Utilizing Cocopeat as a Medium for Wastewater Treatment Biofiltration for Residential and Institutional Applications

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Abstract

Cocopeat is the dust from ground coconut shells once the fibers (coir) have been removed. It can be incorporated into biofilters as a component of on-site and decentralized wastewater treatment systems to provide high degrees of treatment for off-grid applications. Systems can be installed for a wide variety of applications, including schools, residential housing, and small plot agricultural operations, using local materials and labor at a cost of less than two US cents per user per day.

In May 2011, RTI International received funding through the Grand Challenges Explorations, an initiative of the Bill & Melinda Gates Foundation, to test whether this low-cost material can efficiently treat wastewater for reuse in developing country settings. RTI collaborated with Can Tho University in Vietnam; Institut Teknologi Bandung (ITB) in Indonesia; Muntinlupa City in the Philippines; and Duke University in North Carolina, USA to test various aspects of the technology. Analytical results achieved through rigorous testing indicate that cocopeat biofiltration is a viable technology and can serve an important role by improving access to wastewater treatment for the poor and very poor sectors of society in coconut-producing regions around the world. Analysis of the treated effluent show that reductions in biochemical oxygen demand (BOD), total suspended solids (TSS), and coliform bacteria approached 90%, comparable to results for constructed wetlands, lagoons, and aerobic systems.[1] It was also observed that cocopeat systems were more space efficient than many of the other alternatives, and systems could be constructed inexpensively with relatively quick set-up time.

While the social acceptability for the product is high, willingness to pay for wastewater treatment in general remains very low in the regions where the cocopeat products were tested. Utilizing cocopeat filters as a component of an overall system designed to maximize user incentives appears to be a winning strategy for rapidly scaling demand and increasing willingness to pay. This proves especially true for rural farmers in the Mekong region of Vietnam who can utilize cocopeat-based systems to generate biogas for cooking. Incentives for other applications such as producing effluent suitable for reuse or discharge, recycling nutrients for agricultural strengthening, and complying with discharge regulations where these are enforced can also be realized through the cocopeat technology and serve as drivers for generating demand. This suggests a strategy for introducing cocopeat-based wastewater treatment products to market by maximizing the incentives for the end user. This paper details the final testing results and opportunities for wide-scale application.

Keywords: decentralized wastewater, cocopeat, biofilter, sanitation, sustainable, DEWATS

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[1] Drechsel, P., Scott, C. A., Raschid-Sally, L., Redwood, M., and Bahri, A. (Eds.) (2010). *Wastewater Irrigation and Health: Assessing and Mitigating Risk in Low-Income Countries*. London: Earthscan.

INTRODUCTION

Inadequate sanitation has a significant impact on the economies of developing countries (World Bank, 2008). In India, for example, the economic toll from poor sanitation is approximated in the World Bank report at 6.8% of gross domestic product (GDP), or $53.8 billion (2005 data), with the costs associated with death and disease; accessing and treating water; and losses in education, productivity, time, and lost tourism opportunities (Table 1).

Table1. Economic impacts of inadequate sanitation by country

Country	Annual Economic Impact (2005 data)	% of GDP
Cambodia	$450 million	7.2%
Vietnam	$780 Million	1.3%
Philippines	$1.4 Billion	1.5%
Indonesia	$6.3 Billion	2.3%
India	$53.8 Billion	6.8%

Source: World Bank, 2008.

Three strategies for improving sanitation (Lomborg, 2012) have emerged in the last several years that appear to have great potential for success:

- **Community-led Total Sanitation (CLTS)**: a behavior change strategy developed to end open defecation and foster individual and collective responsibility to create communities that are "open defecation free";
- **Sanitation as a business**: a private-sector model that aims to improve sanitation supply and delivery chains to address increased demand generated from programs like CLTS; and
- **Reinventing the Toilet**: an idea developed by the Bill & Melinda Gates Foundation to utilize advances in science to develop new paradigms in household waste management technologies that can convert human sewage to usable products. Such products may include biogas for cooking and heating, treated effluent for irrigation, and biosolids for soil improvement and agricultural strengthening.

