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FIELD TRIALS OF FILAMENTOUS ALGAE NUTRIENT SCRUBBER (FANS) OPERATION MODES TREATING AGRICULTURAL DRAINAGE

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Introduction

Filamentous Algae Nutrient Scrubbers (FANS) represent ecologically designed flow systems that cultivate attached filamentous algae (Sutherland & Craggs, 2017; Hariz et al., 2022). These systems have garnered attention due to their ability for nutrient recovery through algae nutrient assimilation, primarily nitrogen and phosphorus via photosynthesis. The stored nutrients manifest as algae biomass, which can be harvested and repurposed for value-added products. Among the potential applications are slow-release biofertilizers for crops, high-protein animal feed supplements, and cellulose extraction from algae biomass for biodegradable materials manufacturing.

FANS have demonstrated successful bioremediation capabilities across various nutrient-rich polluted water scenarios (Park et al., 2022; Hariz et al., 2023b; Sutherland & Burke, 2023). However, their performance exhibits variability due to seasonal changes in irradiance and temperature (Hariz et al., 2023c). For instance, during summer months, extreme ambient temperatures negatively impact algae growth on FANS. Conversely, limited irradiance and shorter daylight duration in winter can constrain algae growth and algae nutrient uptake.

To optimize FANS performance year-round, we investigated three operational modes at a pilot scale. Our study focused on treating farm drainage water from dairy farms in the north of Waikato, New Zealand. By comparing these modes under the same ambient conditions across seasons, we aimed to identify the most effective FANS treatment. Key performance metrics included algae biomass productivity, biomass organic content, nutrient removal rates and target filamentous algae establishment on FANS. This research contributes to our understanding of sustainable nutrient management and underscores the importance of tailoring FANS operations to prevailing environmental conditions.

Methods

The FANS treatment system was installed on a gently sloped terrain adjacent to the farm drainage stream. In this system, drainage water was pumped from the stream into a header tank using a solar-powered pump. Subsequently, the water flowed through the FANS via gravity (Figure 1). Each FANS floway received a continuous flow rate of 3 L min^{-1}. Three distinct operational modes of the FANS were rigorously tested (Figure 2):

Attached FANS: In this mode, algae growth occurred primarily on the textured bottom liner of the FANS. The algae physically hooked and biologically attached themselves to the surface.

Shallow Suspended FANS: Algae in this mode grew as free-floating entities, while also attaching to the floating mesh within the system.

Deep Suspended FANS: Similar to the shallow suspended mode, algae grew freely and adhered to the floating mesh. However, deep suspended FANS were shorter, spanning 4 meters, compared to the 12-meter length of attached and shallow suspended FANS.

Despite the differences in mode, all three FANS variants shared a common surface area of 1.44 m^2. Their operational depths varied, leading to distinct horizontal flow velocities (HFV), water volumes, and hydraulic retention times (HRT) or algae contact times (ACT) (Table 1).

Throughout the one-year trial period, the drainage water exhibited concentrations of up to 8 g m^{-3} of nitrate (NO_3-N) as a nitrogen source and 0.3 g m^{-3} of phosphate (PO_4-P) as a phosphorus source. Our research aimed to optimize FANS performance and identify the most effective operational mode for treating agricultural drainage water. Comparative analyses were conducted across different seasons.

Each FANS replicate received an initial seeding of 20 g of wet mixed species of filamentous algae collected from the farm drainage stream. These species included *Oedogonium* sp., *Rhizoclonium* sp., and *Spirogyra* sp. biomass (equivalent to a loading rate of 2.5 g of dried biomass per square meter).

Figure 1: Overview of FANS field trials setup adjacent to the farm drainage stream.

