Systematic case-study: Nutrient cycling from wastewater to crop via Algal Turf Scrubber (ATS)

H. Klose & D.L. Reinecke

Forschungszentrum Jülich GmbH, IBG-2 Plant Sciences - Alternative Biomass, Wilhelm-Johnen-Strasse, 52428 Juelich, Germany

Email: D.Reinecke-Levi@fz-juelich.de

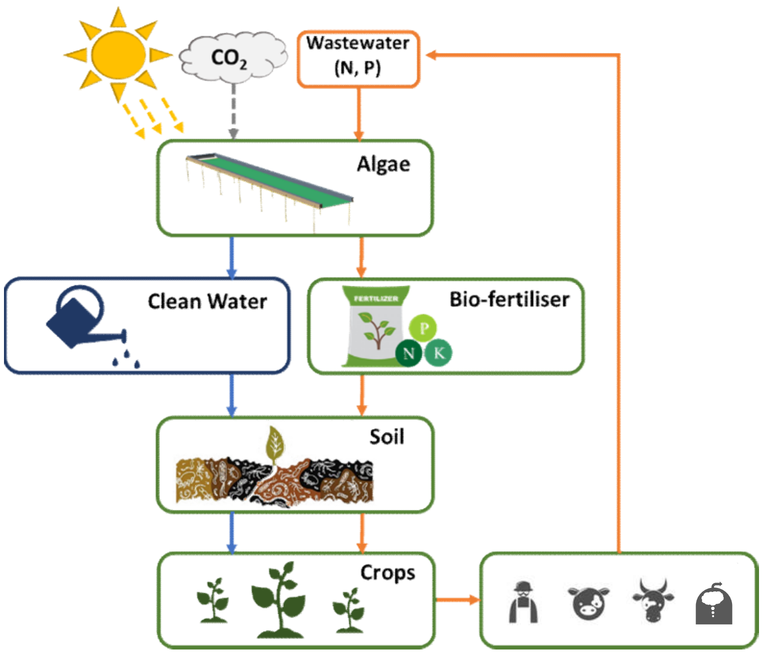

Figure 1. Concept of the Algal Turf Scrubber (ATS) system for the nutrient transfer from wastewaters to crops.

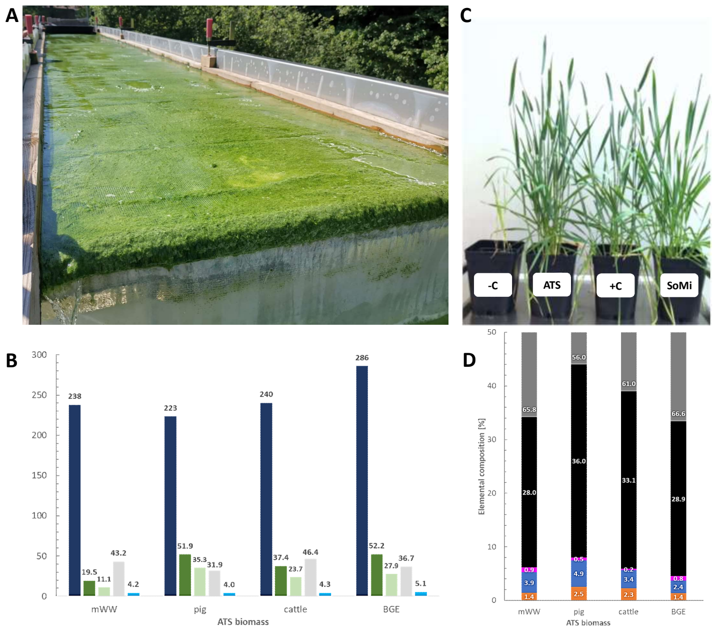

Figure 2. ATS biofilm composition and fertilising properties. Wastewater sources: municipal wastewater (mWW); pig (pig) and cattle (cattle) manure; biogas-effluent (BGE). Biofilm dry weight: yield (g, ■); total (g L^{-1}, ■); organic (g L^{-1}, ■); ash content (% DW, ■); productivity (g m^{-2} d^{-1}, ■). Elemental composition (% DW): phosphorous (■); nitrogen (■); potassium (■); carbon (■); others (■). Fertiliser: neg. control (-C), ATS biofilm (ATS), pos. controls mineral fertiliser (+C) and planting substrate (SoMi).