Market-based Sanitation in Senegal

The US Agency for International Development's Millennium Water and Sanitation Program, managed by RTI International, uses CLTS and social marketing through community radio, schools, and women's associations to trigger demand for sanitation in Senegal's rural Casamance Region. Private contractors installed 432 Arborloo systems in the first four months of the program to successfully integrate service delivery with demand generation.

RTI's cocopeat study has applications for the second strategy mentioned above. In 2011, the Bill & Melinda Gates Foundation[2] funded RTI International to investigate the use of cocopeat, an abundant material in coconut-processing regions of the world, for wastewater treatment. Cocopeat, the dust from crushed coconut shells, is a byproduct of coconut processing that can be used in the development of low-cost wastewater management systems to improve sanitation. Cocopeat is used in the construction of biofilters, which treat septic tank or digester effluent so that it can be used safely for agriculture and landscape irrigation, or discharged into the environment. As wastewater passes through the biofilter, suspended solids are trapped, and organic matter is consumed by the microbes living in the filter,

[2] RTI received funding through Bill & Melinda Gates Foundation's Grand Challenges Explorations forum. Grand Challenges Explorations is a funding mechanism that is designed in part to "generate innovative ideas with the potential to catalyze a next-generation of sanitation technologies across the sanitation value chain, from containment to treatment and reuse."

resulting in a significant reduction of pollution constituents in the final effluent. Figure 1 illustrates the cocopeat technology process in its most basic design. As discussed in further detail below, cocopeat can also be incorporated into other wastewater management systems designed specifically to maximize incentives, such as the generation of biogas that can be used for cooking.

