organic matter and deterioration of the soil structure (Vo Thi Guong *et al.* 2005). In line with Doran and Smith (1987) and Sauerbeck (1992), therefore the authors recommend the application of organic amendments as an alternative fertilizer source and to increase the organic matter status of the soils. On the long - term, soil organic matter is the most important indicator of soil quality because of its impact on physical, chemical and biological soil properties (Revees 1997). However, an increase in soil organic matter after changing soil management is taking several years to be detected (Paustian *et al.* 1997). The same is true for effects on long - term productivity (Werner 1997).

Since all organic matter in soil is cycled through the microbial biomass and release of inorganic forms of nitrogen, phosphorus and sulfur by mineralisation of organic matter is performed by microorganisms, the biomass, the activity and the composition of the microbial community in soil may serve as an early indicator of changes in the soil environment caused by alteration of soil management practices (Franzluebbers *et al.* 1995, Sparling 1997). Our objective, therefore, was to evaluate the effect of four different composts and green manure on soil microbial parameters in raised beds of a rambutan orchard. Our approach included the combination of the analysis of microbial biomass with microbial activity measures (i.e. metabolic quotient and enzyme analysis) as well as some indications on the structure of the microbial community. The latter was investigated by analysis of phospholipid fatty acid (PLFA) profiles which provide a fingerprint of the microbial community in a soil at a given time (White *et al.* 1996). Comparison of PLFA patterns of the same site over a period of time allows the assessment of changes in the microbial biomass at the community level (Bai *et al.* 2000). Modifications of the microbial community with respect to substrate utilization was investigated by using the BIOLOG-method (ECO-plates^{TM}) according to Widmer *et al.* (2001).

Materials and methods

Experimental design

The experiment was carried out at an rambutan orchard grown on alluvial soils in the Mekong delta where raised beds were constructed 16 years ago. A complete randomized block design was applied with four replications. Each plot has a surface area of 25 m^2, consisting of two 5 - years old rambutan plants. One set of plots served as a control (farmer's practice), while the other were treated with 10 t d.w. ha^{-1} sugar cane compost as a carbon source, biogas sludge compost as a nitrogen source, vermicompost as a carbon plus nitrogen source, and fresh Ox eye daisy (*Sphagneticola trilobata*) as a cover plant. Nutrient concentrations of organic substrates are given by Vo Thi Guong (Chapter V-4). *Trichoderma* fungi was added to all organic substrates. Likewise all treatments received low and balanced input of inorganic fertilizer (1.5 kg N, 1.0 kg P_2O_5 and 1.7 kg K_2O per plant and year) in comparison to the treatment of farmer's practice with only inorganic fertilizer (2.2 kg N, 1.5 kg P_2O_5 and 0.3 kg K_2O per plant and year). Basal application of 1.5 t ha^{-1} of $CaCO_3$ (36.10 % Ca content, 1.06 % Mg content) was mixed in all treatments. After fruit harvest following the first organic substrate application, a second amendment with the same rates were performed in the beginning of the second year.

For the soil microbial analysis composite soil samples (consisting of ten soil cores) of the top 10 cm of each plot were taken before the start of the experiment, after 3 and 12 months after the first organic amendment and 6 months after the second organic substrate application. Immediately after sampling, the soil was stored in a fridge until analysis. For organic carbon analysis the soil samples were dried at 105 ^oC.

Methods

Soil organic carbon was measured by dry combustion on an Elementar Maxi elemental analyzer. The measurement of the microbial biomass was done by the substrate-induced respiration (SIR) according to Anderson and Domsch (1986) and Heinemeyer *et al.* (1989) (DIN ISO 16072; DIN ISO 14240-1). From the basal respiration and the microbial biomass the metabolic quotient (qCO_2) was calculated, which serves as an indicator of the effectiveness of an organic substrate utilization (Wardle 1999). The activity of the aerobically living organisms in the soil was determined by the catalase activity according to Beck (1971). The specific reaction of the catalase is based upon the cleavage of the H_2O_2 molecule into water and oxygen.

Extraction of fatty acids was carried out by a dichloromethane - methanol mixture with a modified procedure according to Kästner *et al.* (2006). Derivatisation of fatty acids to fatty acid methyl esther (FAME) was performed with boron trifluoride as derivatisation reactant.

FAME were separated into a hexane phase, evaporated to dryness, redissolved in isooctane and analysed by GC – FID / GC - MS. The resulting FAME were used to characterize the microbial structure. According to Frostegård and Bååth (1996) Gram - positive bacteria are linked to branched - chain fatty acids while Gram - negative bacteria can be coupled to straight mono - unsaturated fatty acids. The C17:1, C18:0, C20:0, C20:1, C21:0, and C22:0 fatty acids were used to describe the bacterial biomass, while fungal biomass was identified by the unsaturated fatty acids C18:1n9t, C18:1n9c, C18:2n6t, and C18:2n6c. The ratio of fungal derived fatty acids to bacterial derived fatty acids was used as an indicator of changes in relative abundance of these two groups (Frostegård and Bååth 1996).
The utilization of carbon sources was analyzed by using the BIOLOG-method (ECO-plates™) as a modification described by Widmer et al. (2001). The BIOLOG ECO-plates™ contained 31 of the most useful carbon sources for soil microbial community (in 3 replicates). The microplates were incubated at 28 ^{0}C for 7 days, and substrate utilization was indicated by the coloration of the tetrazolium dye. Since the color diversity is a function of both the richness and the evenness (variation of color development) of the data, the classical Shannon-Weaver-index H could be calculated for the BIOLOG data (Zak *et al.* 1994).

Results and Discussion

Soil organic carbon

Soil organic carbon concentrations varied between 28 and 35 mg g^{-1} soil d.w. and showed partly quite a large variability within the plots (Fig. 1). While the soil organic carbon concentration tended to decline in the control plot, the values did not change much for the plots with the different organic amendments. The first application appeared not to increase the soil organic carbon concentrations as compared to the control. In contrast, six months after the second application, particularly the plots under sugar cane residue compost and biogas sludge showed larger organic carbon concentrations.

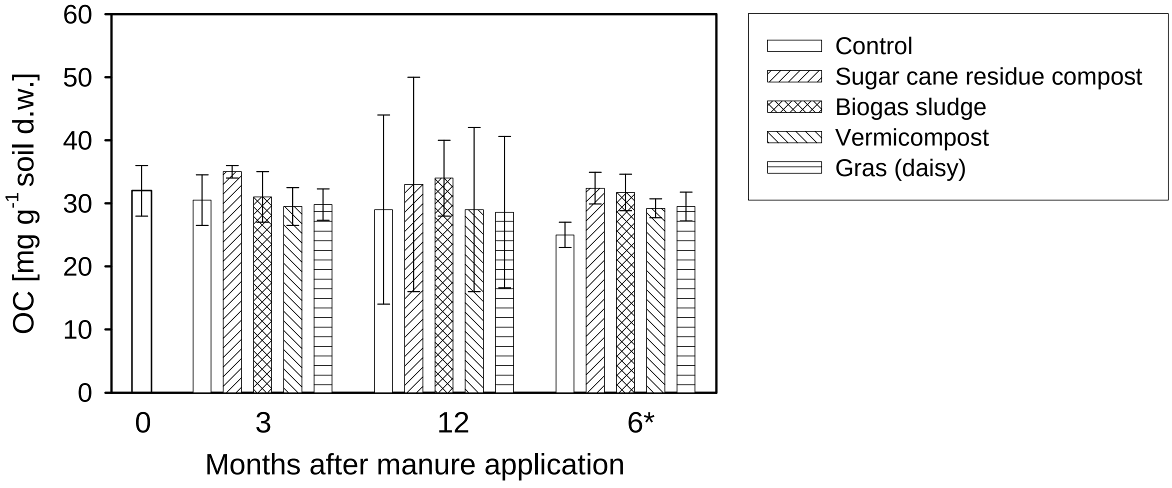

Figure 1: Organic carbon concentrations in soil after application of different organic amendments (6* indicates 6 months after the second application of organic substrates)

At an estimated soil organic carbon stock of 40 t ha^{-1} d.w. and an organic carbon application with the substrate of two times ca. 6 t ha^{-1} the organic carbon concentration must have theoretically increased by about 8 - 10 g kg^{-1}. The fact that only after the second amendment a slight increase was observed shows that the substrates were generally easily available and rapidly mineralized.

Microbial biomass and metabolic quotient

The microbial biomass in the control soils remained almost constant during the 18 months observation time with values of around 0.6 mg C_{mic} g^{-1} soil d.w. (Fig. 2). This corresponds to about 25 mg C_{mic} g^{-1} organic carbon, a value which is typical for agricultural soils but at the lower end of soils under forest or pasture (Sparling 1997). Microbial biomass responded to all organic amendments. However, 12 months after application of the organic substrates, the C_{mic} levelled off to the control value, indicating that the substrate have been cycled completely through the microbial biomass. In combination with the organic carbon concentrations (Fig. 1) this shows that the organic substrate application doesn't appear to be long-lasting and repeated application might be necessary to increase the microbial biomass. This can be seen at the last sampling point. The different organic amendments tended to have different effects on the microbial biomass. The least effect was observed in the Ox eye daisy treatment, which can be explained by the rapid disappearance of the vegetation cover. Of the three other treatments the nitrogen-rich biogas sludge appeared to have the strongest effect. In contrast, at the sugar cane compost application, being rich in carbon and poor in nitrogen, microbial biomass did not increase as much. According to Heimann and Reichstein (2008), this can be explained by possible nitrogen limitation and enhanced mineralization of the carbon and lignin-rich substrate under these conditions. The response of microorganisms to vermicompost was inbetween that to sugar cane compost and biogas sludge.

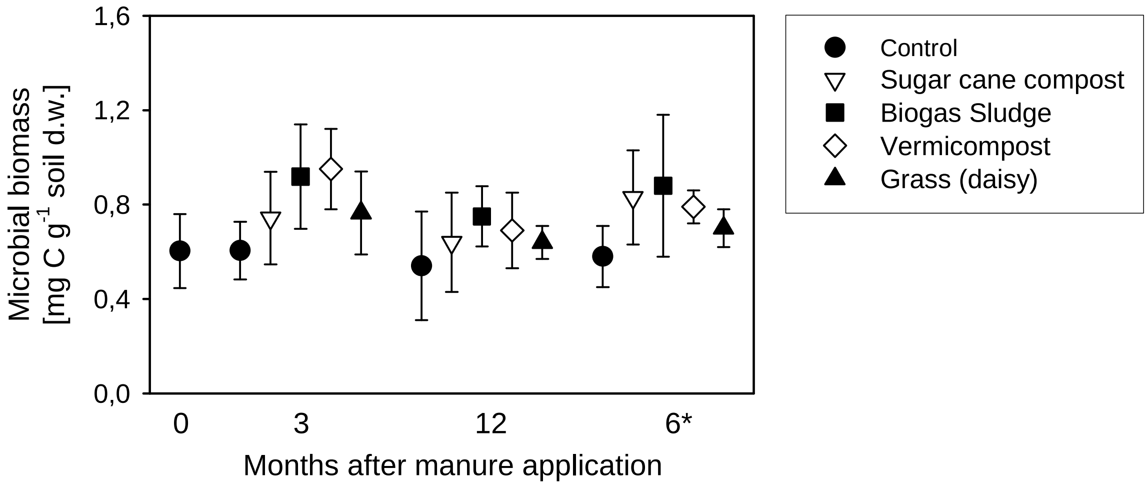

Figure 2: Microbial biomass in soil after application of different organic amendments (6* indicates 6 months after the second application of organic substrates)

The metabolic quotient (qCO_2) (Fig. 3) is equivalent to the maintenance energy requirements of the soil microorganisms (Anderson and Domsch 1985). The quotient can be used as a measure for the energy efficiency of a microbial community to mineralize organic compounds, with lower qCO_2 representing better energy efficiency (Wardle, 1999). All qCO_2 values of the soil under rambutan were large. qCO_2 values of about 9 to 18 are much larger than those found in temperate soils (Insam and Hasselwandter 1989, Anderson and Domsch 1993), and resembled those in soils polluted by heavy metals (Tischer and Priemer 1996). According to Anderson and Domsch (1993), this clearly indicated microbial community stress. The reason could be soil compaction (see Vo Thi Guong, Chapter V-4)) and frequent irrigation, which together caused pronounced anaerobiosis, as can be seen from hydromorphic conditions in the soil, and rotting fine roots (Guggenberger, Shibistova, Guong 2006, personal observation).

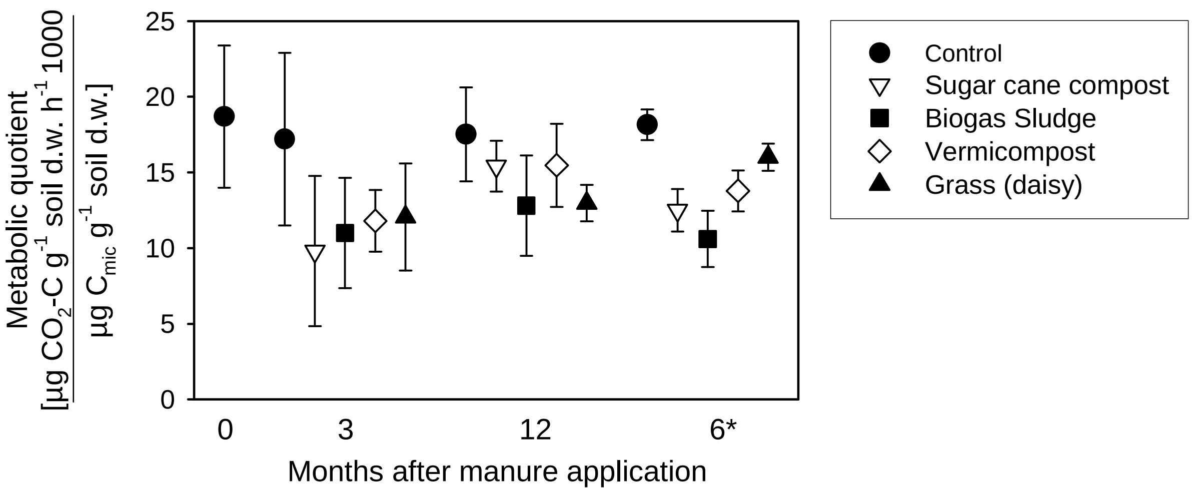

Figure 3: Metabolic quotient in soil after application of different organic amendments (6* indicates 6 months after the second application of organic substrates)

Organic substrate application reduced the qCO_2 values, proofing that indeed not a luxury carbon supply but rather stress was responsible for the high metabolic quotient. Generally, biogas sludge appeared to have the most pronounced effect. At the moment, it is not clear whether this can be attributed to the more favourable soil physical conditions or to the fact that biogas sludge is a nutrient - rich (particularly nitrogen) organic substrate, leading to a more efficient mineralization of the organic matter with relatively smaller losses of CO_2.

Phospholipid fatty acids

The sum of all PLFA identified ranged from about 700 to 1100 µg PLFA g^{-1} soil d.w. (Fig. 4). Based on the carbon contents of the individual PLFA and the organic carbon concentration of the soil, this calculates about 10 to 15 mg PLFA-C g^{-1} organic carbon. Similar values are reported by Bierke *et al.* (in preparation) for Chinese paddy rice soils. Generally, the PLFA, as representing cell-wall constituents of living microorganisms, showed the same trend with different organic substrate application as C_{mic} (Fig. 2). The relation between both sets of parameters is $r^2=0.456$; $P < 0.05$. Biogas sludge increased the concentration of PLFA more pronounced than the other treatments. Frequent occurrence of C16:0, C16:1 and C17:1 suggests the abundance of type – I - methanotrophic bacteria and Gram - negative bacteria, respectively. On the other hand, the concentration of protozoa biomarker C23:0 was small. Together, this indicates the rather unfavourable soil conditions with limited oxygen supply and small number of larger pores, which are the habitat for the soil protozoa.

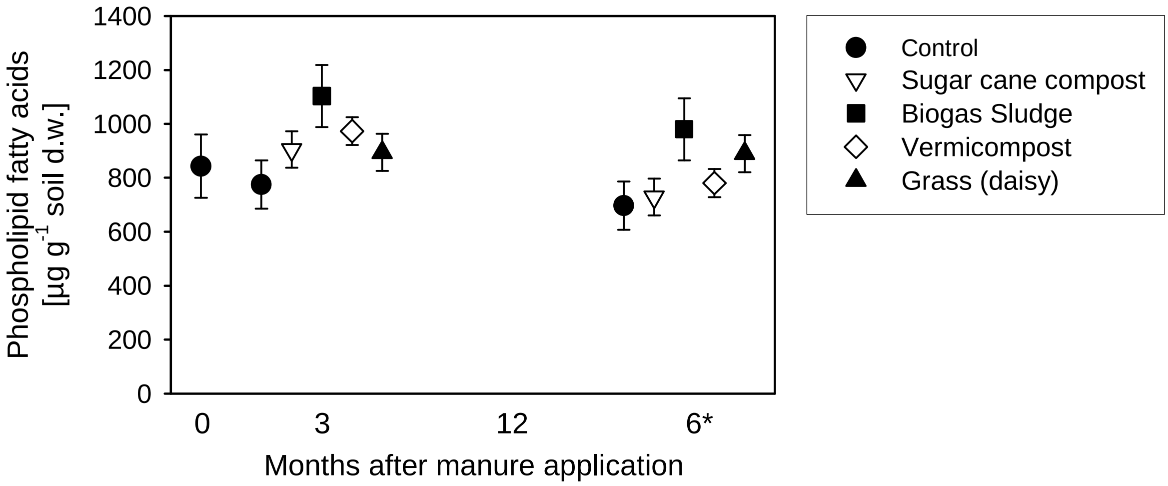

Figure 4: Total phospholipd fatty acids in soil after application of different organic amendments (6* indicates 6 months after the second application of organic substrates)

As compared to the total PLFA concentrations, the response of PLFA assigned to bacteria and to fungi was much more pronounced, at least for the first sampling date (Fig. 5). Organic substrate application did not alter significantly the concentration of bacterial biomarker PLFA but increased the concentration of fungal biomarker PLFA as compared to the control. This resulted in smaller bacterial PLFA – to - fungal PLFA ratios in the soils treated with the organic amendments. Bierke et al. (in preparation) also reported a larger proportion of fungal PLFA when organic residues have been added to a paddy soil. Increasing fungal biomass after application of organic residues may be explained by the fact that primarily fungi are responsible for the decomposition of rather fresh organic matter (Alexander 1971).
However, in particular for the plots with biogas sludge application, which showed the smallest bacterial – to - fungal PLFA ratios, this observation is astonishing because the biogas sludge itself was dominated by (anaerobic) bacterial PLFA (Shibistova and Arnold, unpublished). Obviously, the soil environment had a more profound influence on the PLFA pattern than the added substrate. The reason for the increasing fungal proportion in the microbial community, therefore, cannot be related directly to the organic substrate but rather indirectly. One explanation can be found in the publication of Schnurr - Pütz *et al.* (2006). By comparison of uncompacted with compacted forest soil, they found larger fungal proportion for the former, which they could clearly relate to the smaller bulk density and

more favourable pore size distribution. Since in our experiment soil structure tended to be better in the soil amended with organic substrates, in these plots the conditions were more favourable for fungi. However, also the added lime helped to improve soil structure. Consequently, with increasing time of the experiment the bacterial – to - fungal PLFA ratio declined also for the control plots.