Introduction

Often, small-scale agriculture and industries in remote areas lack the access to cost-effective wastewater (WW) treatment. One techno-economical solution could be WW treatment by algal biofilm in Algal Turf Scrubbers (ATS). Nutrient cycling by micro- and macroalgae has been successfully demonstrated and could be an environmentally and economically sustainable technology[1-4]. The algal biofilm is grown in nutrient-rich wastewater, harvested, and processed to feed, fertiliser, or feedstock for further extractions, while the water is cleaned and oxidised. Yet, systematic studies, to the efficiency and economics of ATS biofilms in nutrient-recovery from WWs and -release to crops, are limited. Here we present the first findings of an ongoing case-study with pilot-scale ATS operated with 4 WW-types under field conditions. We present results to the nutrient transfer, biomass yield and the bioavailability of ATS biofilm.

Material & Methods

Conceptualization & planning: The ATS system was developed, build and evaluated for long-term field-trials in tight cooperation with within an academic partner, a WWTP and several farmers. **Algal biofilm:** All ATS were inoculated with one pre-existing biofilm[4].

Algal Turf Scrubber (ATS): Four identical ATS (8 x 1 m) were set-up with tipping bucket (30 L), medium tank (1 m^3), pump (50 L min^{-1}) and IoT sensors (aquatic, environmental). **Operation:** ATS were operated at the WWTP with municipal WW (mWW) and one farm with pig and cattle manure, and biogas-effluent (BGE). The ATS with pig or cattle manure, and BGE received weekly fresh WW (1 m^3). The mWW was continuously pumped from a secondary sedimentation basin onto the ATS and discharged into a polishing pond. **Sampling & Analysis:** Biofilms were scraped-off and analysed weekly (Jul-Oct) or biweekly (Nov-Apr). Total phosphorous and total nitrogen were measured in in- and outlet. The yield, dry weight, ash-, N-, and P-content, and elemental composition of the biofilm were determined at harvest (d_7). Population assembly and shifts were monitored microscopically throughout the year. Selected biofilms were fully analysed for elemental composition, heavy metals, *Salmonella sp.*, and antibiotics. **Fertiliser experiments:** These biofilms were mixed with sand (23 mg P kg^{-1}) in pots (3 L) and tested with wheat plants (*Triticum aestivum*) under greenhouse conditions.

Results

All four ATS-systems were started in spring 2021. The original biofilm inoculum was supplemented with wild algae of the WWTP. Microscopic observation found a mesocosm-like assembly of bacteria, pro- and eukaryotic algae, fungi, and protozoa in an extracellular polymeric substance. After the biofilms fully covered the substrate, cultivation with the individual WWs began, **Fig. 2A**. Biofilm populations shifted from filamentous cyanobacteria and green algae (Chlorophyta) towards unicellular green algae and Diatoms (Bacillariophyta). All ATS maintained a stable batch-culture with regular harvests, despite harsh weather events. Operational conditions, such as flow rate, WW admixture and sensor mounting, were adjusted to the WW type, but maintained a comparable setting. Workload for the operators were reduced to daily inspections (10 min) and weekly harvests and medium admixture (2h). High content of total suspended solids in pig and cattle manure, and BGE, requited pump replacement and reduced admixture (1% v/v). The mWW was directly (100% v/v) pumped onto the flow-way and 47% of TN were recovered. The biofilm yielded 238 g DW and 4.2 g m^{-2} d^{-1} in one week, **Fig. 2B**. ATS with pig-, cattle- and BGE-medium yielded comparable productivities, **Fig. 2B**. Biofilm in pig manure gained the highest carbon content and N:P:K ratio of 36% and 10:5:1, **Fig. 2D**. Initial results of long-term fertiliser experiments in wheat plants show similar growth and yield for ATS-biofilm and mineral fertilizer or planting substrate, **Fig. 2C**. Analysis to potential human and environment risks are still pending.

Discussion

Our study showed that agricultural and municipal wastewaters can be treated in ATS. The ATS biofilm successfully accumulated N, P, K, and carbon, throughout the year. The highest biomass productivity, of 286 g per week, was produced with biogas-effluent. Currently, the bioavailability of biofilm fertiliser is tested on wheat cultivars. The initial results show comparable growth performances for algal biofilm and mineral fertilizer. Our results indicate that ATS can be a low-maintenance and cost-effective WW treatment technology in rural areas. Yet, ATS systems need to reduce their areal-footprint and liability to environmental conditions to overcome current economic and legal constrains.

Take – Home – Message

- **Customized ATS systems for client-adherence**
- **Year-round operation is possible**
- **N, P, K, and C transfer from WW to algal biofilm**
- **Comparable fertilizing effect of biofilm and mineral fertilizer**

Literature

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