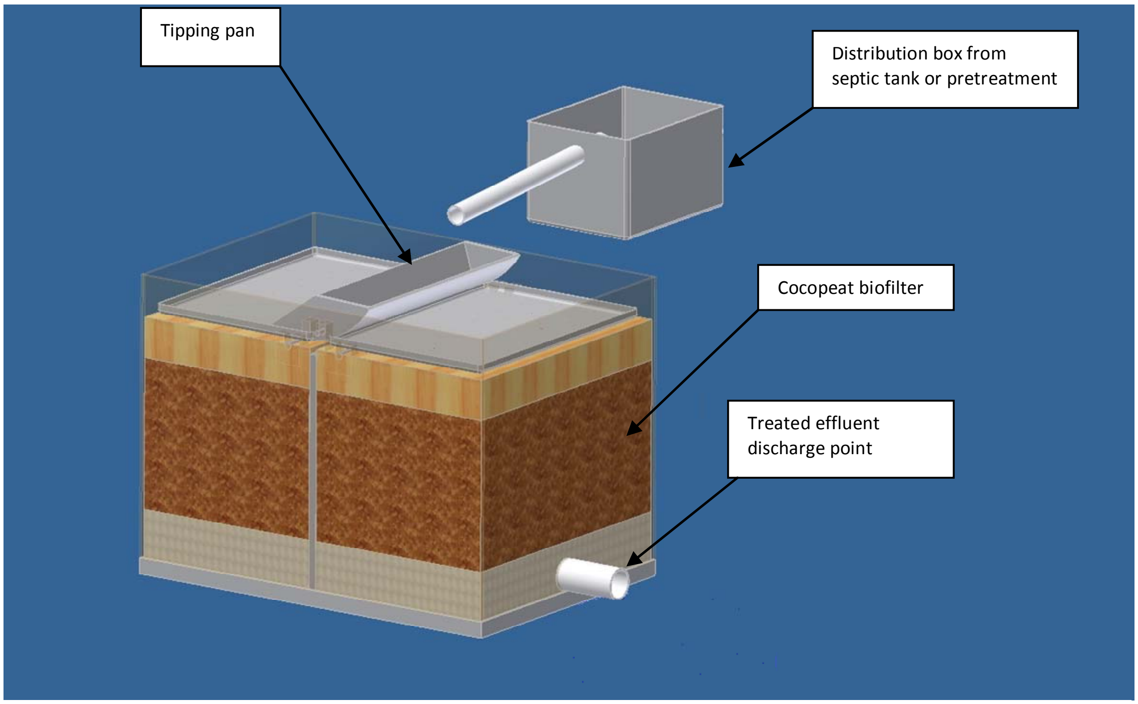

Figure 1. Diagram of typical gravity-fed cocopeat filter: waste flows from pretreatment devices, such as septic tanks or anaerobic filters, to the tipping pan where intermittent dosing occurs. As the pretreated wastewater passes through the cocopeat media, microbes consume organic matter and pathogens.

After 18 months of development and testing, RTI's cocopeat team has observed that this waste product can be used to successfully remove approximately 90% of the organic matter, solids, and pathogens in domestic wastewater, at generally less than 2 US cents per user per day. Furthermore, the RTI team observed that when implemented as a component of an overall system to treat wastewater, cocopeat can help generate social, economic, and environmental incentives significant enough to drive the demand and willingness to pay for an improved wastewater treatment system. These incentives represent significant drivers that can be used for rapid scale-up of cocopeat technology.

Engaging a Wide Range of Partners to Test the Cocopeat Technology

The first step in investigating the viability of the cocopeat technology was to engage local partners. The program team engaged key organizations to help test different aspects of the technology, such as effectiveness, affordability, public acceptance, durability, and ease of incorporation into a larger wastewater management system. The partners engaged helped to develop several scenarios with which to test the technology. Partners and the testing scenarios undertaken include the following:

- <u>Muntinlupa City, Philippines</u>: Two full-scale testing units at two public schools were developed by the City to demonstrate the efficacy of the cocopeat technology under highly variable flows using low-cost construction methods.

- Duke University, USA: Cocopeat was investigated using bench-scale testing to compare the medium's performance with sphagnum peat, which has been investigated extensively and is regarded as an effective biofiltration medium.
- Can Tho University, Vietnam: The University is testing cocopeat biofilters on a pilot scale. The goal of the testing is to understand how the technology can be incorporated into wastewater management systems for rural small plot farmers while generating biogas for domestic use.
- Institut Teknologi Bandung (ITB), Indonesia: ITB is currently testing a version of the cocopeat technology that would be applicable to single family houses in flood-prone areas. The cocopeat technology would be used to reduce pollution entering a sensitive watershed.
- Edeltech Engineering, Inc.: Edeltech Engineering in Bangladesh is also engaged to help identify various dosing mechanisms (including gravity dosing) that enable application of the technology for very low-cost, off-grid applications.

The outputs of these activities indicate that cocopeat is a viable wastewater treatment technology with broad applications to on-site and decentralized applications for residential, commercial and institutional uses.

Results and Findings

The data collected during the study yielded results on the quality of the discharged effluent, comparability to other biofiltration mediums, cost of construction at varying scales, and observational information related to implementation of the cocopeat technology. The results are reported below along with key findings and lessons learned from each implementation scenario.

Muntinlupa, Philippines: cocopeat technology for school-based sanitation improvement

Figure 2. Cocopeat biofilter with distribution pipes (blue) constructed for Putatan Elementary School

Schools represent a bigger wastewater management challenge than many other sources due to their highly variable flows. Systems must be able to function under peak flow conditions common during special events, as well as low flows during weekends and summer vacations. However, the opportunities are equally great because schools represent an ideal entry point into a community interested in scaling up sanitation through wastewater treatment. As students learn about the technology and benefits of treating wastewater, they can teach their parents, help raise awareness of the need for improved sanitation, and increase demand for services.

The system installed for the Putatan Elementary School (Figure 2) is connected to a toilet block that serves approximately one-third of the 2,000 students and 78 teachers. The pour-flush toilets discharge to a septic tank equipped with a small pump that doses effluent to the biofilter. For this study, the biofilter was constructed using a plywood box sealed with fiberglass and fitted with an underdrain system to collect the treated effluent. The box was then filled with cocopeat and covered with an approximately 6-inch layer of coco coir (fibers). Construction was completed over a 3-week period in October 2011, and the system was put into service the following month. Figure 3 shows the observed removal efficiencies from start of operations in November until the time that this paper was written.