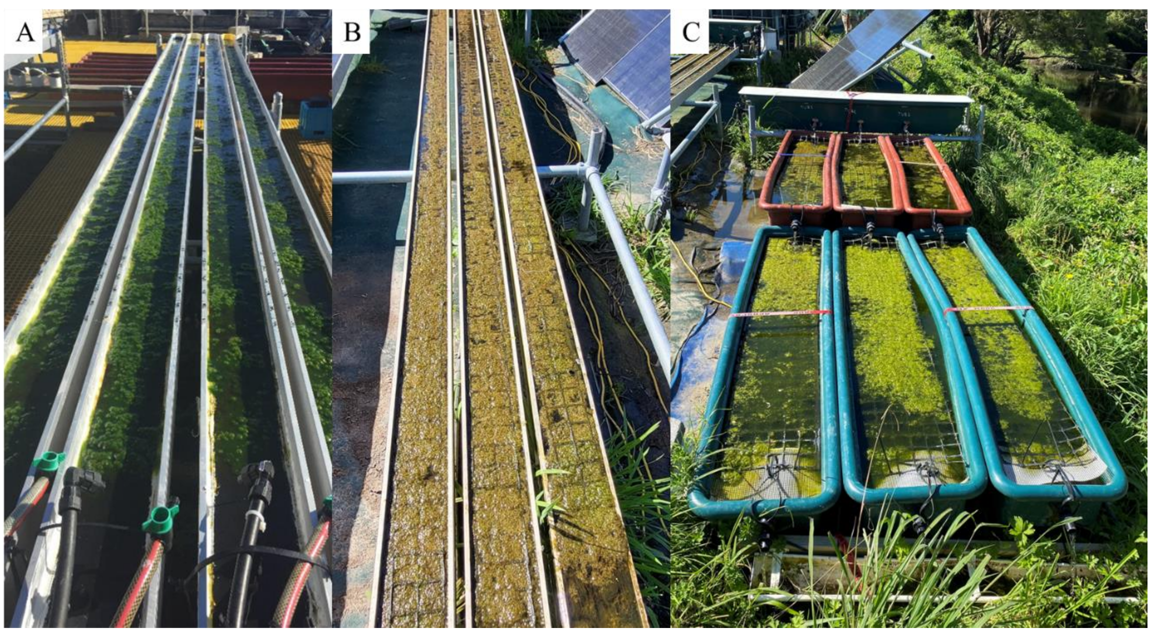

Figure 2: Three different FANS operation modes a) Attached, b) Shallow suspended and c) Deep suspended FANS.

Table 1: Operational parameters of the three different FANS operation modes

FANS operation modes and parameters	Attached	Shallow suspended	Deep suspended
Flowrate (L min^{-1})	3		
Floway width (m)	0.12		0.36
Length (m)	12		4
FANS surface area (m^2)	1.44		
Water depth (mm)	19	38	214
Horizontal flow velocity (m s^{-1})	0.022	0.011	0.0006
Hydraulic retention time (HRT, min)	9	18	102

Results

During the summer and autumn seasons, the FANS system exhibited varying biomass productivity, as measured by Volatile Solids (VS). Shallow suspended FANS achieved the highest median biomass productivity, with 5.1 g VS m^{-2} day^{-1} in summer and 2.2 g VS m^{-2} day^{-1} in autumn (Figure 3). In spring, the deep suspended FANS outperformed other modes, reaching a productivity of 3.9 g VS m^{-2} day^{-1}. However, during spring, the biomass productivity of the shallow suspended FANS remained notably high at 3.8 g VS m^{-2} day^{-1}. In contrast, during winter, all FANS modes exhibited similar biomass productivity, averaging 0.6 g VS m^{-2} day^{-1}. Notably, summer biomass productivity was at least five-fold higher than that observed during winter.

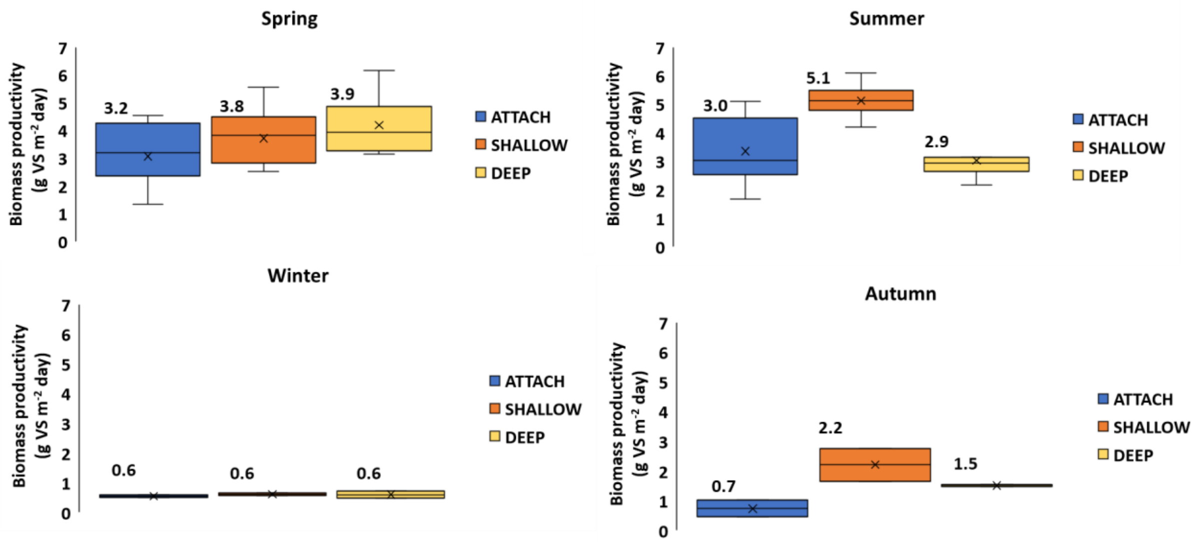

Figure 3: Algal biomass productivity measured as volatile solids (g VS m^{-2} day^{-1}) across spring, summer, autumn and winter.