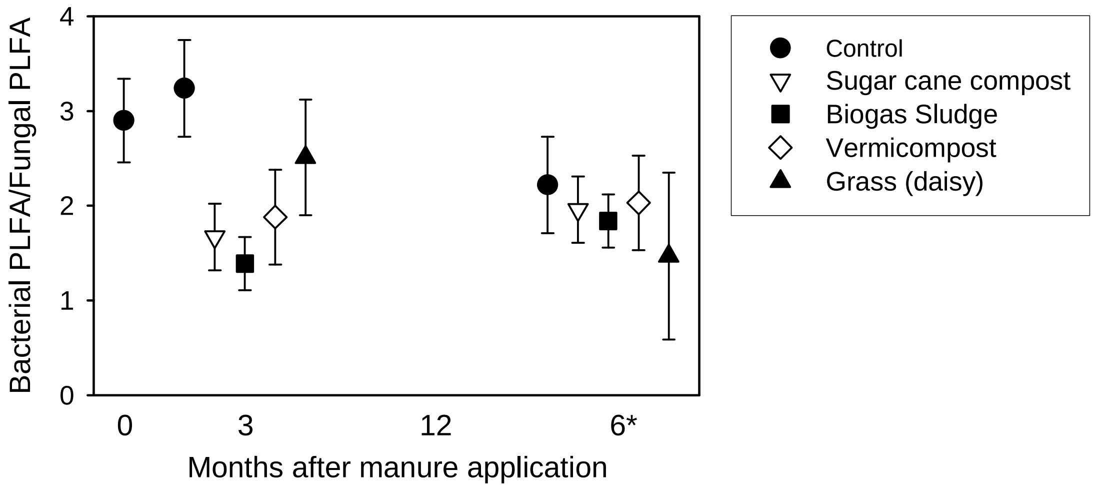

Figure 5: Ratio of PLFA assigned to bacteria to PLFA assigned to fungi in soil after application of different organic amendments (6* indicates 6 months after the second application of organic substrates)

Functional diversity

While PLFA gives some basic information about the structural diversity, the BIOLOG ECO-plates™ produce a metabolic fingerprint of the soil microbial community and thus inform about its basic structural composition. According to Figure 6, amendment of organic substrates did not alter much the functional diversity of the soil microbial community. An exception might be the treatment with biogas sludge, which resulted in a lower Shannon index and a shift in the response to the different substrates added in the BIOLOG experiment.

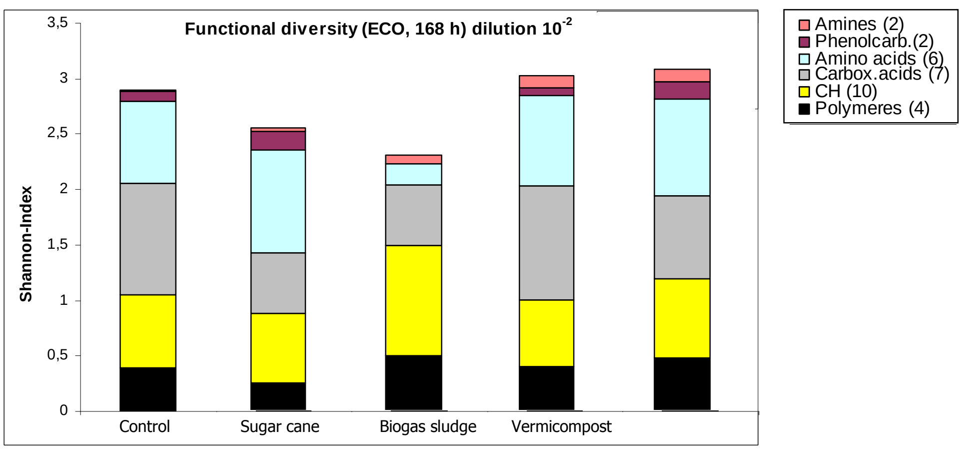

Figure 6: Functional diversity (Shannon index) as obtained from the BIOLOG ECO-plates™ of cultures from soil taken 12 months after application of different organic

Conclusions

The experiment showed that application of organic substrates to alluvial soil under rambutan orchard increases the microbial biomass, increases the efficiency of organic matter utilization and alters the composition of microbial biomass towards a larger share of fungi. However, there were differences in the response of the microbial community to the different substrates. Biogas sludge appeared to be most promising as an organic fertilizer. A larger microbial biomass together with the most pronounced decreasing metabolic quotient indicates a more efficient carbon and nutrient cycling in the soil as compared to the control and the other types of organic amendment. Sugar cane compost, being primarily a carbon source, appeared to be less efficient, likewise vermicompost. Ox eye daisy resulted in the smallest response caused by the relatively rapid die - off of the vegetation cover.

In general, organic amendments proofed to be beneficial to the soil environment. However, under these particular soil conditions it seems to be highly necessary that application of organic substrates is carried out together with liming in order to improve soil structure, i.e. the habitat of the microorganisms. Another measure to improve soil structure is the reduction of the amount of irrigation.

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BIOLOG	Analysis of metabolic fingerprints on microplates of the company Biolog Inc.
C_{mic}	microbial carbon
d.w.	dry weight
GC-FID / GC-MS	Gas chromatography-flame ionization detector/ - mass spectrometer
ECO-plates^{TM}	Microplate of the company Biolog Inc. designed for the microbial ecologist
FAME	fatty acid methyl ester
PLFA	phospholipid fatty acids
qCO_2	metabolic quotient
SIR	substrate-induced respiration

V-5: Testing of dried urine as a source of nutrients in a constructed food chain

Rudolf Hahlweg[14], Frank Panning[15] and Berit Hillbrecht[15]
[14] Engineering Bureau for Aquaculture and Environmental Technologies (IBAU), Germany
[15] Ingenieurbüro Dr. Frank Panning - Gsan Innovative, Germany

Keywords: dried urine, aquaculture, nutrient incorporation, stimulation of primary production, pond fertilization

Introduction

In many developing countries the use of domestic wastewater as a source for nutrients is common praxis in agriculture and aquaculture to stimulate the primary production. Especially urine is a highly concentrated nutrient solution. The technology of urine separation and drying improves the storage and the application of these nutrients and makes this product hygienically safer.

Material and methods

The urine used for these tests was collected and dried in Germany by Gewitra GmbH. The quantity was strong limited. Before drying the urine was divided into 3 charges, each was treated different to avoid losses of N. The amount of N, P, K, Ca and Mg in the dry product was analysed, results are shown in Table 1.

Table 1: Composition of dried urine

Parameter	Unit	Charge 1	Charge 2	Charge 3	Literature Allan (2004)	Literature Hoffmann, Wissing (2002)
N	%	4.91	8.23	7.19	17.1	15 - 19
P	%	2.62	2.75	2.19	1.6	1.1 - 2.2
K	%	6.21	5.07	5.75		2.5 - 3.7
Ca	%	0.76	0.58	0.32		3.2 - 4.3
Mg	%	0.16	0.08	0.07		

For application the three small charges were mixed. The substrate was easy to store and to apply. Tests showed a very high degree of dissolvability (see Fig. 1).

Figure 1: Dried urine and dissolved dried urine

The dry product was applied in concentrations of 0.5 and 1.0 g l^{-1}. As test organisms fish (*Carassius* sp.) and plants (*Lemna* sp.) were kept in plastic tanks. Each tank had a volume of about 600 l. The water for the first filling was taken from a pond. The amount of nutrients, algae and zooplankton of pondwater was not significant, but they were needed to start the food chain.

After three weeks of operation the tanks were stocked with fish (300 - 500 fingerlings per tank) and no additional food was introduced. The tanks were not aerated during the experiment. The temperature changed between 18 °C and 24 °C, pH was estimated between 7.2 and 7.4. The concentration of NH_4 at stocking time was estimated at 7.9 mg l^{-1} (1 g l^{-1} fried urine) and 4.9 and 5.3 mg l^{-1} (0.5 g l^{-1} dried urine). Five weeks after filling the tanks the levels of NH_4 were below 1 mg l^{-1}.

At the beginning of the tests and after 60 days the fish were counted and weighted.

Figure 2: Algae and Lemna as organisms in the level of primary production

Lemna was first time stocked in a quantity of 200 g after filling the tank and applying urine. Two or three times per week the plants were harvested and weighted during the time of tests. The limitation of material did not allow replications of tests.

Results and discussion

Fish

Carassius sp. is a zooplankton feeding fish which cannot utilize the primary production directly. The efficiency to recycle nutrients for better fish growth is higher when using plant feeding fish like silver carp or Tilapia. But these species were not available.

Table 2: Incorporation of nutrients in dependence from urine concentration and density of Fish

concentration dried urine	1g l^{-1}	0.5 g l^{-1}	0.5 g l^{-1}
Input N	39.4 g N	19.7 g N	19.7 g N
Input P	14.82 g P	7.41 g P	7.41 g P
Number of fish	300	300	500
Growth of fish (fm)	107 g	224 g	112 g
Survival rate	2 %	94.7 %	44.4 %
Incorporated N	1.99 g = 5.05 %	4.185 g = 21.2 %	2.09 g = 10.6 %
Incorporated P	0.55 g = 3.7 %	1.16 g = 15.7 %	0.58 g = 7.83 %
Sludge (dm)	200.6 g	208 g	190 g
N in mud	1.08 g = 2.74 %	0.590 g = 2.29 %	0.44 g = 2.23 %
P in mud	0.165 g = 2.22 %	0.199 g = 2.67 %	0.139 g= 1.88 %

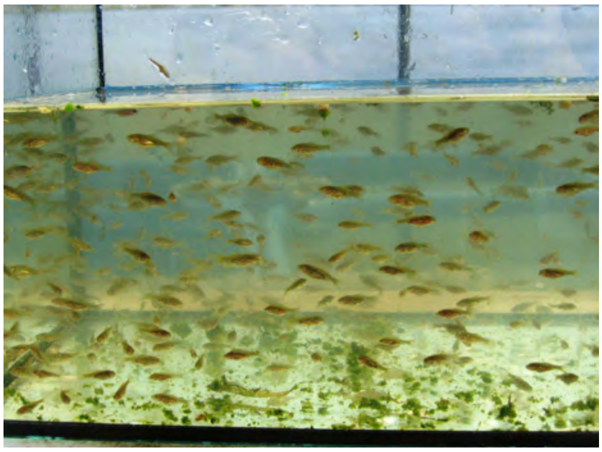

Figure 3: Daphnia, consumers of first level as food organisms for fish (left) Ornamental fish as target organisms in constructed food chain (right)

Best results were achieved with 300 fish per tank and a concentration of 0.5 g l^{-1} of.dried urine.

Compared to the other applications this approach showed best results for nutrient incorporation, fish growth and survival rate.

The results of approaches with higher fish densities (right site) are lower as the feeding pressure on zooplankton limited their development and thus the incorporation of nutrients for fish growth.

Concentrations of 1 g l^{-1} dried urine (left site) resulted in a toxic effect of nitrogen to fish. The high level of mortality caused low rates in nutrient incorporation.

In all applications we found mud in the tanks. Mud is the result of biomass from primary production that could not be utilized by fish.

The tests were made under the conditions of the European climate. The results show, that more research is needed to find the balance between nutrients input and species and biomass of fish. One important question is the concentration of urine and the frequency of application. Algae use ammonia as food and by this they can compensate toxic effects. The absorption of light in ponds could be used as a tool to decide the best feeding time and the amount urine applied.

Food chains in tropical countries work faster and allow higher yields in fish biomass. The results in Germany cannot be transferred to tropical conditions one-to-one.

Plants

Lemna is a fast growing water plant. It is very suitable as food for fish and animals.

Table 3: Growth and nutrient incorporation in Lemna at urine concentrations of 0.5 g l^{-1}

Concentration dried urine	0.5 g l^{-1}
input N	19.7 g N
input P	7.41 g P
Plant growth	1944 g (dm)
incorporated N	6.44 g = 32.70 %
inkorporated P	3.88 g = 52.36 %
Mud (dm)	0 g

In a 60 – day period the test showed a strong stimulation of plant growth due to urine application. Compared to fish higher amounts of nutrients were incorporated. At the end of operation the water was clear and there was no sediment in the tanks.

Conclusions and outlook

The tests showed the effects of nutrients from urine to the stimulation of a constructed food chain and the production of biomass. Application of hygienic safe urine or urine products can stimulate higher yields in fish production. More research is necessary to improve the efficiency of the urine application for biomass production and to minimize losses of nutrients. High concentration of urine can cause toxic effects and losses in fish.

The dried product from gewitra mbH (Chapter III-3) had good properties for storage, handling and application. The degree of dissolvability is very high. It is very suitable to use it as source for nutrients in aquaculture. For the use in large scale it is necessary to analyse the costs of production in comparison to other sources of nutrients.

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V-6: Effects of Urine on Growth of Alage

Vu Ngoc Ut[6], Tran Tan Huy[6], Frank Panning[15], Berit Hillbrecht[15] and Rudolf Hahlweg[14]
[6] College of Aquaculture and Fisheries, CanTho University, Vietnam
[14] Engineering Bureau for Aquaculture and Environmental Technologies (IBAU), Germany
[15] Ingenieurbüro Dr. Frank Panning - Gsan Innovative, Germany

Keywords: dried urine, aquaculture, nutrient incorporation, stimulation of primary production, pond fertilization, human urine, algae, phytoplankton, chlorella, NPK fertilizer

Introduction

Algae play a very important role in the aquatic environment. They are the first link in the aquatic food chain determining productivity of a water body. In aquaculture ponds, algae are either directly or indirectly cosumed by the farmed fish. Recently, algae are very much concerned in the shrimp ponds. Reasonable growth of algae in shrimp ponds helps create a crucial buffer layer to prevent fluctuation of many environmental factors, especially pH. Many species of fish such as silver carp, tilapia, silver barbs, etc. directly consume algae and their products depending upon productivity of algae in ponds (Drenner *et al.* 1984, Starling and Rocha 1990). Other fish are fed on zooplankton which relied on availability of the first link in the food chain. Algae are the major component producing oxygen which is absolutely necessary for respiration of aquatic animals and oxidation processes of degradable organic matters.

Algae growth can be increased in aquaculture ponds by application of either inorganic or organic fertilizers. Inorganic fertilizers often used to promote algae growth in ponds are the ones used in agriculture for plants or rice such as NPK, DAP or Urea. These fertilizers have an advantage that promptly induces growth of algae. Algae can grow immediately after a short time of application. However, algae will rapidly collapse after a few days of development. Frequent application of inorganic fertilizers is often recommended to maintain growth of algae in fish ponds. In contrast, organic fertilizers can maintain and last growth of algae much longer although initial development of algae is slower. Application intervals are therefore longer when using organic fertilizers. Poultry or livestock manures are the best organic fertilizers used in aquaculture ponds. Rice-bran or other organic matters are also used to induce growth of algae in ponds.

Feasibility to use human urine in agriculture was demonstrated by Kirchmann and Pettersson (1995) and Kvarnmo (1998). Potential use of human urine in aquaculture as nutrient for growth of green algae to zooplankton and fish was also mentioned (Adamson 2000). Golder *et al.* (2007) have confirmed human urine as an excellent liquid waste to culture food organism such as *Moina micrura*.

In Vietnam, especially in the Mekong Delta, fish culture has been rapidly developed. Application of fertilizers into fish ponds for direct or indirect use of fish is also increased. Use of human urine in fish ponds may help reduce production costs and increase culture effectiveness. On the other hand, contamination of human waste would be substantially mitigated if its application is extensively used for aquaculture. The objective of this study was to investigate the feasibility to use human urine for inducing algal growth and consequently increasing fish production.

Materials and methods

The experiment was set up in the 2 l beakers system. Six treatments were designed with three replicates in which 4 concentrations of urine including 0.1, 0.3, 0.5 and 0.7 g N l^{-1} were compared with NPK fertilizer (2 mg N l^{-1} concentration used in fish / shrimp ponds) and the control (without fertilizer). The experiment was randomly set up in a controlled temperature room at 28°C and 2000 lux luminous intesity. Water was taken from the river located behind the College of Aquaculture and Fisheries and filled in the beakers. Urine was supplied in liquid form (see Fig. 1) by the College of Technology with a concentration of 2.35 g N l^{-1}. Appropriate concentration of urine equivalent to the treatment dimension was calculated on basis of the nitrogen content in urine. After introducing the equivalent amount of urine in beakers, observation was maintained to record the day when algae start to grow and die-off. Algae were sampled every 10 days both qualitatively and quantitatively. Algae were counted and identified based on standard methods used at the Laboratory of Plankton Analysis in College of Aquaculture and Fisheries.

Figure 1: Liquid urine used in the experiment

Results and Discussion

Algal species compositions, density and growth duration were different between the treatments. The duration for algae growth was significantly different between urine, fertilizer and the control treatments. Algae, treated with NPK – fertilizer, grew rapidly after 3 days but collapsed within 7 days, whereas algae was less developed in in the urine treatments. The higher the concentration of urine the slower the algae developed. Time needed for algae to develop and grow was 6, 13, 22 and 38 days in 0.1, 0.3, 0.5 and 0.7 g N l^{-1}, respectively. However, at higher urine concentration once developed algae could last much longer. In 0.1 g N l^{-1}, algae had

Figure 2: Growth of algae in the first few weeks after setting up. The color (light or dark) indicates growth of algae. The first beaker on the left is the control with very light (clear) colour, next to it is 0.1, 0.3, 0.5, 0.7g l-1 and NPK fertilizer treatments.

maintained for 40 days before collapsing and recovered again after 7 days but the density was lower than before. In 0.3 g N l^{-1}, algae could prolong until the end of the culture but produced substantial suspended organic matter as a result of dead algae. In 0.5 and 0.7 g N l^{-1} algae maintained their growth until the end of the culture. However, initial development of algae was slower in 0.7 g l^{-1} (38 days compared to 22 days). In the control and NPK treatments densities of algae were very low manifested by very light color. While in 0.3 and 0.5 g N l^{-1} dark green colour was observed indicating higher density of algae (Figure 2).

Twenty four species of algae were recorded in all treatments. *Phylum Chlorophyta, Baccilariophyta and Cyanobacteria, Green algae (Chlorophyta) and diatom (Baccilariophyta)* were the most abundant groups (Table 1).

Table 1: Species composition of algae recorded in all treatments classified with phylum

No.	**OCHROPHYTA**	No.	**CYANOBACTERIA**
1	*Gramatophora angulosa*	1	*Anabaena sp.*
2	*Gramatophora sp.*	2	*Oscillatoria sp.*
3	*Melosira sp.*	3	*Phormidium sp.*
4	*Navicula sp.*	No.	**CHLOROPHYTA**
5	*Nitzschia longissima*	1	*Actinastrum sp.*
6	*Nitzschia longissima var. reversa*	2	*Ankistrodesmus sp.*
7	*Nitzschia sp.*	3	*Chlorella sp.*
8	*Pleurosigma rectum*	4	*Coelastrum sp.*
9	*Pleurosigma sp.*	5	*Crucigenia sp.*
10	*Suirirella sp.*	6	*Micractinium quadrisetum*
11	*Synedra sp.*	7	*Pediastrum sp.*
12	*Thalassiosira sp.*	8	*Scenedesmus sp.*
13	*Thalassiothrix sp.*		

The number of species was higher in the control and NPK treatments. However, *Chlorella* sp. appeared to be predominant towards the end of the culture period in all treatments (Table 2, at the end of this chapter). This species grew competitively and depressed other species of *Cyanophyta* and *Diatom* at the end of culture duration. Higher nitrogen concentration in urine may induce selectively *Chlorella* to grow and subsequently predominate in the culture. Through the culture period, the abundant law appeared to be very obvious as there were more species existing in an environment where no / any predominant species were found. When *Chlorella* sp. predominated in the urine treatments, the number of species was low compared to more species found in the control and NPK treatments.