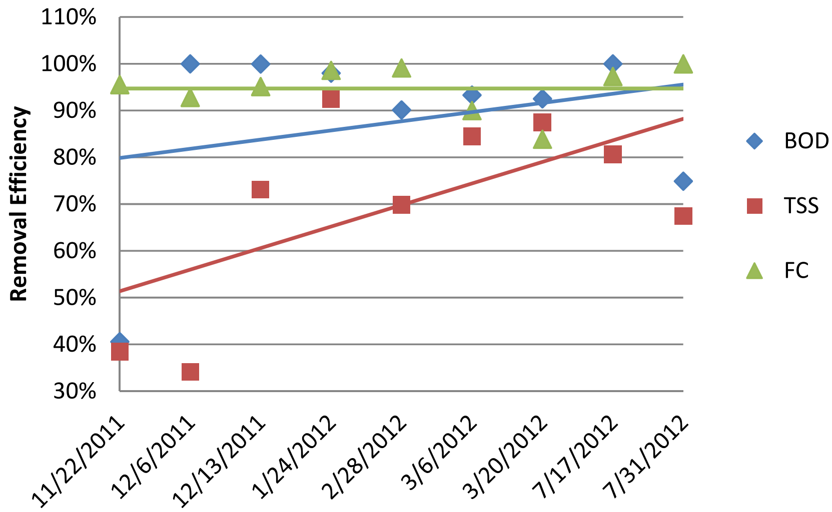

Figure 3. Cocopeat technology removal efficiencies for biochemical oxygen demand (BOD), total suspended solids (TSS), and fecal coliform bacteria (FC) at Putatan Elementary School, Muntinlupa

As illustrated in Figure 3, the cocopeat technology is capable of significant effluent water quality improvement. Specific findings from the testing phase at Putatan are reported in Table 2.

Table 2. Findings from cocopeat technology testing at Putatan Elementary School, Muntinlupa

Observed Parameter	Average Reduction	Average Cocopeat Effluent	Effluent Standard[3]
BOD	88%	6.76	50 mg/L
TSS	70%	13.56	70 mg/L
FC	95%	5,338	No standard[4]
E. coli bacteria	99%[5]	573	No standard
Cost per user per day (US cents)	>1 US cent/day		

During the course of implementation and testing in Muntinlupa, it was also observed that there are several incentives that may be used to motivate school administrators to implement cocopeat wastewater treatment systems. These incentives are the basis of a promotion effort to drive a sustainable business model for service providers interested in this specific market sector:

- Compliance: In Metro Manila and other highly urbanized cities around Asia, there is increasing interest in improving wastewater discharges from institutional buildings

[3] Philippine Clean Water Act Implementing Rules and Regulations – RA 9275.
[4] The Philippines standard is based on total coliform, which is 10,000 MPN/100 mL (MPN—most probable number). If effluent is applied directly to irrigate vegetable and fruit crops which may be eaten raw, FC should be less than 500 MPN/100 mL.
[5] Only one E. coli sample was available for reporting at the time of this paper.

from the regulatory point of view. Cocopeat technology represents one of the lowest cost systems that also require the least amount of space.

- Incorporation into environmental awareness programs: Many schools have greening programs that include school gardens. The treated effluent may be safely used for irrigation for saplings, landscape vegetation, and certain agricultural crops.
- Biogas generation: Schools that have on-site food preparation may use the concepts of co-digestion (anaerobic digestion of multiple waste streams in one digester) to maximize methane gas outputs. Using cocopeat technology, schools can mix human waste with food waste to generate methane for use in cooking. Human waste is typically a low-yielding feedstock for biogas digesters, but with the addition of food service waste, it can increase outputs so that methane can be generated in usable quantities.