The composition of harvested biomass also varied across different FANS operational modes (Figure 4). The deep suspended FANS had the highest percentage of organic matter, ranging from 44% to 70% across seasons. In contrast, the attached FANS yielded biomass with a significantly higher inorganic matter (ash) content. This difference is likely attributed to the greater sediment content associated with algae attached to the FANS liner. Additionally, non-target algae growth such as epiphytic diatoms coating the green filamentous algae contributed to increased inorganic matter in the harvested biomass. These factors collectively influenced the overall biomass quality of the initially seeded green filamentous algae.

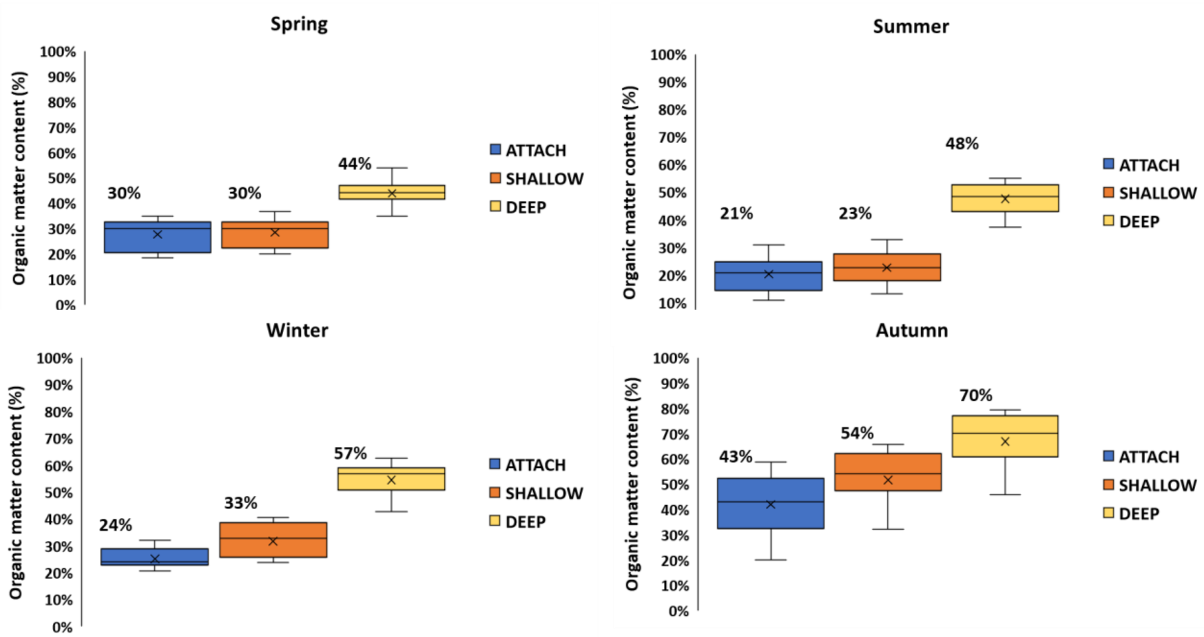

Figure 4: Algal biomass organic content (%) across spring, summer, autumn and winter.

During summer, the nitrate removal rates across different FANS operational modes ranged from 0.31 to 0.74 g N m^{-2} day^{-1} (Figure 5). In winter, the nitrate removal rates spanned 0.19 to 0.30 g N m^{-2} day^{-1}. Notably, the shallow suspended FANS exhibited the highest nitrate removal rate during the warmer months of spring and summer. However, during colder months, the nitrate removal rates remained relatively similar across all FANS modes.