The density of algae fluctuated significantly within and between treatments. At the first 10 days algae were hardly found in all treatments resulting in extremely low densities (uncountable). In the following 10 days, algae started to grow dramatically in the treatment 0.1 with very high density up to 10^8 cells l^{-1}. While in other urine concentration significantly lower densities were measured. The number of algae in NPK and control treatments was negligible (10^4 cells l^{-1} compared to 10^8 cells l^{-1}). In the third period of sampling (after 30 days of culture) densities of algae in all treatments gradually increased above 10^6 cells l^{-1} while in 0.3 the density reached 10^8 cells l^{-1}. Highest densities were obtained in treatments 0.3 and 0.5 during the sampling periods four and five (40 days and 50 days, respectively). However, in treatment 0.5 algae collapsed at day 60 due to contamination of *copepoda* but increased again 10 days later. Algae in treatment 0.3 were more stable at high densities compared to treatment 0.5, whereas in treatment 0.7, algae grew significantly slower and lower in density. There was also a difference in algae composition between the treatments at day 20. *Chlorophyta* accounted for 100 % in 0.1 and 0.5, while in 0.7 *Baccilariophyta* was the only group (100 %). Similarly, treatments with NPK and control contained a completely different algae group with 100 % of Cyanobacteria.

Blue - green algae has the ability to fix nitrogen (Fogg 1951, Wilson *et al.* 1979). In case of unavailability of nitrogen in the water, other algae are depressed but blue - green algae can grow, especially when nitrogen and phosphorus ratio is low (Sze 1998). However, when this ratio is high (greater than 15:1) green algae are favored due to their higher growth rate. Gross & Pfiester (1988) also reported that blue - green algae rarely occur in the environment when the N/P - ratio is above 29:1. *Chlorella* is known as the best green algae for aquaculture. This species contains a high nutrition value with high contents of HUFA (Highly Unsaturated Fatty Acid) (Fukusho 1983). They also help to improve water quality by reducing metabolic products from cultured animals (Orhun *et al.* 1991). Importantly, *Chlorella* can produce the anti-microbial substance chlorellin to depress some harmful bacteria (Sharma 1998). *Chlorella* has been widely used in the "green water" systems for prawn and mud crab larval culture and proved to benefit larval growth and survival (Tran Ngoc Hai & Truong Trong Nghia 2004, Truong Trong Nghia 2005). The larvae in green water system were better than those in clear water systems. Dominance of *Chlorella* could benefit the cultured species in aquaculture tanks or ponds.

In general, the treatments with 0.1, 0.3 and 0.5 g l^{-1} resulted in better growth of algae. In 0.5 g l^{-1} best results with highest density of above 10 billion cells per liter were recorded. Interestingly, urine produces selectively *Chlorella sp.* which is the best algae for aquaculture (for both, the fish itself, like Tilapia and the environmental buffer applied in freshwater prawn hatcheries). The concentration of 0.7 g l^{-1} seems to be toxic to algae. Although the algae could develop and grow in this concentration but at a slower rate and in poorer densities compared to the lower concentration of urine. Adamsson (2000), who used undiluted human urine for algal growth, also stated decreased growth due to ammonia toxicity. In comparison with NPK fertilizer, urine performs significantly better as the algae could maintain stably throughout the culture period with very high densities. Apparently, in the culture fertilized with NPK algae could only maintain 4 - 5 days and collapsed. This result reflects the practical situation in the fish ponds where regular application of fertilizer is always implemented to maintain the optimal growth and density of algae as feed for fish (Lewis 1998). However, when applying urine, algae can grow and maintain at a stable and high density during the culture period, making regular supplementation unnecessary.

Conclusions

Urine or dried urine can be used as an efficient fertilizer to promote algal growth. Algae maintained stable in the urine addition treatments compared to NPK fertilizer. The best concentration of urine for algal growth was 0.5 g N l^{-1} while 0.7 g N l^{-1} was toxic to algae. Application of urine could be an alternative to inorganic fertilizers in fish culture in the Mekong Delta. However, suitable concentration of urine should be investigated to prevent toxicity to cultured fish.

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Table 2: The occurrence of representative algal phylum and *Chlorella* sp through sampling periods in the urine treatments and control. U_0.1, U_0.3, U_0.5 and U_0.7 are treatments of urine with different concentration of N as 0.1 g N l^{-1}, 0.3 g N l^{-1}, 0.5 g N l^{-1} and 0.7 g N l^{-1}, respectively.

Sampling period	Species	U_0.1			U_0.3			U_0.5			U_0.7			NPK			Control		
17/10/06	**OCHROPHYTA**																		
1	*Nitzschia longissima*													+	+	+	+	+	+
1	**CYANOBACTERIA**																		
1	*Anabaena sp.*														+	+			
1	**CHLOROPHYTA**																		
1	*Actinastrum sp.*													+	+	+	+	+	+
1	*Chlorella sp.*																	+	
27/10	**OCHROPHYTA**																		
2	*Navicula sp.*											+							
2	**CYANOBACTERIA**																		
2	*Oscillatoria sp.*														+	+	+	+	+
2	**CHLOROPHYTA**																		
2	*Chlorella sp.*	+++	+++	+++	+++	+++	+++												
7/11	**OCHROPHYTA**																		
3	*Navicula sp.*	+	+									+							
3	**CYANOBACTERIA**																		
3	*Oscillatoria sp.*															+	+	+	+
3	**CHLOROPHYTA**																		
3	*Chlorella sp.*	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++		+	+
17/11	**OCHROPHYTA**																		
4	*Nitzschia sp.*			+											+	+	+		
4	**CYANOBACTERIA**																		
4	*Oscillatoria sp.*														+				
4	**CHLOROPHYTA**																		
4	*Chlorella sp.*	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++	+	+	+		
Sampling period	**Species**	**U_0.1**			**U_0.3**			**U_0.5**			**U_0.7**			**NPK**			**Control**		

27/11	**OCHROPHYTA**																		
5	*Pleurosigma rectrum*	+														+		+	+
5	**CHLOROPHYTA**																		
5	*Chlorella sp.*	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++	++
7/12	**OCHROPHYTA**																		
6	*Nitzschia sp.*		+		+						+			+	+	+		+	
6	**CHLOROPHYTA**																		
6	*Chlorella sp.*	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++
6	*Scenedesmus sp.*	+	+	+	+	+	+	+	+	+	+		+	+	+	+	+	+	+
19/12	**OCHROPHYTA**																		
7	*Nitzschia sp.*	+			+		+		+	+	+			+		+		+	+
7	*Pleurosigma rectrum*	+			+		+		+		+			+		+		+	+
7	**CHLOROPHYTA**																		
7	*Chlorella sp.*	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++
7	*Scenedesmus sp.*	+	+	+	+	+	+	+			+	+	+	+	+		+	+	+

"+" indicates the lowest abundance of the species in the population while "+++" indicates highest abundance

V-7: Use of Human Urine in Fish Culture

Vu Ngoc Ut[6], Tran Tan Huy[6], Huynh Truong Giang[6], Frank Panning[15], Berit Hillbrecht[15] and Rudolf Hahlweg[14]
[6] College of Aquaculture and Fisheries, Can Tho University, Vietnam
[14] Engineering Bureau for Aquaculture and Environmental Technologies(IBAU), Germany
[15] Ingenieurbüro Dr. Frank Panning - Gsan Innovative, Germany

Keywords: dried urine, aquaculture, nutrient incorporation, stimulation of primary production, pond fertilization, human urine, tilapia, fish culture, zooplankton, phytoplankton

Introduction

Fish are cultured popularly over the world and serve as an important food source for mankind, especially when the world population is dramatically increasing. Today, many fish culture models have been established to improve production and farmer's income. Rice fish culture has been practiced for at least 2000 years as it associates closely to the farmers and considered a suitable model in the rural areas. In the Mekong Delta of Vietnam, rice-fish culture has been developed and more and more enlarged. Mono-culture and poly-culture of fish in ponds are also the common models that have been practiced over the Mekong Delta. In these systems fish are usually fed with natural food which is induced by fertilizers. Improved fish production may be achieved by stocking fish fry into ponds which have been established with natural food such as rotifers or cladocerans (Morris and Mischke 1999). Poultry manure is one of the best sources of fertilizers recommended to use in fish ponds (Rangayya 1977, Little and Satapornvanit 1997). Use of organic fertilizers not only helps to stabilize the development of natural feed but also helps to reduce potential pollution caused by these waste sources.
In an attempt to find possible ways to reduce pollution generated from human activities and increase fish production this study was conducted to investigate the potential use of human urine in fish culture.

Materials and methods

The experiment was designed with 4 treatments including two concentrations of urine (0.1, 0.3 g N l^{-1}), N-P-K fertilizer (2 mg N l^{-1}) and the control (no fertilizer addition). The experiment was conducted in 2 m^3 tanks covered with transparent plastic sheet to protect from rain. Before filling in the water, the bottom of the tanks was inlayed with 10 cm of mud taken from a natural canal. Water was pumped from a fish pond and filled up to three quarters of the tanks. The urine was used in liquid form and contained a concentration of 2.35 g N l^{-1}. First application of urine was implemented by adding one-time the total amount of urine calculated, based on the concentration of nitrogen in urine for different treatments. In the following weeks urine was applied during the culture period by trickling method. NPK fertilizer was applied regularly every week. Phytoplankton was sampled before and after adding urine or NPK.

ilapias with an average weight of 2.76 g were stocked at a density of 200 individuals per tank when the concentration of nitrogen was optimal / stable after almost 20 days of urine addition. They were not fed during the culture period in all treatments. Regular sampling was implemented towards the termination. Water parameters including temperature, pH, DO, TAN, NO_2, NO_3, PO_4^{3-}, TN and TP were analyzed weekly together with phytoplankton and zooplankton. Phytoplankton was sampled using the settling method in a 1 l bottle, whereas zooplankton was taken with the zooplankton net of 60 µm mesh size. The net was filtered with 20 l of culture water taken from different sites in the culture tanks. The samples were fixed with formalin (2 %) and analyzed qualitatively and quantitatively.
The weight of fish was estimated monthly by sampling 15 fish per experimental run, the survival rate was calculated at the end.

Results and discussions

Temperature and pH

Overall temperature ranged from 27.5 to 33.9 °C and slightly decreased towards the end of the experiment. pH was higher in the urine treatments and fluctuated more than in the control and NPK. Mean pH in the morning and afternoon for the control, 0.1 and 0.3 g N l^{-1} ranged from 7.1 - 8.5, 7.4 - 9.0 and 7.4 - 8.3, respectively. Although the range of mean pH in the 0.3 g N l^{-1} experiment was low, fluctuation in one replicate was substantial and increasing to 9.4. There was a higher fluctuation of pH during the day and between the sampling periods in the urine treatments, compared to the control. This fluctuation was likely correlative to growth of algae.

Dissolved oxygen (DO)

DO was high at the beginning of the culture when algae were at peaks and decreased toward the end of the culture when algae started to decline (Figure 1). DO concentrations in the morning were higher in the control and NPK than in the urine treatments and vice versa for the afternoon, except in the last few sampling periods. The reason for this deviation is very likely linked to the algae densities. High concentration of algae may produce more oxygen in the afternoon when light is optimal but adversely consume more oxygen in the early morning. The decline and die - off of algae during the last few weeks of culture period may cause drop of oxygen even in the afternoon due to decomposing procedures. Highest DO concentrations were recorded in the urine treatments in the afternoon, up to 14 - 15 mg l^{-1}, particularly it was very high in a few days of May (up to 18 - 25 mg l^{-1}).

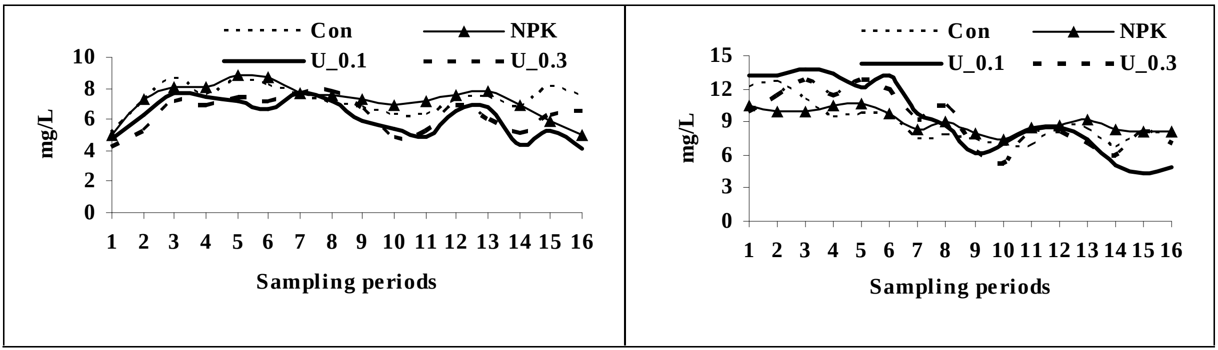

Figure 1: DO measured in the morning (left) and in the afternoon (right) in all treatments during 16 sampling periods (4 months)

Water turbidity

The clarity of the water in all treatments was measured using the Secchi disk and corresponding to algae density and solid suspension. As a result of denser algae, water clarity in the urine was significantly lower than that of the control and NPK treatments. In these treatments, algae grew well during the first few sampling periods but decreased afterward when nutrients were exhausted resulting in higherwater clarity towards the end.
Highest clarity was obtained in the control where no nutrients were supplemented. In the NPK treatment, although fertilizer was applied regularly every week, water clarity was still higher.

Total ammonia nitrogen (TAN)

TAN was high in the 0.3 g N l^{-1} treatment during the first few weeks (Figure 2). In one replicate (tank), high concentration of TAN coincided with high pH in the afternoon and resulted in mass mortality of fish in this tank. There was a deviation in TAN concentration and algae growth between two replicates of this treatment.
A sudden increase of TAN during the 6^{th} sampling period occurred again in this tank with a concentration of more than 80 mg l^{-1} and caused 100 % mortality of the remaining fish. However, in the other replicate, TAN was high but did not severely affect the fish. Towards the end of the culture, TAN in all treatments was stable at low levels (not greater than 10 mg l^{-1}) probably due to the constant activities of nitrifying bacteria communities.

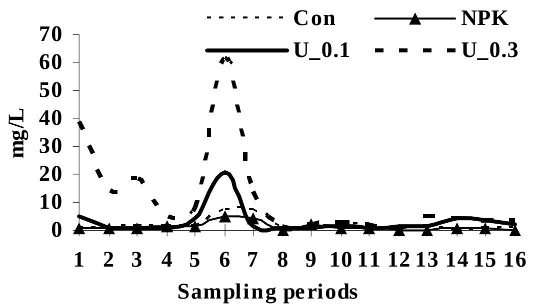

Figure 2: Mean TAN concentration recorded in all treatments during 16 sampling periods (4 months)

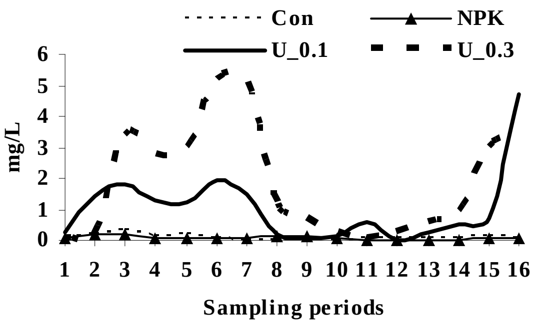

Figure 3: Mean NO_2^- concentration recorded in all treatments during 16 sampling periods (4 months).

Nitrite (NO_2^-)

Similar to TAN, nitrite was high and variable mainly in the urine treatments. As the results for nitrogen show transformation by nitrifying bacteria, nitrite increased in sequence with TAN. The increased concentration of nitrite in one tank of the 0.3 g N l^{-1} treatment in coincidence with high levels of TAN during the first few sampling periods had certainly killed the fish in the tank. According to Timmons *et al.* (2002) and Boyd *et al.* (2000), NO_2^- concentration in aquaculture ponds should be less than 1 mg l^{-1}. However, the mean concentration of NO_2^- in the 0.3 g N l^{-1} treatment was 1.89 ± 1.80 mg l^{-1} which is considered too high. Moreover, in some periods this factor was excessive greater than 4 mg l^{-1} (Figure 3).

Nitrate (NO_3^-)

Highest concentration of nitrate was observed in the 0.3 g N l^{-1} treatment with 12.5 mg l^{-1} during the 15th sampling period (1 week before termination). In most of the sampling periods nitrate was always greater than 5 mg l^{-1} which indicates the status of eutrophication including growth of algae.

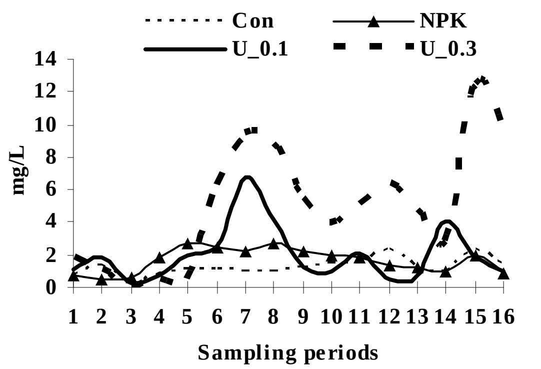

Figure 4: Mean NO_3^- concentration recorded in all treatments during 16 sampling periods (4 months).

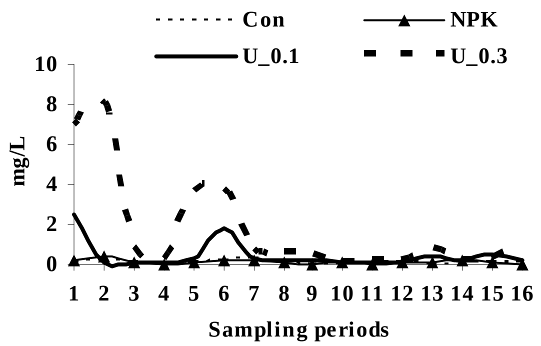

Figure 5: Mean PO_4^{3-} concentration recorded in all treatments during 16 sampling periods (4 months).

Nitrate in 0.1 g N l-1 treatment was also high especially after 2 months of culture period (Figure 4). High concentration of nitrate is not toxic to fish but indirectly causes fluctuation of pH due to increased growth of algae. Lawson (1995) stated that suitable concentrations for nitrate in fish production are usually less than 3 mg l-1.

Phosphate (PO_4^{3-})

Phosphate concentration was very low in the control and NPK treatments whereas it was very high in the urine treatments. This nutrient is a limiting factor for algae growth. With a concentration of 0.2 mg l^{-1} phosphate can induce rapid growth of algae (Lawson 1995). In the urine treatments, particularly in 0.3 g N l^{-1}, phosphate was exceeding this essential level especially at the first half cycle of culture period (Figure 5). This is the reason why algae were rapidly growing during these periods.

Total Nitrogen (TN)

TN in the urine treatments was obviously patterning following the application of urine. The concentration was high during the first sampling period when urine was added. The second peak appeared in the 6th sampling period and maintained stable at lower levels until the end of the culture. The highest concentration obtained in the 0.3 g N l^{-1} was 116 mg l^{-1} at the beginning. The lowest level was recorded in the NPK treatment with 1.5 mg l^{-1} (Figure 6).

Total phosphorus (TP)

Similar to TN, TP was also fluctuating in the urine treatments following the application periods. Highest concentrations were obtained in the 0.1 g N l^{-1} (19 mg l^{-1}) and lowest concentration was found in the control with 0.09 mg l^{-1} (Figure 8). Thus, when using urine phosphorus was increased and this is the essential condition for algae development and growth.

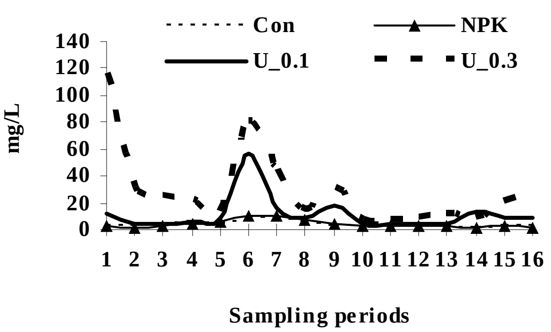

Figure 6: Mean TN concentration recorded in all treatments during 16 sampling periods (4 months).