Can Tho, Vietnam: using cocopeat technology to enable residential sanitation in rural agricultural settings

Rural agricultural families represent a large market sector for scaling up cocopeat-based sanitation systems. The Lower Mekong Delta is one example of a coconut-producing region with millions of rural families relying on agriculture for their livelihood. Similar regions in India and other coconut-processing areas in many developing countries offer analogous opportunities.

The cocopeat technology testing in Can Tho University in Southern Vietnam illustrates the great potential of cocopeat-based sanitation systems for rural households. In this system, human waste is mixed with agricultural wastes in biodigesters to maximize the generation of biogas. The cocopeat is used to treat the effluent from the biodigesters, which has levels of BOD and TSS too high to safely reuse without additional treatment. Cocopeat-treated digester effluent then flows to the agricultural systems, either aquaculture ponds or fields, for nutrient recycling.

In rural settings, most households utilize biomass cookstoves, fed by either firewood, animal dung, or other combustibles. In these families, mostly women and children spend up to four hours per day in collecting biomass and tending wood fires. Biogas offers a highly desirable option, which not only frees up women's time to allow other pursuits, but is cleaner and healthier too. Cocopeat-based biogas systems can be installed for approximately one half-month's agricultural income, which is generally considered to be affordable given the value of the biogas. The concept is represented in the following photo (Figure 4).

Figure 4. The photo illustrates a method of wastewater treatment where waste from humans and livestock is treated together in the digester, and the effluent flows through the cocopeat filter (not shown) to the aquaculture pond. Biogas is produced for methane; treated effluent and biosolids are reused for agricultural strengthening.

Following are the results of the Can Tho University study showing removal efficiency of the cocopeat filter:

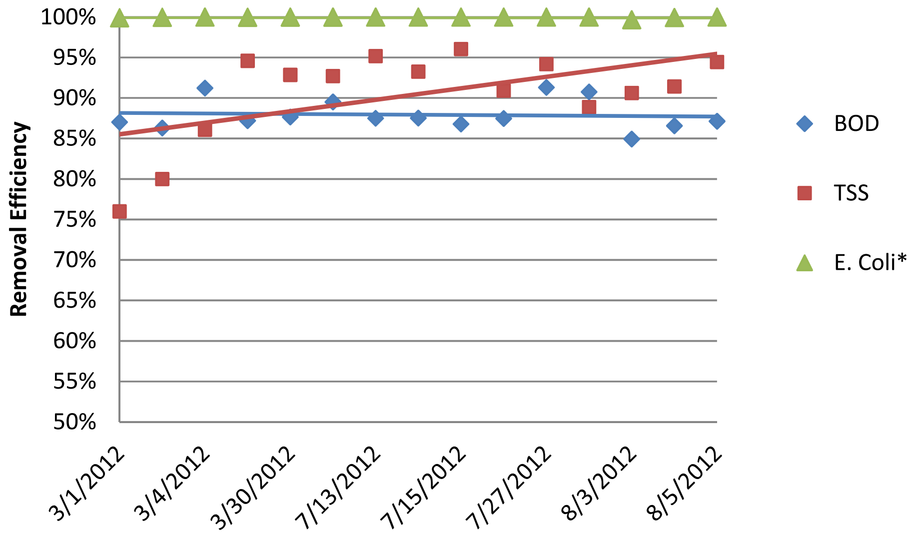

Figure 5. Cocopeat technology removal efficiencies for BOD, TSS, and E. coli at Can Tho University
** July and August estimates for E. coli were reported as FC.*