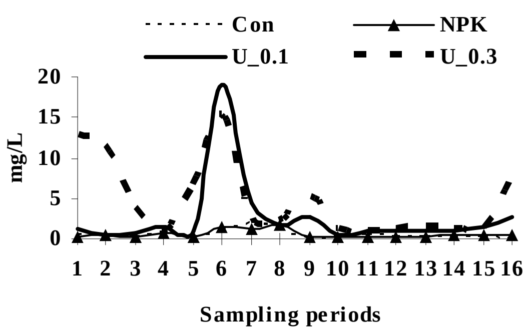

Figure 7: Mean TP concentration recorded in all treatments during 16 sampling periods (4 months).

Phytoplankton

There were 48 species of algae found in the experiment, belonging to 4 main phyla of *Chlorophyta, Baccilariophyta (diatom), Cyanobacteria and Euglenophyta*. The species composition structure was not significantly different between the treatments. Numbers of species observed in each sample was low as only 5 species were found per sample. Most of the algae species occurring in the culture are species indicating a nutrient enriched environment due to high nitrogen levels. The most abundant species with high densities are *Chlorella sp.*, *Tetraselmis sp.* (Chlorophyta), *Thalassiosira rotula* (Diatom), *Euglena sp.* (Euglenophyta). Although species composition structure was not significanty different, in the urine treatments the proportion of algae adapted with eutrophic environment such as Chlorophyta was higher (38 - 40 % with 12 to 13 species) compared to the control (only 14 % with 2 species). In addition, the total number of algae species in the urine treatments was also higher than that of the control (30 - 34 compared to 14).

The density of algae fluctuated between the sampling periods and treatments. In the urine treatments, algae grew much faster at higher densities. The highest density was found in 0.3 g N l^{-1} at the first sampling period (10 days after urine addition) up to 239 million cells l^{-1}, while in the control, with limitation of nutrients, algae did not grow well maintaining in a range of few thousand to few million cells per liter. Highest density of algae in this treatment was obtained in the first period when nutrient was available at the beginning and fresh water was taken from a fish pond (Figure 8-A). Algae in the 0.3 g N l^{-1} run dropped dramatically after the first period and maintained low during the following periods. If the first period was truncated from the graph, densities of algae in this treatment were much lower than those of the 0.1 g N l^{-1} (Figure 8-B). Too high nitrogen concentrations (up to 61.6 ppm) might affect growth of algae in a negative way, especially when temperature is high in the tank.

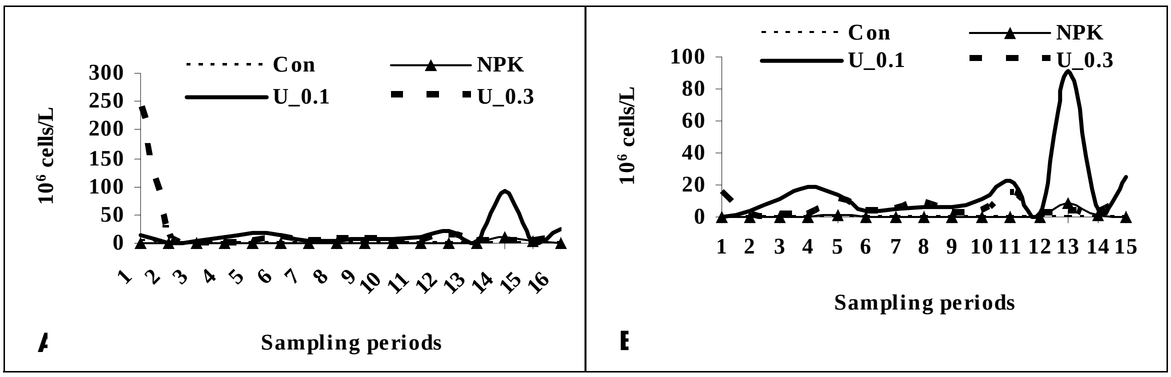

Figure 8: Growth of algae with during the culture period with (A) and without (B) a highest peak in 0.3 g N l^{-1} treatment at the first sampling period

Algae in the 0.1 g N l^{-1} were more stable and maintained at higher densities. In the NPK treatment densities of algae were substantially lower than those in the urine treatments but not higher than those in the control. Algae densities maintained from a few hundred thousands to a few millions cells per liter in this treatment during the culture period indicating the lack of nutrients to operate higher densities.

Zooplankton

Zooplankton found in the experiment belonged to four main groups including *Protozoa, Rotifera, Claodcera and Copepoda*. Rotifers were the most abundant group encountered in all treatments and samples (Figure 9). Rotifers are small in size and nutritionally very suitable to small fish. According to Bowen (1982) and Diana *et al.* (1991) tilapia juveniles prefer small sized zooplankton, especially rotifers. This group accounted for approximately 50 % of total zooplankton population in all treatments. However, quantitatively the rotifers predominated over the sampling periods in all treatments, especially in the urine treatments when nutrients were rich. They accounted for up to 100 % in some sampling periods (Figure 11). Highest numbers of zooplankton were obviously found in the urine treatments. Especially in the 0.3 g N l^{-1} treatment, with over 40 millions individual per liter of which 99 % were rotifers. *Brachionus angularis* was the predominant species occurring throughout the culture in the urine treatments indicating for a rich nutrient environment (Figure 12). Densities of zooplankton were also fluctuating during the culture period occasionally in accordance with phytoplankton fluctuation. It is very obvious that live food was promoted by fertilizers (urine) to support growth in the fertilized treatments. In the control and NPK treatments although, zooplankton reached some peaks but was significantly lower compared to the urine treatments.

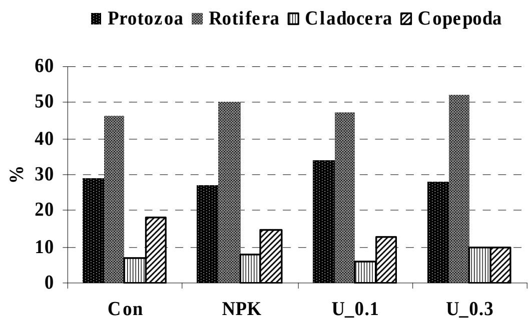

Figure 9: Proportion of zooplankton groups in different treatments during the culture period

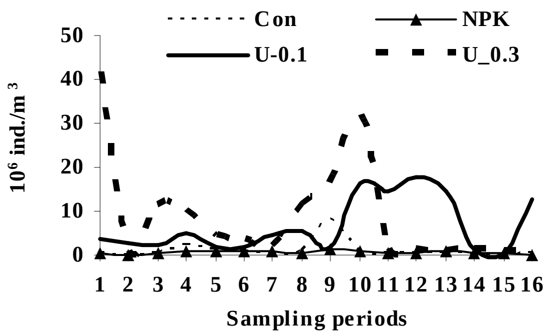

Figure 10: Densities of zooplankton fluctuated in different treatments

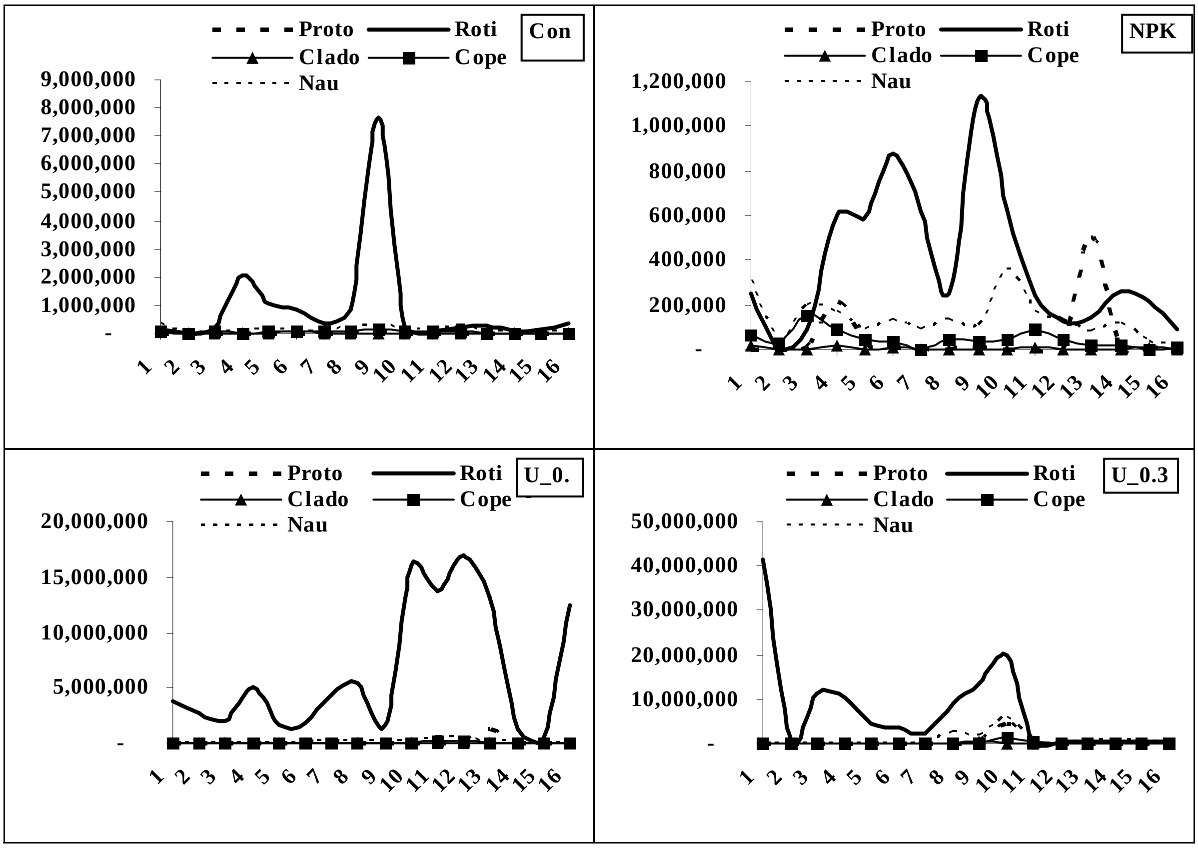

Figure 11: Densities of zooplankton during the 16 sampling periods in different treatment top left: Control; top right: NPK; bottom left: Urine 0.1 g N-1; and bottom right: urine 0.3 g N l-1. Rotifer was the predominant group in all treatments

Fish Growth

Tilapias were solely nourished by zooplankton and their growth was totally relied on this group which was basically dependent upon the algae induced from nutrient availability in the tanks. In the NPK and control live food quantity was not sufficient for fish subsistence and consequently causing high mortality in these treatments. Even the densities of zooplankton were extremely higher in the urine treatments growth of fish was still retarded.

It is very obvious that fish grew significantly better in the urine than in the control or NPK treatments (Figure 12-left). Although NPK fertilizer was given weekly, it was not possible to induce and maintain high and stable growth of algae, as the first link in the food chain, and to supply feed for fish. As a result algae and zooplankton densities were significantly low in this treatment leading to lower growth rate of fish. In the urine treatments (especially in 0.3 g N l^{-1}) live food developed well right away from the beginning, forming a rich food resource for fish. Rotifers were the main group growing predominantly in the culture in all treatments, especially the urine application tanks showed better growth rates for fish (Figure 12-right). However, due to high stocking rates the fish did not grow up normally. After 4 months of culture the biggest fish obtained was only about 12 g in weight. Specific growth rate of fish obtained in 0.3 g N l^{-1} treatment was 1.20 % day^{-1} which is triple than that of fish in the control and NPK treatments (0.39 and 0.41 % day^{-1}, respectively). Similarly, absolute growth rate (g day^{-1}) of fish in the 0.3 g N l^{-1} was 7 times higher than that in the control (0.07 and 0.01 g day^{-1}, respectively). Growth rate of tilapia in this experiment is substantially lower than that cited in paper by Rakocy (1989) who estimated growth of tilapia reared in tank at the same density (but much bigger fish, 100g) and fed with pellets at 1 - 2 % was 2.5 g d^{-1}. This indicated that although fish was supplied with very high density of live feed, there was not enough food for desirable growth or this stocking density is still high.

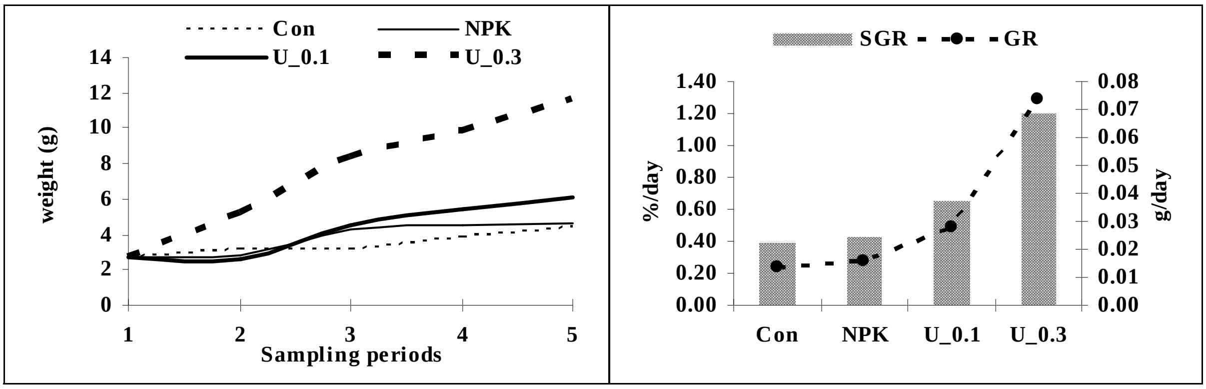

Figure: 12: Weight gain (left) and growth rate (right) of tilapia culture in NPK and urine fertilizers and without fertilizer after 4 months of culture in 2 m^3 composite tanks at density of 200 fish per tank.

Fish Survival

Fish died substantially at the beginning of the culture period, especially in 0.3 g N l^{-1}. The causes of death were different. In the control and the NPK runs starvation and predation due to shortage of food supply may be the reasons. In the urine treatment, a possible reason could be a toxic environment due to high urine concentrations. Up to 80 % of the fish population died after 2 weeks of stocking in one replicate and 69 % after 3 weeks in a replicate of the 0.3 g N l^{-1} treatment. Evans *et al.* (2006) exposed Tilapia to 2.0, 3.0, or 4.0 mg l^{-1} NH_3 and stated a mortality rate of 93 - 100 % within 24 h. The mortality of fish in this experiment inclined to 100 % at the fourth week in the first replicate, however, in the other replicate the rest survived until the end. Mass mortality, observed in one replicate of 0.3 g N l^{-1} treatment, was caused by high nitrogen concentrations (Figure 3). However, this big deviation between 2 replicates within a treatment remained unknown (possibly due to manipulation of water level, amount of urine addition, etc.). Fish mortality was different in different replicates of the same treatment resulting in high deviation within the treatment (Figure 14). High mortality only occurred at the beginning and no more significant mortality was recorded towards the end of the experiment. Although mass mortality was not observed in the control and NPK treatments after one month, the survival rates of fish were extremely low at the end (Figure 15). The reason for this may be cannibalism in terms of of high population densitiy and scarcity of food. Hecht and Pienaar (1993) reported that cannibalism can occur in fisheries in the cases of size variation, limited food or high population densities. Among these factors, food availability and size variation are considered the primary causes of cannibalisms (Hecht and Appelbaum 1988, Katavic *et al.* 1989). Cannibalism among tilapia fingerlings has been identified as one of the major problems in small-scale hatchery operators (Pantastico *et al.* 1988).

Highest survival rate was obtained in the 0.1 g N l^{-1} with 70.8 % in average (83.5 and 58 % in each replicate). Lowest survival was found in the control and NPK with only 4 - 5 %. Mediate survival was obtained in the other replicate of 0.3 g N l^{-1} treatment (28.5 %). Cannibalism in the 0.1 g N l^{-1} treatments was prevented by high feed availability (plankton) although fish densities were still very high (high survival) (Figure 9 & 11). However, high fish densities were also negatively affecting growth rate (Figure 13). Lower fish density and high food availability may be direct proportional to higher growth rate of fish in 0.3 g N l^{-1} treatment (Figure 13).

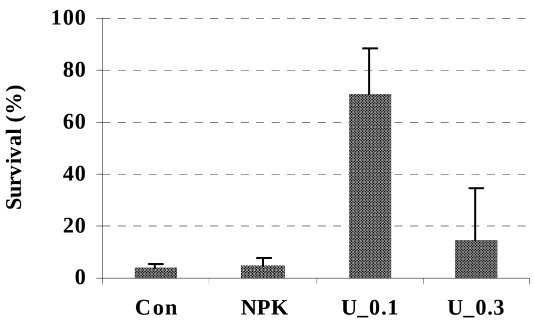

Figure 13: Survival of fish in different treatments.

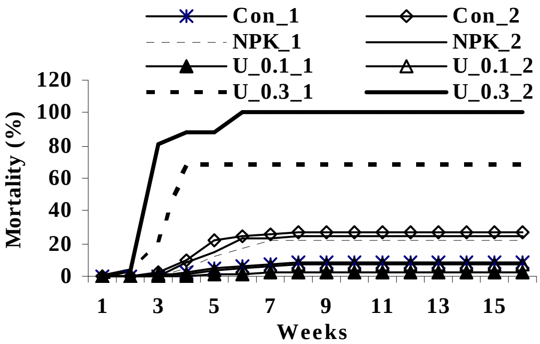

Figure 14: Mortality of fish in each replicate (tank) of each treatment through 16 sampling period observation

Conclusions and Recommendations

Urine or dried urine can be used as an efficient source to produce natural food supplied to fish culture. There are very clear effects of urine application on induction of natural feed in terms of phytoplankton (algae) and zooplankton growth from this study. Algae were blooming rapidly and stably in the urine addition treatments. Subsequently zooplankton population, especially rotifers as the most suitable food for fish juveniles, was established dramatically to support fish growth and survival. However, high concentration of urine must be taken into consideration to prevent toxic effects on fish. A concentration of 0.3 g N l^{-1} of urine seemed to be toxic to fish before the complete metabolism process took place (growth of plankton). Moreover, with high stocking densities of fish and without supplemental feed fish growth may be retarded. Suitable stocking densities of Tilapia cultured under urine application, separately in a tank and in larger scale applications like ponds, should be further studied.

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List of Abbreviations:	
DO	Dissolved Oxygen- determined by YSI meter
TAN	total ammonia- determined by Indo-phenol blue method
$N\text{-}NO_2$	Nitrite- titration with Diazonium method
$N\text{-}NO_3$	Nitrate- titration with Salicylate
PO_4^{3-}	Orthophosphate – determined by Ascorbic acid method
TN	Total nitrogen – determined by gas chromatography with Indo-phenol blue method
TP	Total phosphorus – determined by gas chromatography with Ascorbic acid method

Chapter VI: Implementation

VI-1: Acceptance Analysis for Application Opportunities of Urine Fertilizer in Agriculture in the Mekong-Delta

Christopher Scharfe[3], Huỳnh Thị Ngọc Lưu[4], Ralf Nolten[3]
[3] Institute for Food and Resource Economics, University of Bonn, Germany
cscharfe@uni-bonn.de
[4] College of Environment and Natural Resources, Can Tho University, Vietnam
htnluu@ctu.edu.vn

Keywords: Acceptance analysis, Urine fertilizer, Operating farm-households, Mekong-Delta, Farm-produced fertilizers, Application opportunities, Use of excrements

Introduction

Nutrients of human urine can supply a large amount of current nutrient demand in agriculture and are therefore seen as a potential substitute to mineral fertilizers (Lienert *et al.* 2003: 47). Consequently, separate collection of feces and urine aiming at efficient nutrient recycling and reuse of the processed urine as fertilizer is being propagated and investigated by scholars and research projects around the world (Hoff 2006).

When thinking about the introduction of a new decentralized sanitation concept for the Mekong Delta, which is based on this idea, the question arises whether or whether not the people, that are supposed to use the urine and apply it on the field are willing to do so. Thus, acceptance research is necessary, exploring the farmers' attitudes regarding the exposure to excrements, and factors influencing their decision-making-behavior, that is steered by more principles than just profit-maximization.

In the framework of SANSED phase I an empirical research regarding the acceptance of different interconnected innovations (modern latrines, biogas plants and biogas sludge in operating farm households (OFHs) in the Mekong Delta) was carried out (Wieneke 2005). As a follow-up, hence using the same holistic approach proven and tested in Wienecke's work, the socio - economic workgroup conducted further explorative investigations in project phase II, analyzing factors influencing attitudes of OFHs towards fertilizer made out of urine.

Major objectives of the research are:

- Assessing the nutrient demand and the actual commercial and self-producible fertilizer use in the research area, with special emphasis on the use of human and animal excrements.
- Analyzing attitude acceptance of farmers regarding the use of urine as fertilizer in plant production.
- Appraising marketing and application opportunities for human or animal urine collected in separating toilet systems like the ones installed and tested by the project.

Concept and Methods

As theoretical basis for the study acts Wieneke's Generated Model for Attitude and Acceptance Analysis (Wieneke 2005: 46f), which combines several socio - psychological theories and models on decision - making and acceptance of innovations as well as Doppler's definition of the operating farm household as socio - economic system (Doppler 1991: 15ff).

With this theoretical fundament in mind and an understanding of attitudes as consisting of cognitive, affective and conative components, analytical dimensions derive, building the logical framework for the research. These dimensions include the OFHs' social, economic, cultural, political and ecological environment as well as the three components of the OFHs' attitudes towards the innovation.

The use of fertilizers in plant production was taken as the sole criteria for the selection of households within the two communities. Besides that, random sampling was applied within the limitations given by local authorities. A total of 120 interviews in OFHs were realized, allocated equally with 60 interviews in Hoa An Community (Hau Giang Province) and 60 interviews in Long Tuyen Ward (Can Tho City). The respondents were chosen following their decision-making power concerning fertilizer procurement and application in their farms, thus usually the household head.

Pre - test and principal data collection were conducted by five Vietnamese interviewers, coordinated and supervised by the Vietnamese speaking German head of the workgroup in September 2007. A questionnaire with 72 closed and open questions served as basic instrument for data collection, resulting in an average length of approx. 40 minutes for one interview. Samples of the innovation under assessment, urine fertilizer in two variations, liquid and solid, were introduced to the interviewees in the course of each interview.

Results and Discussion

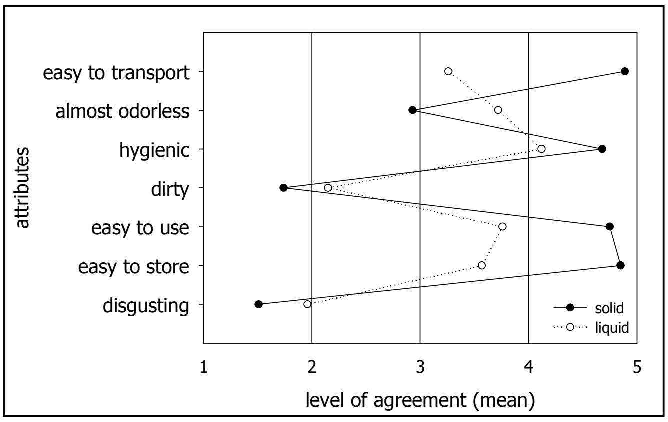
Setting

To understand the decisions farmers in developing countries make, knowledge about their farm-households' environment, including social and economic, but also cultural, ecological and political aspects, is crucial. A selection of key findings regarding the OFHs' environment is presented in Table 1.

As one objective of the study, detailed questions about the current use of fertilizer and organic matter in the research area were asked, aiming at the assessment of nutrient demand that can potentially be covered by urine. As can be seen in Table 1, almost all OFHs make use of the locally most common mineral fertilizers, urea (av. 348 kg $year^{-1}$), DAP (av. 334 kg $year^{-1}$) and NPK (av. 430 kg $year^{-1}$). Use of organic matter is low, with straw and field residue, compost and biogas sludge being the most prevalent forms, predominantly used in fruit growing and upland crop production. Only one respondent stated to use urine as fertilizer already. Being asked about past and estimated future developments of the volume of fertilizer use, 50 % of respondents noticed an increase in fertilizer use during the past three years. 53 % of those estimate further increases in the upcoming years, while only 10 % believed, they will use less fertilizer in future.

OFHs' Assessment of Urine Fertilizer

The OFHs' overall assessment of urine fertilizer, which was introduced to them in small samples during the interviews, is very positive. The farmers were asked to assess several cognitive as well as affective attributes of the fertilizer on a scale from one to five. While appraising cognitive aspects, such as transportability, smell and easiness to store the respondents were still left unaware, what the product they were holding in hand is actually made of. The moment of surprise after the revelation of the fertilizer's nature was used to measure affective aspects of the farmers' attitudes. The different items measured were used to aggregate an index of positive, neutral and negative attitudes towards the product.
Hence, 77 % of the respondents view urine fertilizer with a positive attitude. Only 23 % assessed it neutrally. No negative attitude was measured.
However, significant differences between the two versions of the fertilizer occurred, since there is a clear preference of solid (powder) against the liquid product (Fig. 1). While 94 % assessed the urine powder as positive, only 55 % did so with liquid urine, while another 41 % expressed a neutral and 4 % a negative attitude towards the latter (see Table 1).



These differences should be taken seriously, since processing of urine to a powder is more complicated and it might therefore be a constraining factor in the diffusion of the idea of OFHs' self-producing fertilizer with urine collected on their farm.

Figure 1: OFHs' Assessment of Liquid and Solid *Urine Fertilizer (n=120)* ***(1=I totally disagree, 5=I totally agree)***

Furthermore, different correlations to variables influencing the farmers' attitudes can be pointed out. Farmers of higher education than primary school assess both, liquid and solid urine fertilizer more positive than the others. Likewise, age and the duration of experience with fertilizer application has an impact. Farmers having used fertilizer since more than the samples average of 23 years (hence, older farmers) show a more positive view towards the liquid product, while the solid one is preferred by the ones using fertilizer since less than 23 years. However, the most interesting correlation could be found between those farmers that already used excrements in any form on their farm and those who didn't. 65 % of excrement-users stated a positive view on urine fertilizer, while only 54 % of non-users did so. Since the sample size of users makes up only 20 OFHs, further investigations to proof significance of these data is necessary.

Table 1: Selection of key findings describing the environment and attitudes of the operating farm households surveyed*

	Category		Unit	Total Survey, n=120	Hoa An, n=60	Long Tuyen, n=60
Social	age of respondents (av.)		*(years)*	46	47	45
	family size (av.)		*(heads)*	5	6	5
	sex ratio	male	*(%)*	80	82	78
		female		20	18	22
	ethnicity of respondents	Kinh	*(%)*	98	97	100
		Khmer		2	3	0
	toilet system installed (multiple answers)	fishpond	*(%)*	83	88	77
		WC		26	23	28
Economic	annual income	> 19.2 Mio. VND	*(%)*	74	82	77
		<= 19.2 Mio. VND		26	18	33
	income by source	on-own farm	*(%)*	78	81	74
		on-other farm		1	2	1
		off-farm		21	17	25
	farmed land per OFH (av.)	total	*(ha)*	1.28	1.76	.8
		paddy		*.22*	*1,27*	*.22*
		fruit orchard		*.27*	*.13*	*.41*
		sugar cane		*.12*	*.25*	*.0008*
		upland crops		*.08*	*.005*	*.16*
	livestock per OFH (av.)**	chicken	*(heads)*	14	13	15
		duck		15	25	5
		pig		2	3	.9
		cattle		.02	0	.03
Use of Fertilizer	use of commercial fertilizer	urea	*(%)*	97	100	93
		DAP/ P-fertilizer		93	93	92
		NPK		93	95	92
		organic commercial fertilizer		47	48	45
	use of self-producible fertilizer	biogas sludge	*(%)*	16	5	27
		compost		23	8	37
		vermi-compost		4	0	8
		untreated feces		13	7	18
		urine		1	0	2
		straw / field residue		51	43	58
		green manure		5	3	7
Attributes of Urine Fertilizer	positive assessment of urine fertilizer	general	*(%)*	77	70	83
		liquid		*55*	*47*	*63*
		solid		*94*	*93*	*95*
	reservations to consume food fertilized with urine	general	*(%)*	11	12	10
		human		*11*	*12*	*10*
		animal		*11*	*12*	*10*
	disposed to use urine fertilizer	general	*(%)*	91	92	90
		human		*91*	*92*	*90*
		animal		*89*	*88*	*90*
	disposed to produce urine fertilizer		*(%)*	86	90	82
	disposed to collect urine from neighbors		*(%)*	47	52	42

** percentages are rounded, ** rounded if above 1*

Key Factors Influencing OFHs' Production and Use of Urine Fertilizer

Before considering the possibility that OFHs recycle urine accruing on their farm as a fertilizer, it is important to examine two other aspects first: are consumers willing to eat food that was fertilized with urine and are the farmers disposed to use such fertilizer in their daily work?

OFHs' disposition to consume food fertilized with urine

As shown in Table 1, the share of respondents having reservations to consume food which was fertilized with urine, amounts to only 11 %, with no differences between human or animal urine. However, these reservations are correlated to different variables of which the attitude towards the urine fertilizer is the most apparent. Respondents indicating a positive attitude towards urine fertilizer in general, have with 9 % far less reservations than those having a neutral or negative attitude, amounting to 19 % calling to have reservations. Again, the use of excrements shows another correlation. Users' have far less reservations of 5 % than non-users with 12 %. Similar correlations can be pointed out with income-groups, where farmers with higher annual income utter more reservations than poorer farmers, or, the number of different kinds of fertilizers, that farmers are aware of. Farmers that know more than ten kinds of mineral or organic fertilizers tend to have fewer reservations than those knowing less. A possible explanation for this is, that the former dispose of more knowledge about fertilizer in general and therefore of more cognitive considerations that outweigh reservations of affective nature.

OFHs' disposition to use urine fertilizer in agricultural production

The general disposition to apply fertilizer made out of urine is high. 91 % of all respondents replied that they would use human urine to fertilize (see Table 1). Only slightly less, 89 %, are willing to use animal urine as well. Of course, these numbers only depict a principal willingness to use and can not predict, whether the idea of urine fertilizer will be successful in the long term.

Again, several variables of the OFHs environment could be pointed out to have possible correlations to the OFHs disposition to use. 94 % of farmers that positively assess the fertilizer samples are willing to use it, while only 82 % of farmers that have a more neutral or negative attitude show themselves disposed to do so. 100 % of excrement users showed themselves willing to apply, while out of the non-excrement users only 89 % responded they would do so. Another correlation found concerns education. The more educated farmers show more disposition to use urine than the less educated. Prestige of the exposure to excrements is another important factor. Those farmers, believing that other people would judge their use of excrements as negative are less likely to give urine fertilizer a try.

Regarding the origin of the urine to apply, whether it derives from ones own farm or from a larger production plant, out of 109 OFHs disposed to use urine, 64 % showed themselves open for both, while 17 % prefer urine from their own production and 18 % urine produced and processed somewhere else.

OFHs' disposition to produce urine fertilizer

Being asked if, and under which conditions they would be ready to produce urine fertilizer with the urine accruing on their farm (provided that they had the knowledge, and technical equipment to do so), only 14 % of OFHs answered, that under no condition they would produce. 41 % of OFHs would produce, under the premise, that they can safe costs for buying commercial fertilizers. 32 % of respondents stated that they would take issues such as safety and effectiveness into consideration before starting with production. While 27 % of those willing to produce stated they would only do so for their own consumption, 26 % are willing to also sell their products additionally. Those farmers, more likely to refuse a production are significantly older, less educated, have smaller families, have less income and savings, smaller consumption of urea fertilizer than the samples' average of 348 kg $year^{-1}$, and a stronger belief that the use of excrements is being looked down on by others.

47 % of OFHs showed themselves open to the idea of collecting urine from neighbors in order to start a small-scale business by selling processed urine as fertilizer. However, regarding the question of market production, again significant differences among different OFH groups appear. The farmers more disposed to open a urine business are younger of age, more educated, have larger families and belong to the higher income groups. They dispose of a larger area of farmed land, and a higher consumption of mineral fertilizer. Also farmers having experience in the use of excrements already show more interest in producing to sell. No correlation to the current share of off-farm/on-farm employment of farmers could be found. Since details of requirements for production were not addressed during the interviews, different factors such as affective reservations or lack of knowledge about the nutritional value of urine fertilizer might have led to the similar result of these two groups.

Conclusions and Outlook

The OFHs surveyed almost exclusively use commercial mineral fertilizers in plant production. Large nutrient demand is therefore given with increasing tendency. Most farmers are aware of the possibilities of the self-production of organic fertilizers with excrements accruing on their farm, but very few actually do so, since animal husbandry (cattle and pigs) is rare and fluctuates with market-price situations (for e.g. pigs). Because self-production of urine fertilizer requires larger daily amounts of urine, other areas in the Mekong-Delta, with higher shares of livestock per OFH should be envisaged.

Farmers' attitudes towards urine fertilizer are predominantly positive, acceptance is exceptionally high. However, several factors can be pointed out, that might have positive influence on acceptance. Farmers that are young, more educated than the average, have higher income and saving rates and that make use of excrements on their farm already are more likely to accept using and self-producing fertilizer out of urine. Furthermore, prestige of the use of excrements is found to play a central role. Perceived social pressure and the farmers' motivation to comply, influence their attitudes and therefore acceptance of use and production. Image campaigns (e.g. via mass organizations, extension service) for safety, cultural compatibility, nutritional value and effectiveness of the use of urine fertilizer might be helpful measures preceding introduction or diffusion programs. In local model farm households close to the farmers, pilot systems could be installed to give comprehensible proof of feasibility and profitability of the innovation. On proving grounds on local level, where crops fertilized with urine can be compared to crops not fertilized, the farmers can assure themselves about the product's efficiency and effectiveness. In a next step, measures could be taken, to make farmer's disposition to produce as a premise for benefiting from agricultural extension services. Due to the small sample size of 120 OFHs, this survey has an explorative character only. However, it might give important hints for directions further investigations may concentrate on.

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List of Abbreviations	
av.	average
DAP	Diammonium phosphate fertilizer
NPK	Nitrogen-Phosphorus-Potassium fertilizer
OFH	Operating farm-household
P-fertilizer	Phosphate fertilizer
SANSED	Project "Closing Nutrient Cycles in Decentralized Water Management Systems in the Mekong-Delta"
VND	Vietnamese Dong (1 USD ~ 16,800 VND)
WC	water-closet with toilet bowl (with or without automatic flush)

VI-2: Water and sanitation-related hygiene behaviour

Susanne Herbst[2], Simon Benedikter[2], Ute Koester[2], Phan Thị Trung Ngọc[*], Nguyễn Phú Quốc[*], Andrea Rechenburg[2], Thomas Kistemann[2]

[2] Institute for Hygiene and Public Health, University of Bonn, Germany
susanne.herbst@ukb.uni-bonn.de
[*] Faculty of Public Health, Medical University of Can Tho, Vietnam

Keywords: behaviour, health perception, household water management, sanitation, water

Introduction

Progress in access to drinking water in adequate quantity and quality as well as to improved sanitation is essential to reduce the incidence of faecal-orally transmitted diseases. In Vietnam, the overall access to improved drinking water supplies increased from 65 % to 85 % between 1990 and 2004. Over the same period, the sanitation coverage increased by 25 % (United Nations 2006). The Mekong delta, in the south of Vietnam, is home to around 18 million people, of whom approximately 14 million live in rural areas. According to estimates, about 5.7 million lack safe drinking water and in these still underprivileged rural areas 10 million people live without adequate sanitation (Vietnamese Academy of Social Sciences 2007).

As part of the SANSED project and sub-contracted by the Dep. for Environmental Engineering + Ecology, Faculty of Civil Engineering, University of Bochum, the Institute for Hygiene and Public Health, University of Bonn, Germany, studied local hygiene behaviour concerning drinking water sources, treatment methods, storage and handling, and sanitation issues. During a pre-survey in 2003, it was found that people use multiple water sources for drinking purposes and household needs. Furthermore, the application of physical and chemical treatments, even to improved drinking water sources such as piped and already treated groundwater, was observed. Even more surprisingly, piped groundwater seems to be rejected for drinking purposes by the population. Instead, rainwater and surface water are preferred. These findings were the reason for the design of the present study on the perception of water and health, and health-related hygiene behaviour taking into account cultural and traditional practices relating to water and health.

Material and Methods

To obtain insight into the complex water, sanitation and behaviour linkages, the study employed a combination of quantitative and qualitative methods. One component was a household survey collecting data on family structure, socio-economic situation, access to water and sanitation, water management practices, perception, awareness, attitudes and hygiene behaviour regarding water and health. Standardised questionnaires, containing open - ended and closed - ended questions, were completed for 120 households in the peri-urban community An Binh. Other components of the study were semi-structured interviews and focus group discussions. Focus group discussions utilising Venn diagrams, seasonal calendars, mind mapping, hygiene and problem ranking exercises were conducted with a male, a female and a children's group.

The selected households are situated within the service area of a water supply station abstracting groundwater with a capacity of 6,000 litres per day. The water treatment comprises rapid sand filtration with sand and activated charcoal. Due to high demand for more piped household connections and suitable hydrological conditions, it was intended to upgrade the water supply station. Taking into account the results from the pre-survey, it was decided to study first the contradictory facts, demand versus rejection of ground water for drinking purposes and associated issues. Of the 120 surveyed households, 53 % have a piped connection to the water supply station. The field work was carried out between May and September 2007 in Can Tho province, Vietnam.

Results and Discussion

This study confirmed the observation that in the Mekong delta various water sources are utilised for drinking water purposes (Figure 1). A large proportion of the surveyed households indicated the utilisation of two or more water sources to cover drinking water needs during rainy (55 %) and dry seasons (42 %). Overall, the most popular drinking water source is bought purified water (38 %), followed by rainwater (34 %) and groundwater from the water supply station (18 %). The reasons for these preferences were indicated as being hygiene concerns (87 %), socioeconomic situation (2 %), spiritual reasons (1 %) and others (10 %).

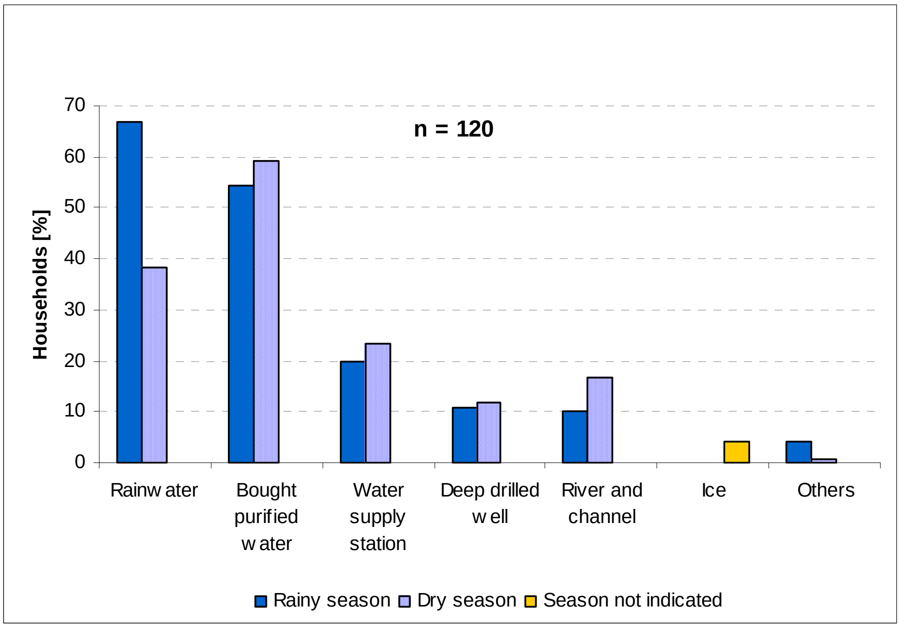

Figure 1: Utilisation of different drinking water sources during rainy and dry seasons

It was expected that the practices regarding water and health-related issues would be driven by traditional and cultural considerations, but this assumption could not be verified for the water sources used for drinking and household purposes. The fact that hygiene concerns are reported as the basis for the choice of preferred drinking water source shows that respondents clearly link hygiene to health.