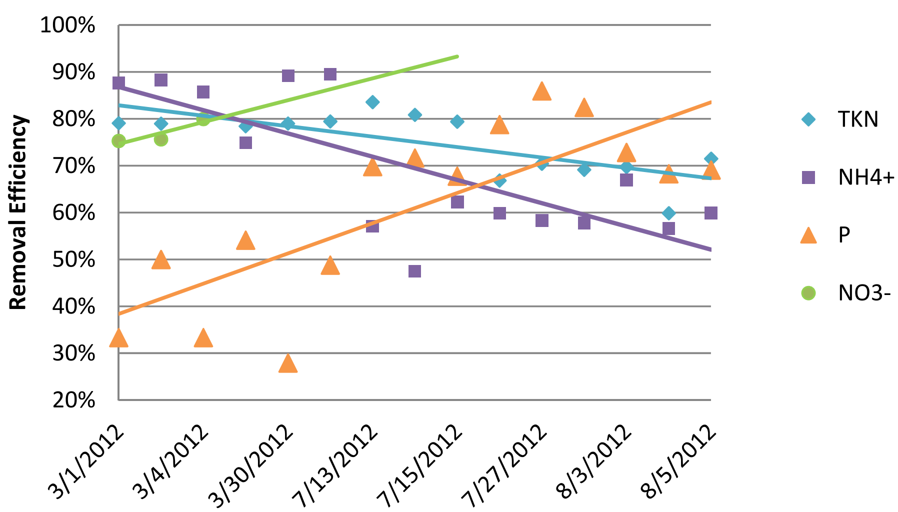

Figure 6. Cocopeat technology removal efficiencies for nutrients at Can Tho University[6]

As illustrated in Figures 5 and 6, the cocopeat technology is capable of significant effluent water quality improvement. Specific findings from the testing phase at the University are reported in Table 3.

[6] Nitrate levels in both influent and effluent were below the Detection Limit for Purposes of Reporting after March 4, 2012 and are therefore not included in the analyses.

Table 3. Findings from cocopeat technology testing at Can Tho University

Observed Parameter	Average Reduction	Average Cocopeat Effluent	Effluent Standard[7]
BOD	88%	26.14	50
TSS	90%	10.53	100
E. coli bacteria	100%[8]	41.67	No standard
Total Coliform	100%	440	5000
Ammonia (NH_4^+)	69%	4.87	10
Total Kjeldahl Nitrogen (TKN)	75%	11.51	No standard
Nitrate	77%	3.44	50
Phosphate	61%	2.27	10
Cost per user per day (US cents)	<1 US cent/day		

As illustrated by the findings in the table, the effluent characteristics meet the domestic wastewater effluent standard.

The Duke University cocopeat study

Lab-scale reactors were operated to evaluate the performance of cocopeat compared to sphagnum peat, a biofiltration medium utilized in several commercial wastewater treatment products. Figure 7 illustrates the experiment design in which simulated wastewater is passed through the filter mediums seeded with activated sludge obtained from the North Durham Wastewater Treatment plant. Following are the results of the Duke study showing the successful performance of cocopeat in comparison to sphagnum peat:

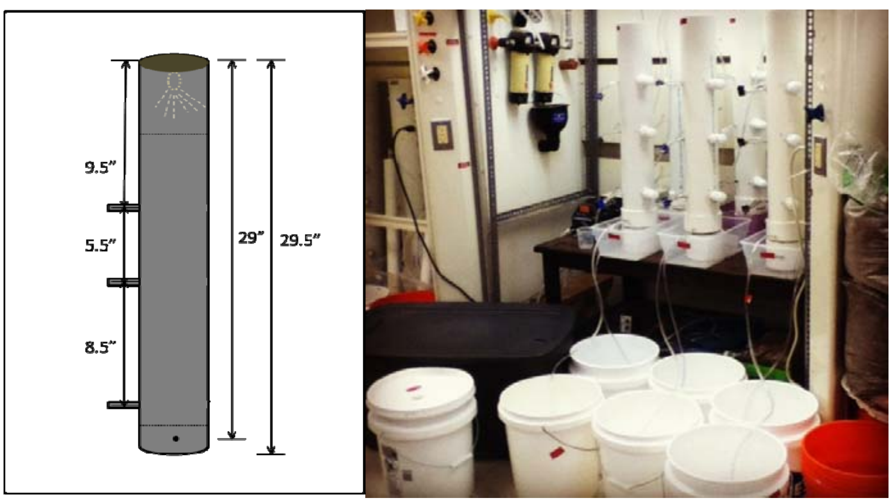

Figure7. Experimental setup at Duke University

[7] National regulation QCVN 14:2008/BTNMT "Domestic wastewater" (column B, discharged into a water body that is not used for water supply).
[8] July samples were reported in FC rather than E. coli.