Considering the actual use of different water sources, it becomes clear that during the rainy season rainwater is the most important drinking water source (67 %), while during the dry season the use of alternative drinking water sources increases (Figure 1). A measure to prevent contamination in rainwater harvesting is the collection of runoff water from roofs not directly after the onset of rain, but after the dirt from roofs has been washed off. Of the households practising rainwater harvesting, 28 % collect rain water immediately, 14 % after 5 minutes and 55 % 5 to 15 minutes after it starts raining.

In total, 98 % of the households store water in their homes. Even the majority of the households, which are supplied with groundwater by home connection directly from the water supply station, store water (always 69 %, sometimes 7 %). The reasons for the storage of drinking water from the water supply station were specified as intermittent supply (64 %), sedimentation (17 %), and others (19 %). Water is mostly stored inside the house within clay jugs (42 %), plastic barrels, tanks and flasks (51 %). Taking care of the treatment and storage of both water for drinking purposes and household needs is a predominantly female issue, which is carried out mostly by the wives of the household heads (44 %), female household heads (26 %) or daughters – in - law (9 %).

People assess the quality of drinking water according to visible contamination (43 %), turbidity (18 %), odour (18 %) and other factors (20 %). The majority rated the quality of their drinking water source as good (70 %). Water from all drinking water sources is boiled before consumption, more or less on a regular basis (Table 1). For the treatment of rain water, a cloth filter is often used (67 %). Aluminium sulphate is used to enhance the flocculation of suspended particles in surface water and water from drilled wells. Such treatment points to the fact that people are aware that access to good drinking water sources does not necessarily imply that the water is hygienically safe.

Table 1: Treatment methods applied to drinking water from different sources

		Treatment methods applied to drinking water				
Water source		**Aluminium sulphate**	**Cloth filter**	**Binh loc**	**Boiling**	**Others**
	n*	**HH**[%]**	**HH**[%]**	**HH**[%]**	**]**	**HH**[%]**
Rainwater	79	1	67	8	46	5
Water supply station	29	10	3	14	83	0
Drilled Well	13	69	15	0	77	0
River/ Channel	20	85	0	10	80	0
Bought purified water	70	0	0	0	6	0

*number of households

** households

Most of the households which apply household drinking water treatment apply it on a comparatively regular basis (Table 2).

Table 2: Frequency of drinking water treatment from different sources

		Treatment frequency of drinking water		
Water source	**n***	**Always HH** [%]**	**Sometimes HH** [%]**	**Never HH** [%]**
Rainwater	80	65	14	21
Bought purified water	70	3	6	91
Water supply station	28	71	11	18
Deep drilled well	14	86	7	7
River and channel	19	89	11	0

*number of households
** households

Seventy four percent of the surveyed households indicated ownership of a sanitation facility, which for 41 % is exclusively utilised by the family members. The predominant sanitary facility utilised is the fish pond toilet (64 %). Other common sanitary facilities are pit latrines (17 %) and flush toilets (13 %). Even though fish pond toilets are prohibited and represent an unimproved sanitation type, the majority of the respondents (77 %) are satisfied with the current sanitary situation. About 57 % would be willing to invest in an improved sanitation facility, if this would be subsidised to a level of 50 %.

Personal hygiene is another important factor in faecal-oral disease transmission. In particular, hand washing should be practiced thoroughly by everyone after defecation, after cleaning a child who has defecated, after disposing of a child's stool, before preparing food, and before eating. Hand washing is regarded as essential by 90 % of the respondents and practiced by 40 % before preparing food, 43 % before eating and 51 % after defecation. To an open question, out of those households with children under the age of 5, only 9 % indicated that they washed their hands before feeding babies and 18 % after handling infant excreta. In contrary, the direct question on washing hands after defecation was answered in the affirmative by 97 %. As hands are most often washed when they are visibly dirty, using soap or another type of detergent is very common. The average hand wash frequency indicated is 6 (median) times per day, with a range from 2 to 6. The contradictory facts on hand washing behaviour pinpoint a gap between the personal assessment of risks and actual practice. This is emphasised by the practice of taking a shower or a bath either in a bathroom (86 %) or in the river (44 %). As rivers are often visibly polluted with contaminants such as garbage and faecal matter, it is very surprising that people who have an idea of basic hygiene bath there.

Similar to results from Central Asia, overall diarrhoea is perceived differently according to gender, but is seen as a disturbing fact of daily life (Herbst *et al.* 2008). Water, in particular river water, is frequently (75 % of respondents) linked to the occurrence of diarrhoea. About half of the respondents are not aware of the importance of hand washing as preventive measure for diarrhoeal diseases. Most respondents (97 %) rated diarrhoea in children as a dangerous or very dangerous disease, which can lead to death (75 %), but symptoms for dehydration are hardly known. Dehydration is the loss of water and salts from the body caused by diarrhoea and is one of the biggest killers of children. The fact that 25 % of the respondents are not aware that diarrhoea can lead to death in children and the fact that symptoms of dehydration such as dark urine, infrequent urination and dry skin are rarely known, demand the further education of the population.

Conclusions and Outlook

The results and observations on water and sanitation-related hygiene behaviour described lead to the assumption that people in the Vietnamese Mekong region have a basic knowledge of proper hygiene. However, hygiene measures such as hand washing are put into practice in an untimely manner, most probably due to the misconception of risks and/or a lack of background knowledge of cause - effect relationships. According to a case study from Rwanda the implementation of a hygiene education programme (PHAST) had actually almost no impact on the people's knowledge but has achieved its goal in strengthening the people's appraised self-efficacy and competence to overcome the most important barrier for realising the recommended hygiene practices (Zoellner *et al.*).

Thus, a curriculum for water and sanitation-related hygiene behaviour change tailored to local needs should be developed and implemented. Besides messages to improve hygiene skills, the training should aim at closing the deficits between knowledge and personal risk assessment. Selected reasons and important aspects for the development of a sustainable education and promotion strategy are summarised in the following paragraphs.

Although, household water management is an area of female responsibility in the Mekong delta, water should not remain an exclusively female issue. Drinking water safety starts with the protection of the water resources, which demands the commitment of the general population. Therefore, short - term and long - term strategies in education on water - related health should complement each other. As the average age of the women in charge of household drinking water is 40 (mostly aged between 26 and 55), the short-term strategy should aim at training this female age group, e.g. via the Women's Union. As a long-term strategy, education in primary schools for boys and girls should be adapted to promote sustainability in behaviour change. Because water is the most essential resource for both sexes, both should be aware of the hazards relating to the resource as well as its protection and management practices on a household level.

With regard to the lack of knowledge of the symptoms of dehydration due to childhood diarrhoea and the timely action which is needed to prevent adverse effects due to this condition, education on this matter is also needed.

The abolishment of fish pond toilets is an essential measure to break the faecal-oral route of transmission. Because the majority of the respondents are obviously satisfied with the current sanitation situation, a behaviour change will not be easy to achieve. Therefore, it is important to investigate locally what different groups want from sanitation and use this information to develop messages and promotional material to reflect the real experienced needs for improvement of the different groups (Jenkins and Sugden 2006). With respect to these difficulties, a very successful project has been carried out by the international NGO "International Development Enterprises" (IDE) in the provinces of Thanh Hoa and Quang Nam on Vietnam's central coast. This market-based project on sanitation for the rural poor increased the access to sanitation by about 100 % within only one year (Frias and Mukherjee 2005).

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List of Abbreviations:	
PHAST	Participatory hygiene and sanitation transformation
NGO	Non-governmental organisation

VI-3: Selection of systems for a district in Can Tho and training activities for the water supply and sewerage company in Can Tho (CWSSC)

Dr. Bernd Kuse[17] and Dr. Jürgen Wummel[17]
[17] Sachsen Wasser GmbH, info@sachsenwasser.com

Key words: system selection, training, Water Supply and Sewerage Company

Introduction

The aim of the research project SANSED is to adapt and optimize appropriate methods for decentralized wastewater treatment and drinking water supply. These systems are designed, built and operated, where possible, for a beneficial agricultural utilization of waste water. The densely populated agricultural area of the Mekong Delta in Vietnam serves as the project area. In the first phase of SANSED an agro - ecosystem was evaluated by the University of Bonn, University of Bochum, and by ITH Bayreuth. The goal was to determine possible and applicable solutions for the Mekong Delta. These solutions contribute to the potential food production with the help of nutrient recycling and hygienically safe handling of secondary resources under economic and social conditions of the region.
Based on the results and experiences of the first phase this should be taken up again and analysed for a district of Can Tho City under SANSED II. By a feasibility study sewage disposal alternatives will be considered, which are suitable for the District Le Binh. For doing so, the technical and economic side took more advantage of the basis of local knowledge.
Basis of the feasibility study is the actual state analysis. For this purpose the current state was recorded on the spot by specialists from Germany and Vietnam and additionally analysed and evaluated. The possibilities of a waste disposal and treatment was discussed, documented, compared and evaluated. As a result the preferred option was evaluated.
In addition, selected employees of the water supply and sewerage disposal company in Can Tho City (Can Tho Water and Sewerage Company) have been trained by internationally experienced professionals in the fields of water supply, sewerage and management capacity in several training units.

Material and Methods

Conventional sewage disposal

One component of the feasibility study is the analysis of conventional methods of sewage disposal for:

- wastewater collection
- wastewater treatment

For the wastewater collection, analysis have been engaged with regard to applicability of separation and mixed systems for the District Le Binh. Additionally the analysis for possible locations of a treatment plant in Can Tho City has been carried out as well as for the transportation of sewage in appropriate facilities.

Recycling technologies

Another part of the feasibility study is the analysis of different recycling technologies. The following partial methods are used:

- Separation of urine,
- Composting of sewage sludge,
- Generation of biogas from sewage sludge and
- Irrigation with mechanically purified waste water

None of the considered partial procedures is able to recover the waste water completely. There won't be any savings compared to a conventional solution. Even if the sewage disposal will be partially recovered with a partly alternative procedure and changes its composition, there will be no impact on the financial burden of property owners.
With the help of a micro-defined area within the district Le Binh, it is possible to implement an area-wide overall concept with the help of recycling technologies, with full nutrient use, and compare it with the cost of a conventional sewage disposal.

Training Activities

The aim of the training programme was to train selected employees of the local water supply and sewerage disposal companies in their respective areas. With the help of training units the awareness of specific topics has been created and new approaches have been identified in professional daily life of the participants. The training units covered the following areas:

- water supply network,
- management capacity,
- sewerage network

Results and Discussions

Conventional sewage disposal

Regarding the analysis on wastewater collection for the District Le Binh the following results were gained:

- 3.900 Mio. VND investment costs for the variant separation system
- 3.510 Mio. VND investment costs for the variant mixed system

Because of the similar investment costs no decision on the environmental aspects can be derived. Only a cost estimation and no final cost determination can be developed. For environmental reasons a separation system will be adopted for additional considerations.

Table 1 provides information on the transport impacts to the location of the sewage treatment plant and site factors for the construction costs of the sewage treatment plant:

Table 1: Cost calculation depending on the location

	LE BINH [Mio. VND]	**HUNG THANH** [Mio. VND]	**PHU THU** [Mio. VND]
separation system:	3.900	3.900	3.900
transport costs:	800	2.700	11.200
construction of the WWTP:	11.250	11.250	5.000
total sum:	**15.950**	**17.850**	**20.100**

As compared with the cheapest location LE BINH the variant PHU THU had additional costs of 23 %. This is in consideration of possible optimization potential and the uncertainty of the availability of the site LE BINH relativists. According to the present master plan for Can Tho the identification of a location for creating a central wastewater treatment plant is preferable.

Recycling technologies

The analysis of the results in the field of separation of urine is given in Table 2.

Table 2: Comparison of expense and benefits for separation of urine

EXPENSE	BENEFITS
Expense per diluted urine: 118,000 VND: - 60,000 VND m^{-3} for transportation costs - 52,600 VND m^{-3} the cost for PE-tank	Equivalent of fertilizer value of 20,000 VND m^{-3} calculated from the current world market prices for urea

Regarding the listed costs, there is no financial benefit for urine separation for the owners.
In case of the need of further treatment levels for the urine collected before use in agriculture the corresponding costs have to add on the expense side.

The analysis of the results in the field of composting of sewage sludge is shown in Table 3.

Table 3: Comparison of expense and benefits for composting of sewage sludge

EXPENSE	BENEFITS
Investment costs of 4,000,000 VND per household for pipes, ground and Rotte-tanks. expected useful life of approximately 10 years → 400,000 VND investment costs annually	Equivalent of composting value of 50,000 VND a^{-1}

Regarding the listed costs there is no benefit for composting of sewage sludge. As part of an overall concept for the full use of nutrients from the wastewater composting is a possible alternative.

Table 4 informs about the analysis of the results in the field of biogas production from sewage sludge.

Table 4: Comparison of expense and benefits for generation of biogas form sewage sludge

EXPENSE	BENEFITS
Investment costs of 1,775,000 VND per household for pipes, digesters and biogas tubes. expected useful life of approximately 10 years → 177,500 VND investment costs annually Costs of 15,300 VND kg^{-1} for produced methane	Equivalent of heat value of 13,800 VND kg^{-1} produced methane and benefits for investment costs 160,000 VND a^{-1}

Regarding the listed costs there is no economic efficient approach for generation of biogas from sewage sludge. It is important to mention that the digesters are designed for households with livestock and not for the small amount of faeces from households without animals.

The analysis of the results in the field of irrigation with mechanically purified waste water can be seen in Table 5.

Table 5: Comparison of expense and benefits for irrigation with mechanically purified waste water

EXPENSE	BENEFITS
Investment costs of 2,000,000 VND per household for pump, storage and distribution facilities. expected useful life of approximately 10 years →200,000 VND investment costs annually	Equivalent of fertilizer value of waste water of 120,000 VND m^{-3}

Regarding to the listed costs there is no benefit for irrigation with mechanically cleaned waste water. As part of an overall concept for the full use of nutrients from the wastewater, the mechanically purified waste water is always a possible alternative.

As a result, it should be noted that the outlined cost benefits for the SANSED technologies are economically inefficient for the property owner. A major reason for this is the complete absence of a cost transparency of conventional wastewater treatment for the property owner.

Training Activities

During the seminars, the vietnamese staff of the water and waste water utility in Can Tho (CWSSC) was trained and qualified to special issues and problems of water distribution and management topics, and thus to the requirements of modern water supply. Selected topics of the seminars are listed in Table 6.

Table 6: Topics of the seminars

TRAINING OF WATER SUPPLY SYSTEMS	MANAGEMENT CAPACITY TRAINING
quality requirements for drinking water	planning the assets
maintenance	operating the network
losses in the water supply system	tariff system
fault management	personal policy

Conclusions and Outlook

Feasibility Study

Starting point for evaluating the procedures of the project area was the estimation of the costs to implement a conventional wastewater treatment. For this purpose various options for the sewer system and for the location of the treatment plant were compared and evaluated. As a preferred solution, the sewer system as a separator system with the transition to Phu Thu was selected, where an extension of the currently planned wastewater treatment plant was reported.

The following alternative procedures (so - called recycling technologies) for sewage treatment and recycling of wastewater ingredients were analysed: urine separation, sludge composting, biogas production from sludge and irrigation with mechanically purified sewage. The results show that the selected recycling technologies are inefficient. Only biogas production can realise revenue surpluses in the future (exploitation of cost - cutting potential, price increases in energy resource).

Within a micro area the technological requirements for a comparison of the so-called recycling-technologies the conventional wastewater treatments are given. This is a comparison between the motivation of property owner to use alternative procedure combinations based on costs and expected revenues (currently only 71 % of all costs can be covered) and extremely high investment costs for conventional sewage disposal.

Training Activities

The trainings were found to be very useful for the staff of CTWSSC as well as for the trainers.

VI-4: Modelling the groundwater dynamics of Can Tho City – challenges, approaches, solutions

Thomas Nuber[8], Vu Van Nam[4], Harro Stolpe[8]
[4] College of Environment and Natural Resources, CanTho University, Vietnam
[7] Environmental Engineering and Ecology, University of Bochum, Germany

Keywords: groundwater management, drinking water supply, groundwater modelling, groundwater drawdown, small scale tube wells

Introduction

In the Mekong Delta, groundwater is often used for various purposes (e.g. drinking water, industrial water supply, etc.). In Can Tho City there are over 32,000 small scale tube wells, more than 400 medium sized groundwater supply stations with a capacity of up to 20 $m^3\ h^{-1}$ and 20 large scale wells which are used for drinking water supply or industrial purposes. Within the next few years it can be expected that the use of ground water will increase because of the rapid economical and population growth of Can Tho City. For instance, the Centre of Rural Water Supply and Sanitation of Can Tho is planning to construct more than 150 ground water supply stations until the year 2010 in order to secure the water supply in the rural areas of Can Tho City. At the same time the ground water recharge in Can Tho City is very low because of its geological conditions (e.g. covering clay layer of approx. 60 m thickness). Also, significant indicators of an overexploitation of the groundwater resources were found. In some areas of Can Tho City the ground water level is declining approximately 0.7 m $year^{-1}$.

In this context, a groundwater model for Can Tho City was developed within the SANSED project. The goal of the model is the determination of the groundwater yield and the estimation of the influence of the groundwater discharge on the groundwater drawdown. The objective of this paper is the chosen modelling approach including the calibration process. With the chosen approach it is possible to achieve the modelling goals in spite of a rather limited datapool.

Material and Methods

In the following section the used software as well as the modelling approach concerning the spatial and temporal discretisation, the definition of the boundary conditions and input parameters, the estimation of the groundwater discharges and calibration are described in detail.

Processing Modflow (PMWin)

The groundwater flow is simulated with the Finite-Difference-Groundwatermodel MODFLOW (McDonald and Harbaugh 1988) using the software package PMWIN 5.0 by (Chiang and

Kinzelbach 1998). MODFLOW is a three - dimensional model coupled to the module PMPATH99 for the calculation and the graphical illustration of flowpaths and isolines, the module PMDIS for the spatial interpolation and the module MT3D / MT3DMS (Zheng 1996, Zheng and Wang 1998) for the calculation of transport- and simple degragation processes. Additionally, PMWIN gives the opportunity to calculate detailed water balances for free defined groundwaterbodies.

Model area, spatial and temporal discretisation

The chosen model area encloses Can Tho City in the centre and its surrounding area including the groundwater recharge area located in the northwestern part of the Mekong Delta (Do Tien Hung *et al.* 2000).

For the spatial discretisation of the model area a compromise has to be made between the available data density, the realistic simplification of the hydrogeological conditions, the plausible assumption of the boundary conditions as well as a detailed delineation of the groundwaterbodies for the determination of the groundwater balance. Thus, for the areas with a low data density a grid with a meshsize of 6 x 6 km was chosen, whereas for the area of special interest and with a high data - density (namely Can Tho City) a discretisation with a meshsize of 0.6 x 0.6 km is chosen. For numerical reasons the grading between the different meshsizes is done stepwise with the factor 2.

According to the hydrogeological conditions of the Mekong Delta (see Do Tien Hung *et al.* 2000) only the Holocene and the Pleistocene layers are simulated with the model. Therefore, the horizontal discretisation is done with 6 Layers. The first layer represents the covering Holocene layer which can be understood as an aquiclude. The second, third and fourth model layer are covering the main aquifer (upper - middle Pleistocene), whereas the third layer functions as the discharge horizon. The fifth model - layer stands for the aquiclude between the upper - middle Pleistocene and the lower Pleistocene, whereas the sixth layer represents the lower Pleistocene aquifer. The underlying Pliocene aquiclude is the lower boundary of the groundwatermodel.

The change between the rainy and dry season causes different surface water levels and surface water discharges as well as different groundwater recharge rates. These and also the changes of the groundwater discharge rates is causing transient groundwater flow conditions. Regarding the expenditure of time and the available datapool a transient simulation of those conditions is not suggestive. Instead, a quasi - steady state approach is chosen. For the simulation time the period between 2000 and 2005 was selected, because reliable data on the groundwater drawdown was available for this period. For the calibration of the model the time – period from 2000 to 2005 was divided into 11 time periods, with a length of 6 months each.

Boundary conditions and input parameters

For a steady-state simulation only boundary conditions are required for the solution of the flow equation. Three different types of boundary conditions are distinguished. The first type (Dirichlet - condition) is defined by a fixed head, which is constant over time. The second type (Neumann-condition) defines a fixed groundwater discharge or recharge. Here, a special case is the so-called "No-Flow" boundary" which is used for the bordering of the model area by a flowline. The third type (Cauchy - condition) is a combination of the first and the second type and is used for the simulation of semipermeable boundaries such as leakage by surface waters or for groundwater flow outbound of the model area.

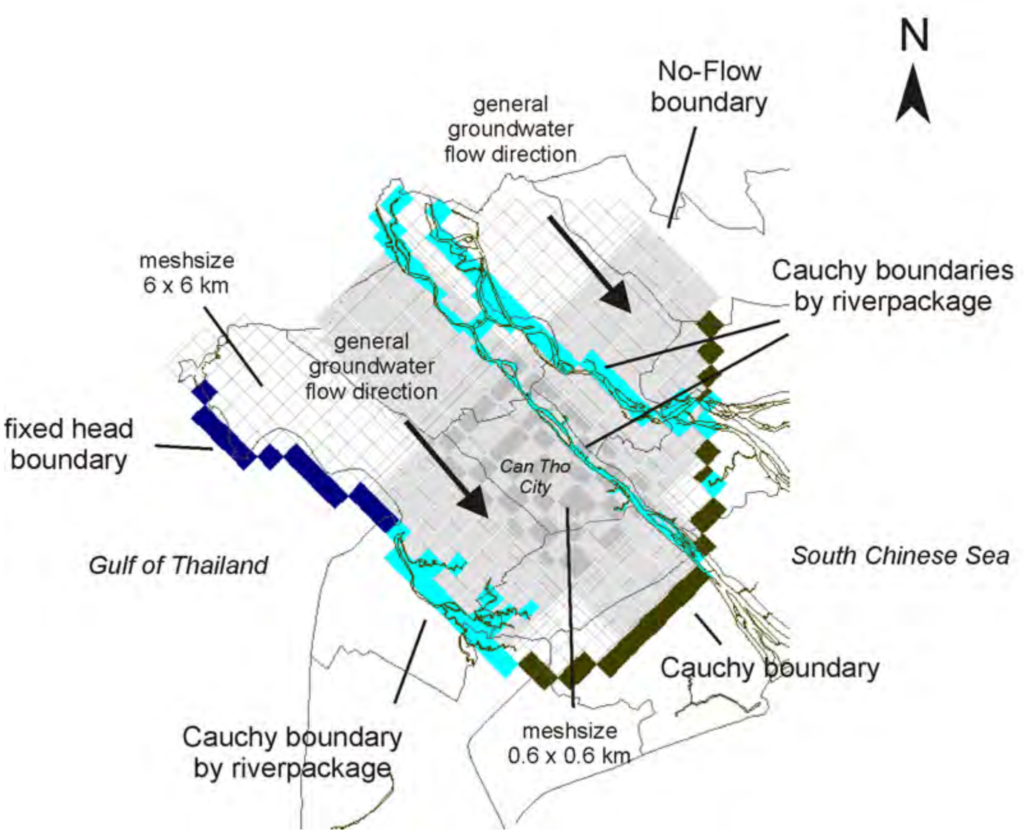

Figure 1: Boundary conditions and discretisation

For the modelling approach described in this paper the definition of the boundary conditions is based on the following concept (see also Figure 1):

- According to several reports (Do Tien Hung *et al.* 2000) the general groundwater flow direction is from northwest (Cambodian border) to southeast (South Chinese Sea).
- The nortwestern boundary is simplified as a a "No-Flow" boundary. In the northwest of the Mekong Delta the transmissivity of the aquifers is rather low because of a small aquifer thickness; in some areas near-surface bedrock is present.
- The northern boundary of the groundwater model is simulated by a "No-Flow-Boundary" perpendicular to the groundwater flow direction.

- The eastern boundary is simulated by Cauchy conditions. With this, it is possible to simulate the groundwater flow outbound of the model area in direction to the South Chinese Sea. The required parameters are calculated according to the hydrogeological conditions described by (Do Tien Hung *et al.* 2000)
- The influence of the Gulf of Thailand on the aquifer system is simulated by a fixed head
- The hydraulic interaction of the big rivers (Hau River, Cuu Long) with the groundwater system is realized by Cauchy-conditions. Here, the in PMWIN implemented riverpackage is used. For the parameterization, values according to a study on the interaction between the Hau River and the upper-Pleistocene aquifer in Can Tho (Schneider 2007) are selected.

Estimation of the groundwater abstraction

For the simulation an estimation of the groundwater discharge is required. For this purpose, data from different source are evaluated (e.g. Centre of Rural Water Supply and Sanitation, Can Tho Water Supply and Sewerage Company, Division of Hydrogeology and Engineering Geology). Groundwater is discharged by small scale tube wells, groundwater supply stations run by the Centre of Rural Water Supply and Sanitation and the Can Tho Water Supply and Sewerage Company and wells operated by companies (industrial wells).

For the estimation of the groundwater discharge assumptions based on the following concept are made:

- Approximately 3,000 small scale tube wells are known in the year 1994 (Do Tien Hung *et al.* 2000), 32,000 small scale tube wells are known in the year 2005. For the missing years a linear interpolation was made. Furthermore, it was assumed that with one tube well approx. 1 m³ day^{-1} is discharged. This groundwater discharge is simulated as a diffuse discharge equally distributed in the populated areas.
- Number, locations of the groundwater supply stations and the amount of accessed households are available since the year 2000. Here, it was assumed that one accessed household extracts 10 m³ HH^{-1} $month^{-1}$. This figure bases on experience of the Centre of Rural Water Supply. Each groundwater station is simulated individually.
- Locations and the water discharge consent of industrial wells are known. Here it was assumed that each industrial well discharges 50 % of its water discharge consent. Each industrial well is simulated individually

With this approach for Can Tho City a total groundwater discharge of 44,000 m³ d^{-1} was estimated for the year 2005.

Calibration of the model

Usually, during the calibration process a matching between the calculated and measured groundwater heads should be achieved by the variation of unknown parameters within their plausible boundaries. In most cases those parameters are the hydraulic conductivity and the groundwater recharge. Here, the big challenge is the so-called ambiguity, which means that various combinations of parameters can lead to the same result. The quality of the calibration is often characterized by the root-mean-square deviation (RMSD) of the difference between the measured and calculated groundwater heads (Kinzelbach and Rausch 1995).

In this approach randomized data sets - existing out of various combinations of groundwater recharge and hydraulic conductivities within their plausible boundaries - are generated in order to minimize the uncertainties resulting out of the ambiguity, The plausible boundaries for the groundwater recharge and the hydraulic conductivity are chosen according to previous studies on the hydrogeological conditions of the Mekong Delta (Benstoem *et al.* 2005, Do Tien Hung *et al.* 2000). Here, data-sets simulations are done, the RMSDs are calculated and the simulated drawdown is compared to the measured groundwater drawdown. The data-sets which deliver a low RMSD and a plausible drawdown are considered as "plausible data-sets" and are taken into account for the further evaluation.

Results and Discussion

Simulating the groundwater flow with a data set, that represents average conditions, a good approximation to the measured groundwater drawdown can be achieved as exemplary shown in Figure 2.

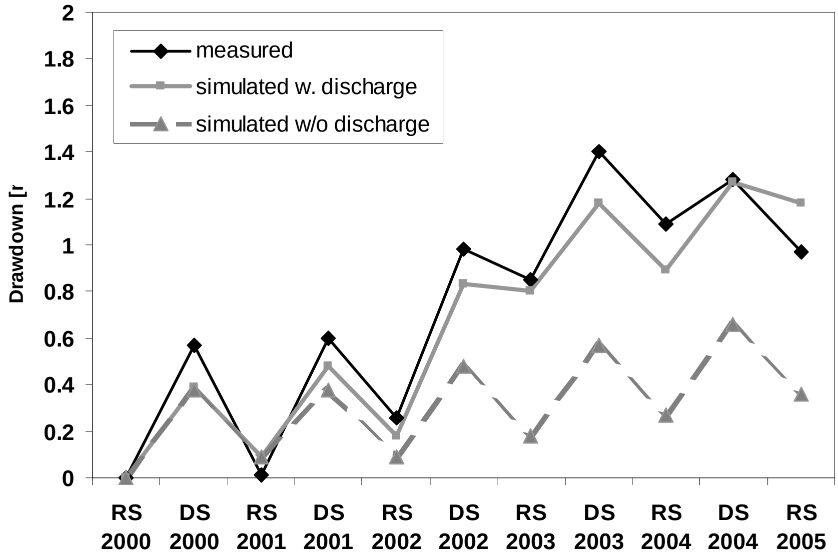

Figure 2: Calculated and observed drawdown [m] with discharge and without discharge at the groundwater observation well QT09b in for time period 2000 – 2005

RS = rainy season, DS = dry season

Here, it is possible to simulate the observed drawdown of approximately 70 cm a^{-1}. A simulation with the same data set - but without any groundwater discharge - is also shown in Figure 2. Here, the drawdown is more moderate and approximately 40 to 60 cm below the measured drawdown. Figure 3 illustrates the distribution curve of the calculated groundwater yield for Can Tho City based on the simulation results for the different plausible data-sets. Here, the average value for the groundwater yield is around 125,000 m³ d^{-1} (standard deviation 39,000 m³ d^{-1}). Regarding the daily estimated discharge of 44,000 m³ d^{-1} in Can Tho almost 35 % of the mean groundwater yield is withdrawn from the aquifer.

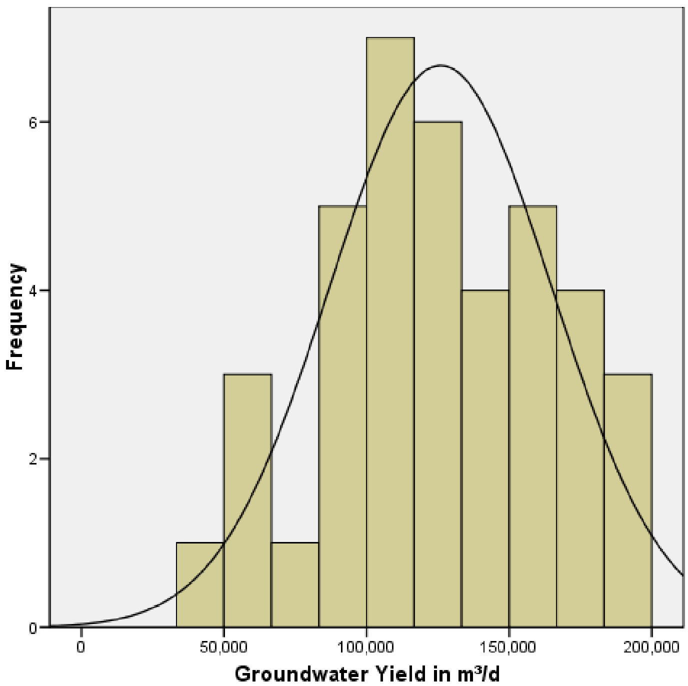

Figure 3: Distribution curve of the available groundwater yield for the groundwater body "Can Tho City"

Conclusions and Outlook

With the modelling approach described in this paper, it is possible to simulate the observed groundwater drawdown in Can Tho. Therefore, it can be concluded that the assumptions which are made are plausible and that therefore it is possible to make an estimation of the groundwater yield for Can Tho City. Also by evaluating the groundwater yields calculated for a high number of plausible data-sets statistically, the groundwater yield can be estimated with an assigned certainty.

But, it has to be pointed out, that the figures calculated with this model approach are not absolute, since there are still many uncertainties and missing data. Nevertheless, it can already be concluded that, according to the results of the groundwater model, the groundwater household of Can Tho City is out of balance. Also, it can be concluded that there's an influence of the groundwater discharge on the groundwater drawdown and that approximately 35 % of the groundwater yield is withdrawn from the aquifer.

Keeping the uncertainties and assumptions in mind, this groundwater model can be a powerful tool for the future groundwater management in Can Tho City. With this model it is possible to simulate different future scenarios in order to develop sustainable groundwater management strategies. It is a first and pragmatical approach which needs to be maintained and compared with future findings and field observations.

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VI-5: Evaluation of systems for recycling of nutrients from waste water in the Mekong Delta

Ute Arnold[1], Uwe Klaus[1] and Joachim Clemens[1]
[1] INRES – Plant Nutrition, University of Bonn, Germany

Keywords: evaluation, system comparison, requirements, waste water characteristics, waste water treatment technologies, recycling system

Introduction

The prerequisite within the SANSED project was to focus on treatment technologies that allow recycling of the produced substrates and nutrients instead of only eliminating these. Conventional sanitation minimises water pollution by elimination of substances. But most valuable substance, like nutrients from human or animal excreta reaching the sewer will be lost. In areas with a low rate of centralised waste water treatment systems, nutrient recycling technologies may be an interesting option, as for the infrastructure of the waste water treatment has not been invested yet on a bigger scale.

In the first phase of SANSED, the Mekong Delta was investigated regarding waste water treatment (WWT) and agricultural use of organic substrates. This status quo was used to select promising techniques to be tested in SANSED´s 2nd phase.

For the workshop, the results of the different working groups were evaluated and combined to "treatment and recycling systems". Here we describe the approach, record first results of the evaluation and give some examples for beneficial combinations.

Material and Methods

In Table 1, the experimental approach to identify feasible technologies is summarised.

Table 1: Experimental approach to identify appropriate technologies

	Steps of the experimental approach
↓	Status-Quo of technical, socio-economic conditions (SANSED I)
	Selection of promising treatment systems and representative sites
	Experimental Phase (SANSED II)
	Questionnaires for evaluating systems and products for sites
	Answers by expert companies and scientists
	Evaluating answers, discussion producer/user, creating database
	Refining data base.

Sansed Phase I, promising technologies were selected and pilot systems were constructed. In an experimental phase, the treatment plants were operated and the produced substrates were tested as fertilizer. Then, the partner in the project received a questionnaire about treatment technologies and substrate quality. Finally, the data were processed and aggregated.

Selected Treatment Technologies

For SANSED II promising technologies were selected to treat waste water and recycle nutrients. The different systems varied in their state of technology, nutrient output, requirements etc. All systems were tested on their applicability and feasibility using criteria such as cleaning efficiency, nutrient transfer rate and costs (Table 2).

To minimise the input of chemical non-degradable pollutants by industrial discharge, only waste water from households and farms was examined. “Wet systems” were favoured as dry sanitation (composting toilets) is not common in the Mekong Delta and was not desired (Wieneke 2005).

Table 2: Treatment technologies tested in SANSED and evaluation criteria

Technologies for rural, peri urban situations	Criteria
• Source separation systems followed by different treatments: Storage, Precipitation, Drying (yellow water), Membrane Treatment (grey water) • Anaerobic treatment (brown and black water) • Soil Filter • Removal of solids and composting • Ponds	• Cleaning efficiency: reduction of Solids, COD, P, N, pathogens • Nutrient transfer (rate) to substrate/fertilizer • Availability of energy, technical know-how, possibility of maintenance (e.g. replace damaged/rotten parts), acceptance • Cost for construction and maintenance (area, technical system, energy)

Definition of Agricultural Production Systems

For the Mekong-Delta typical agricultural production systems were defined by soil and planted crops (Table 3).

Table 3: Selected sites – typical soils with suitable crops - and evaluation criteria

Sites: Soils	Crops	Criteria
• Severe Acid Sulphate Soils • Light Acid Sulphate Soils • Alluvial Soils, degraded/compacted • Alluvial Soils, good condition • Ponds	• *Trees* • *Ornamental Plants* • *Maize, sugar, cereal* • *rice* • *Vegetable*	• Production of valuable, profitable crops • High Yields • Yield safety (regarding nutrient deficiencies, plant diseases) • Health safety

Additionally, site and crop specific criteria for the quality of the substrates were defined related to yield stability, soil fertility and feasibility:

- Nutrients for rapid plant response (N, P)
- Organic matter fractions for improvement of soil fertility
- Supply of alkalinity
- Hygienic safety (pathogen sensitivity)
- Acceptance, feasibility, benefit

Questionnaires

The questionnaire aimed on water treatment systems and on reuse (application) of substrates of waste water treatment in agriculture (Table 4).

Table 4: Requested Information on Treatment Systems and Sites in the Questionnaires

Treatment Systems	Sites/Substrates
1. Possible Input material (type, capacity)	1. Existing sites (soils, cropping systems)
2. Cleaning efficiency and Output material	2. Substrate demands (type and amounts)
3. Operation and maintenance	3. Feasability
4. Costs	4. Benefits
5. Application/Implementation	5. Evaluation

Results and Discussion

The results are structured along the flux of nutrients from the origin of the waste water via the treatment system to the final use of the products in agriculture.

Waste water types

In SANSED a variety of waste water types such as municipal waste water, yellow water, grey water, black water, brown water pre-treated by a septic tank and animal slurry were used. Their recycling potential depends on nutrient concentration (for fertilizer) and carbon content (for gaining biogas or compost). For example, about 80 % of the total N and P was found in yellow and brown water (= black water) which accounted for only 18 % of the total wastewater volume (Wohlsager 2007). By this, black water is 5 times more concentrated than mixed waste water from a household.

In Table 5, the different types of wastewater investigated in SANSED and their recycling potential are summarized.

Table 5: Waste water types and potential benefits

Water type ☐	***Dilution***	Benefit **Recycling of Nutrients**	**Recycling of Water**	**Biogas-production**
Fishpond (extensive)	*High*	O	++	O
Combined Sewer		O	+	O
Rain- and Grey water	↓	-	++	-
Septic-Tank Effluent		+	-	+
Black water	*Low*	+	-	++
Yellow water		++	-	O

++ very advantageous;+ advantageous; o not recommended; - not possible

Evaluation of tested treatment technologies

In Table 6, the three tested treatment technologies for **yellow water** are compared.
The technologies comprise one "high tech" solution with precipitation of PO_4^{3-} (producing MAP, struvite) and subsequent stripping of NH_3 (producing $(NH_4)_2SO_4$). The 2nd technology is treatment of urine via solar radiation producing a solid N-P fertiliser and a liquid N-fertiliser. The 3rd treatment is the storage in a closed tank.