Nutrient cycling is of particular interest in the Duke study. Significant nitrification was observed in both the cocopeat and sphagnum peat reactors; however, nitrogen conversion was 10% higher in the cocopeat reactor, suggesting that it is a better support material for ammonia oxidizing bacteria, which carry out the first step in nitrification. When the reactors reached steady state, they achieved an average ammonia removal of approximately 59% and 49% in the cocopeat and sphagnum peat reactors, respectively. Full removal of nitrogen is not necessary for effluent destined for irrigation or aquaculture use. Figure 8 displays the observed ammonia removal efficiencies.

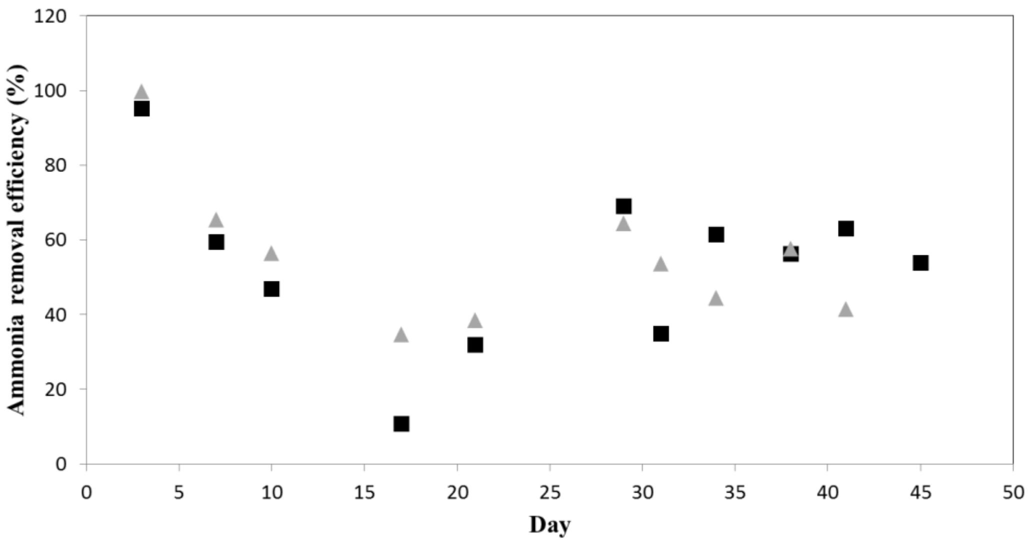

Figure 8. Ammonia removal efficiencies in cocopeat reactors (■) and sphagnum peat reactors (▲) at Duke University

BOD and TSS removal was also tested in the cocopeat reactors. The cocopeat reactors achieved between 90–100% removal efficiency of BOD. TSS removal was variable, and occasionally, breakthrough was experienced. It should be noted that no TSS was added to the influent synthetic wastewater; TSS was simply monitored. Generally, TSS in the influent was between 0–26 mg/L, which is only about 5% of the typical TSS concentration in septic tank effluent. TSS in septic tank effluent is generally between 521–745 mg/L (Brandes, 1978).

The Duke Lab reactor data demonstrates that cocopeat is a desirable biofiltration medium for septic tank effluent; it was shown to support nitrifying microbial growth. Cocopeat's higher performance compared to sphagnum peat also suggests that it presents select attributes for its field use. Follow-up experiments are currently underway to improve column design relative to redox zone distribution.

CONCLUSION

Cocopeat biofiltration represents a viable technology for treating septic tank or digester effluent. It may have benefits over other technologies, such as economy of space, cost, and simplicity of installation. As with all on-site and decentralized wastewater treatment programs, project proponents must carefully consider the nature of the wastewater source and the site where it will be managed to make informed technology decisions. Once the specific wastewater source has been characterized and the site evaluated, practitioners may perform a cost-benefit analysis of different technology options to determine the "best" alternative for a given wastewater discharge.

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