Table 6: Comparison of three urine treatment systems

Criteria	**Precipiat./stripping** **"high-tech"** *Antonini et al. (2009)*	**Urine drying** *Phong et al. (2009)*	**Closed Storage** **"low-tech"** *Wohlsager (2006)*
Nutrient transfer rate	more than 90 %	more than 90 %	more than 95 %
Products, nutrients (%)	Solid N/P (6/13), liquid N (ca. 8)	Solid N/P (~10/2), liquid N (~2)	Liquid, N/P (~0,6/0,05)
Pathogen removal	Efficient	Efficient	Efficient with time
Fertiliser effect	High	Medium	Good
Energy demand, technical know how	High	Low	None
Maintenance in project	Difficult	Rather simple	Simple
Space requirement	< 0.03 m² $person^{-1}$	> 0.5 m² $person^{-1}$	< 0.1 m² $person^{-1}$
Acceptance	High	High	Medium - Low
Cost for construction	High	Low	Very low
Suitable treatment site	hotel/industry, urban	peri urban, rural area	rural, peri urban

Regarding the technique to gain yellow water as the basic material for all three technologies, waterless urinals are excellent when tightness and absence of smell can be guarantied. It releases the nutrient solution –urine- in highest concentration. Yellow water from separation toilets is already diluted. Furthermore, separation toilets have to be used appropriate: due to the male habit of standing (Wohlsager *et al.* 2009) separation toilets seemed only suitable for woman.

Septic tanks/Biogas systems: Septic tanks which are mandatory when building a new house, is a kind of a non-mixed anaerobic treatment with a low hydraulic retention time. Due to findings of Kermer (2006), their treatment efficiency was around 50% for BOD and less for COD. N recovery was less than one third. However, more data are needed to validate these results.

Anaerobic treatment of brown or black water in biogas digesters is regarded as a more efficient pre-treatment, with higher nutrient transfer rates, small space requirements (less than 0.3 m^2 per person) and additional gain of biogas. Treatment efficiency of small biogas digesters was found to vary, 50-80% for BOD, less for COD (Arnold & Clemens 2004, Arnold *et al.* 2006). Usually concrete fixed-dome digesters were slightly more efficient than PE-tubes. As a 90 % pathogen reduction (Rechenburg *et al.* 2009) not sufficient for further use in agriculture (WHO 2006), subsequent treatment is necessary.

Soil filter: Soil Filter treatment of the effluent from septic tanks or biogas digesters may provide irrigation water with reduced pathogen level but residual nutrients. Whilst the experiments are not yet finished an area demand of 0.5 to 2 m^2 per person is assumed for the tropical Mekong Delta. Extended area will improve pathogen removal, reduced area will result in lower losses of nutrients.

As general observation during installation and operation of waste water systems in the Mekong Delta, obstacles appeared due to lack of

- Suitable locally available material (e.g. pumps, connecting valves, test-kits for analysis etc.); as imports are time-consuming, expensive, especially for replacement
- Sufficient technical Know-how (at construction companies and potential operators outside university) for construction, skillful observing and trouble-shouting
- Stable electricity

Assuming the ongoing fast development in Vietnam, these hindrances are expected to disappear in the future.

Cropping systems and substrate use

The beneficial reuse of substrates depends on the needs of the agro - ecosystem. Table 7 illustrates examples for the nutrient demand dependent on soil site and cropping system.

Table 7: Substrate requirements of some selected site systems

Site (soil)	Cropping system / Production	Requirement N	P	C	alkalinity	Hygienic safety
Acid Sulphate Soil	*Maize, cereal, sugar cane*	*+*	*++*	*O+*	*++*	*+*
Alluvial soil, degraded	*Trees*	*+*	*+*	*++*	*+*	*O*
Alluvial soil, degraded	*Vegetable*	*++*	*++*	*++*	*++*	*++*
Alluvial soil good	*Ornamental plant*	*++*	*++*	*O+*	*O*	*O+*
Ponds	*Algae -> fish*	*++*	*++*	*O*	*+*	*+*

Urine derived fertilisers containing fast available nutrients, are useful to supply these to systems where to maintain or increase the yield. However, the liquid $(NH_4)_2SO_4$ fertiliser is less useful on ASS as the fertiliser has a rather low pH, adds more sulphate and can not provide alkalinity.

As these fertilisers do not contain organic carbon, they are very suitable for ponds where no carbon is desired. On the other hand they are not able to fulfil the needs of sites where organic matter is needed to improve soil fertility.

As a consequence, urine based treatment technologies may be less useful in areas with compacted alluvial soils.

Treatment and Recycling Systems

To illustrate appropriate combinations of treatment technologies and application possibilities to treatment and recycling systems, two examples are given (Table 8).

Table 8: Suitable combined Systems (selection)

System	Water Type	Water / Substrate treatment	Application
Improved existing sanitation	1-Brown water	Digester & Soil-filter	Fishpond
Separation System	1-Yellow water 2-Brown water solids	Urine Storage & Composting &	Fishpond Soil amendment for degraded alluvial soils

Considering space limitation, an efficient way to treat brown water is a combined system of a digester and a soil filter followed by a fishpond. The digester reduces COD and produces biogas that can be used as regenerative energy. The soil filter removes pathogens. The effluent is used as fertilizer in a fishpond. As nutrient transfer rates in aquatic systems in the tropical climate of Mekong Delta are higher than in other ecosystems, fishponds seem to be a space-efficient way to recycle nutrients. Based on first results about one square meter per person of pond surface can be assumed. We estimated the space requirement for the whole system with 3 m^2 per person.

Especially if soil filters and/or fishpond can be integrated in public green areas or in private garden design, the system can be realised even in peri-urban areas (Stockmann 2007). The system should not serve less than 50 inhabitants.

Separately collected urine can be applied as a fertiliser to fishponds after drying. The urine could be stored at household level, whereas treatment and application is to be organised for more than ~100 inhabitants. For brown water solids, composting or vermicomposting can provide a soil amendment for a number of sites.

Financial aspects: Treatment and recycling systems can save (i) expenses for mineral fertiliser but even more important in terms of economy (ii) they make other additional treatment systems for the residual wastewater cheaper.

Conclusions

An evaluation method has been shown to identify site specific recommendations for waste water treatment and agricultural application – based on the prerequisite to recycle nutrients.
The examined treatment technologies were found to be efficient - each of them has particular advantages related to the produced substrates, waste water sources, available space within the settlements and natural and sociological conditions.
Appropriate application in agriculture and aquaculture could be identified for the different types of substrates produced. According to the site specific conditions, favourable treatment systems have to be selected.
Future development and implementation of waste water treatment will depend strongly on the political decisions and legal framework.

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VI-6: Land use development and future application of water treatment systems in the Mekong Delta, Vietnam

Nguyen Hieu Trung[4] and Ute Arnold[1]
[1] INRES- Plant Nutrition, University of Bonn, Germany
[4] College of Envrionment and Natural Resocurces, Can Tho University, Vietnam

Keywords: feasibility, land use planning, socio-economy, agriculture, implementation, water treatment systems

Introduction

For a successful application of new systems, it is important to look upon the land use and the expected development of the area, especially when the concerned region has an extremely fast development processes like the Mekong Delta and Vietnam in general.
So far, several steps have been carried out within the SANSED project to find out about suitable water treatment solutions for the Mekong Delta:

- Pilot plants have been constructed to measure the water treatment efficiency and the substrate production, providing answers to the **technical feasibility** (see Chapter I-III, VI)
- Pot and field experiments with different substrates have been conducted to gain information on the fertilizing potential and performance in the field, providing answers to the useability and **agricultural feasibility** (see Chapter III-V)
- Interviews have been carried out to find out about the local conditions, behavior towards water (e.g. regarding sanitation, health), the use and acceptance of new systems and fertilizers, providing the first answers to the **socio-economic feasibility** (see Chapter VI, Wieneke 2006)
- To integrate these different detailed in formations, determining parameters for the selection of systems and needs of the sites have been set up (see VII-1).

The steps implemented in the framework of the SANSED project have been discussed in the previous papers. This paper discusses more about a proposed integrated decision approach, by which, biophysical, socio - economic and environmental aspects are integrated into the decision making process.

Land use development in the Mekong Delta

Soil and hydrology are the major physical factors determining agricultural land use in the Mekong Delta. Combined local rainfall and seasonal discharges of the Mekong River cause seasonal and spatial variations in water availability within the delta (Nhan *et al.* 2007a). The upper region is subjected to prolonged and deep flooding in the wet season coinciding with

the high flow period, while the coastal region downstream faces freshwater scarcity and salinity intrusion in the dry season with the low flow period (February - April).
In 2004, about 74 % of the delta surface was devoted to agriculture, and rice farming constituted about 70 % of agricultural land (CSO 2005). Over time, agriculture and aquaculture have shifted from subsistence to market-orientated production and progressively intensified. Intensive rice culture expanded during the 1990s and is still the principal farming activity. Most of rice growing areas are irrigated with about 80 % of the total surface water volume diverted for agriculture uses, mostly rice, while only 5 % is devoted to domestic consumption (White 2002).

Recognizing the potential of aquaculture, since 1999 the Vietnamese government has promoted diversification in agriculture, aiming to increase the contribution of aquaculture to economic growth (Nhan *et al.* 2007b). Between 1999 and 2004, the growth rate of aquaculture production was rapid, annual growth rates of 31 % for production and of 19 % for farming area (GSO 2003, 2005), suggesting a gradual intensification of aquaculture. Coastal shrimp farming and intensive fish culture upstream have been the main drivers of this expansion of aquaculture production, but there are indications that this growth is not sustainable, globally (Naylor *et al.* 2000) and regionally (Loc *et al.* 2007). Intensive rice farming and aquaculture practices are both water-intensive (Boyd and Gross 2000, Cantrell 2004, Tuong *et al.* 2005).

For the future, an increase of aquaculture activities can be expected. Agriculture will not re-develop to sustainable farming but continue intensification. Rice will remain the main crop, although more diversification, e.g. cash crops and a trend towards higher quality can be expected. Livestock is expected to increase too, as the food demand is raising by an increasing population. This increase will be claiming more land for residential areas and space consuming infrastructure.

Development of environmental, water related issues

Impacts of upstream development interventions contribute to changes in the flood regime, reduction in dry season flows, increase in water pollution, and changes in sedimentation. During low flow periods of the Mekong River, the intensive rice development in the upper delta abstracts a large quantity of freshwater resulting salinity intrusion in the downstream delta (Nhan *et al.* 2007a).
Aquaculture expansion contributes to further water pollution in the downstream areas through flushing pond/cage effluents during water exchange. In the coastal zones, rice and shrimp development causes conflicts over water among crop and shrimp production, fishing and mangrove forests. Development of rice and recently of shrimp culture both result in losses of coastal mangrove forests. This reduction of coastal mangrove forests leads to deterioration of water quality and fish populations. Consequently threaten the productivity of shrimp farms and the livelihood of the poor population who strongly depending on the wild fish catch (Hirsch and Cheong 1996).

The overconsumption of inorganic fertilizer and chemical pesticides in agriculture and aquaculture production activities constitutes a high pressure on the environment of the Mekong, especially to its water body. Moreover, the reclamation of ASS for food production pollutes water in canals and shallow ground water by acidic substances, aluminium, iron and other heavy metals.

High population density (430 inhabitants per km^2 in 2004) and even higher densities in urban and peri-urban areas are producing increasing amounts of waste water that is not treated yet. In rural areas where people are living along the canals or rivers, sanitation often is open defecation and sky toilets (Wohlsager 2008).

The expected land use developments are not likely to improve the environment and water quality. They may, however, put higher pressure on decision makers to develop solutions when the health of the people in the Mekong Delta and their source of income is is threatened.

Considering the importance of water resources and environmental protection, since 1998, the Vietnamese Government has set up the water resources law, and recently, the environmental protection law in 2005. The environmental projection law consists of more comprehensive and systematic provisions, which deal with almost all environmental elements and problems as well as environmental protection. It clearly defines the functions, tasks and powers of state administrative agencies in charge of environmental protection, as well as rights and obligations of organizations and individuals in exploitation and use of natural resources and environmental protection (Diem 2006).

Application of water treatment systems in the Mekong Delta

Since the Mekong Delta people's livelihoods are mainly based on agriculture, their income is very low compared to the other regions of the Country. Therefore, environmental sustainable and socio-economical acceptable land-use plan and suitable water treatment systems are essential to ensure the sustainable development of the Mekong Delta.

To contribute to a sustainable water management of the region, site adapted solutions to recycle nutrients and improve water quality are evaluated. Water treatment will reduce transmission of water born diseases. The resources, e.g. water, phosphorus and others, will be preserved. Furthermore recycling nutrients can bring a benefit to the budget of farmers and municipalities.

To select environmental sustainable land uses with suitable water treatment systems for the Mekong Delta, a decision support approach is proposed. In this approach, participatory, multi-criteria evaluation (MCE) and linear programming would be used.

Three groups of stakeholders should be involved in the approach: scientists/experts, decision makers and local people.

The participatory rural appraisal (PRA) should be carried out first with local people to obtain data on biophysical conditions (e.g. terrain, water supply and drainage, soil types, land uses, etc.), local people's knowledge (e.g. on suitable water treatment, the use waste to produce fertilizer, cropping techniques), people livelihood (e.g. sources of income), and their perceptions on environment issues (e.g. how much pollution affect their health and income, the effects of land uses to the environment, the affordable cost for water treatment systems).

In the next step, scientists analyse data acquired from the participatory step and validate them with available data and their expert knowledge of the study areas. The scientists will classify the land into land units and socio-economic units in which biophysical and socio-economic characteristics are homogeneous.

From that the scientists will apply linear programming to check the physical (e.g. soil type, infrastructures, and terrain, water quality), socio-economic (e.g. affordable capital, acceptability of output products) and technical feasibility (e.g. treatment efficiency, implementation requirement during implementation) of applying water treatment systems in the land uses in the study areas.

In linear programming, the decision maker has to give the goals which the plan should achieve. One example of the goal is minimizing the waste from the land uses and minimizing the total cost to treat the water to certain level of quality. Together with the goals the decision maker also defines the biophysical, socio-economic and environmental limitations or constraints of the study area (e.g. available land, labour and capital, maximum fertilizer demand, level of technical skills, culture or ethnic, etc.). In fact, many scenarios of goals and constraints are tested according to the short or long term strategy of the decision makers. The analysis will be based on the available resources (land, infrastructure, capital available, volume of waste, livestock density, etc.) and the land use or water treatment requirements (e.g. suitable soil, water, terrain, input waste, cost, etc.). Since scenario analysis in linear programming provides different alternatives of land use and water treatment systems, the decision makers have to make their final decision of which water treatment systems should be used for which land uses. Then MCE is a suitable tool. In MCE, the decision makers have to state their priority, e.g. first: low cost; second: effective; third: easy to implement, etc. To evaluate the alternatives, indicators for each priority should be defined and evaluated by the experts/scientists. By using MCE, difference criteria can be compared so that the decision maker can chose the alternative that fulfils their priority. To make sure of the acceptability of the people, the selected alternative should be discussed again through PRA to get people feedback. If the selected alternative is not accepted, negotiation can be held or priority of the decision maker must be changed.

Conclusion

There is strong relation between land use and environmental problems in the Mekong Delta. For the future, the expected development will put higher pressure on the environment and especially the water body. Therefore:

- Proper land use planning can reduce the problems put to the environment.

- Land use planning should include treatment of waste and waste water before loading it to the environment to reduce pollution, health problems and minimise subsequent drinking water treatment
- Due to high costs of construction and maintenance of many treatment systems, and the low income of the farmers in the Mekong Delta introduction is difficult. Thus, to select suitable treatment systems which bring obvious benefit to the farmer is more acceptable for the Mekong Delta.
- An integrated evaluation of biophysical, socio-economic and environmental data is necessary to select suitable land use and treatment system for the Mekong Delta.

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VI-7: German-Vietnamese Water Forum

Le Hoang Viet[4], Uwe Klaus[1] and Joachim Clemens[1]
[1] INRES- Plant Nutrition, University of Bonn, Germany
[4] College of Environment and Natural Resources, Can Tho University, Vietnam

Keywords: Water Forum, know-how transfer, hands-on-training, lecture, presentation, seminar, exhibition

Introduction

Water related challenges and technologies are of increasing interest for students, local companies and authorities. To satisfy this demand a Vietnamese-German Water Forum is installed within the frame of the SANSED project at Can Tho University. This forum aims at visualizing the results of the Vietnamese-German collaboration in the fields of research and applied water sciences. The topics addressed in the forum are water-recycling, wastewater treatment, drinking water purification, agricultural application of hygienic safe fertilizer from waste water systems, hydrology, and modeling in the field of water management and integrated water resource management. Target persons of the forum´s activities are students, local experts and decision makers.

Design of the water forum

The main part of the Water Forum will be located at the new college of Environment and Natural Resources. Two rooms with more than 130 m² will be used for know-how-transfer and exhibition of German water technology for sustainable water management. Results from the ongoing Vietnamese - German projects such as SANSED, IWRM and WISDOM will be presented in form of models for hands – on - training (Table 1), posters and video presentations.

Table 1: Hands-on-models and research plants

Substrate treatment models	**Drinking water models**
• Constructed Wetland (Wastewater)	• Groundwater measuring point
• Continuous biogas reactor	• Drinking water purification
• Biogas reactor	• Constructed wetland
• Separation toilet	• Clay pot for flocculation
• waterless urinal / smell stop	• Clay pot with UV-disinfection
• activated sludge system	• Electric disinfection device
Substrates and Application models	
• substrate samples	
• pot experiments	
• pot experiments	
• soil profiles	

Besides hand-on-training, there is the possibility to give lectures or presentations in one of the two rooms. The two rooms are the "heart" of a whole set of water related activities on the CTU campus. Different treatment plants that were installed during SANSED are part of the integrative design. They are addressed in the water forum and can be visited on the campus (Table 2) such as soil filters, source separation with biogas production, membrane technology to treat grey water and a precipitation reactor to treat urine. Other treatment plants are located at Hoa An research site of Can Tho University (Table 3).

Table 2: Water treatment plants at CTU campus

Demonstration plants
• Constructed wetland (wastewater)
• Constructed wetland (agricultural application)
• Septic tank
• Urine precipitation and stripping column
• Urine drying device
• Greywater treatment with aerated membrane
• Biogas reactor
• Wastewater separation

Table 3: Water treatment plants in Hoa An

Demonstration plants
• Constructed wetland (drinking water)
• Drinking water treatment
• Biogas reactor
• Urine drying device
• Biogas reactor
• Wastewater separation

It is planned to increase the number of models and presentations, especially based on results from the projects IWRM and WISDOM, but also by the input of German companies. The area outside next to the two rooms in the College of Environment and Natural Resources will be designed in a way to demonstrate the possibility of combination of recreation and environmental sound wastewater treatment. It is projected to construct a soil filter for treatment of a part of the wastewater effluent from the college building.

Activities

Students and local experts are invited to study the results of Vietnamese-German cooperation. Video clips of the research sites and of the demonstration plants at CTU will be available. Links to water related activities in Vietnam and Germany are placed on the computers for additional information. Cooperating German companies will present their activities on- and offline as well.

From the German side it is planned to have three seminars on different topics per year. Topics that can be addresses are: biogas production, (web based) GIS and water, water quality, water modeling.
Additionally, it is planned to participate at different national activities such as the "Environment Day".

Initially, the exhibition focuses on the results of SANSED project. In the future the results from other ongoing projects will be added.

Partner of the Water Forum are various german companies, the Universities of Can Tho, Bonn and Bochum and the projects SANSED, IWRM and WISDOM (Table 4).
Later on more institutions and companies will be invited to become partners.

Table 4: Partners of the Water Forum

Companies	Universities
• Biogas Beratung Bornim GmbH	• University of Can Tho
• Bioreact mbH	- College of Environment and Natural Resources
• Gesellschaft für Wissenstransfer mbH	- College of Technology
• Gsan & Ingenieurbüro für Aquakultur und Umwelttechnik	- College of Agriculture
• Hans Huber AG	• University of Bonn
• Ingenieurbüro für technische Hydrologie und Bodenschutz	- INRES- Plant nutrition
• Sachsenwasser GmbH	- Institute for Hygiene and Microbiology
• Moskito GmbH	- Institute for Economic Sociology
	• University of Bochum

Projects
• SANSED
• IWRM
• Wisdom

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