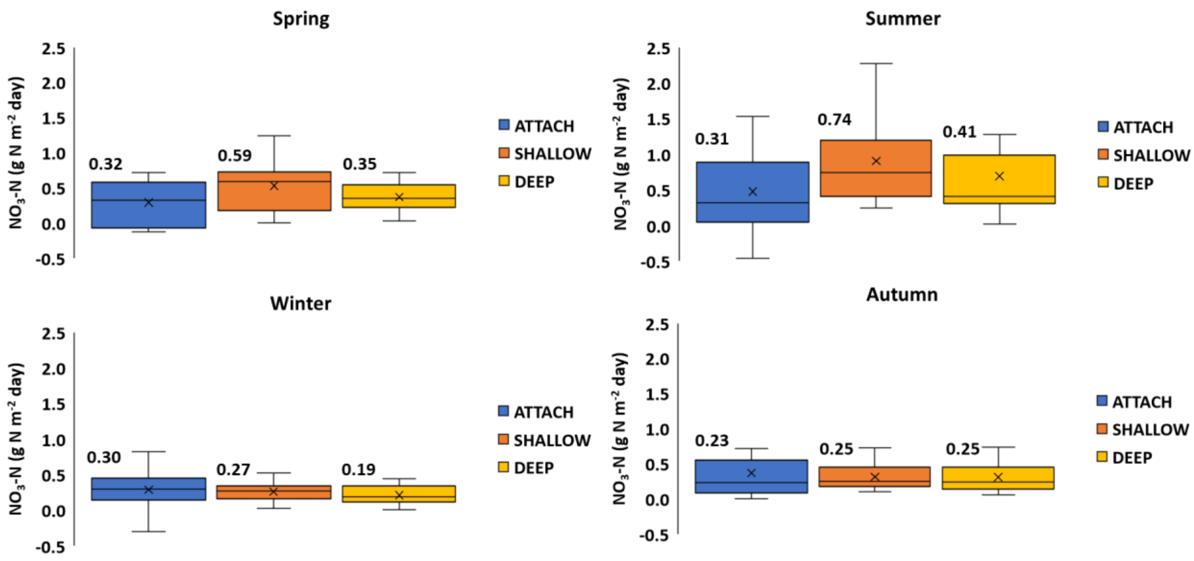

Figure 5: Nitrate removal rate (g N m^{-2} day^{-1}) across spring, summer, autumn and winter.

In summer, the phosphate removal rates across FANS modes varied from 0.13 to 0.17 g P m^{-2} day^{-1} (Figure 6). During winter, the phosphate removal rates ranged from 0.05 to 0.13 g P m^{-2} day^{-1}. Overall, the shallow suspended FANS demonstrated a relatively high phosphate removal rate.

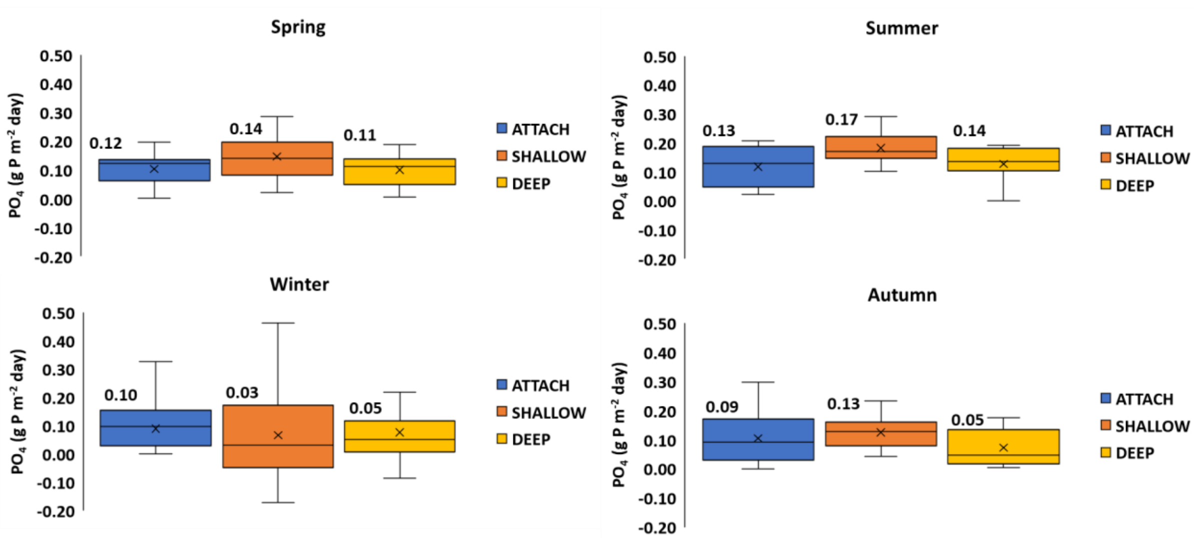

Figure 6: Phosphate removal rate (g P m^{-2} day^{-1}) across spring, summer, autumn and winter.

During the one-year trial period, the composition of green filamentous algae initially seeded in the FANS system exhibited intriguing patterns. Notably, the deep suspended FANS maintained a consistent relative abundance of at least 80% green filamentous algae throughout the study. The shallow suspended FANS held a relative abundance of approximately 50% green filamentous algae. The attached FANS had a lower composition of green filamentous algae and experienced a substantial decrease to 20% during the summer months. Interestingly, diatoms proliferated in this mode, dominating the system with up to 80% relative abundance during summer. Findings revealed that utilizing suspended FANS resulted in improved biomass quality, characterized by higher organic content. This finding holds significance for the advantageous utilization of the biomass.

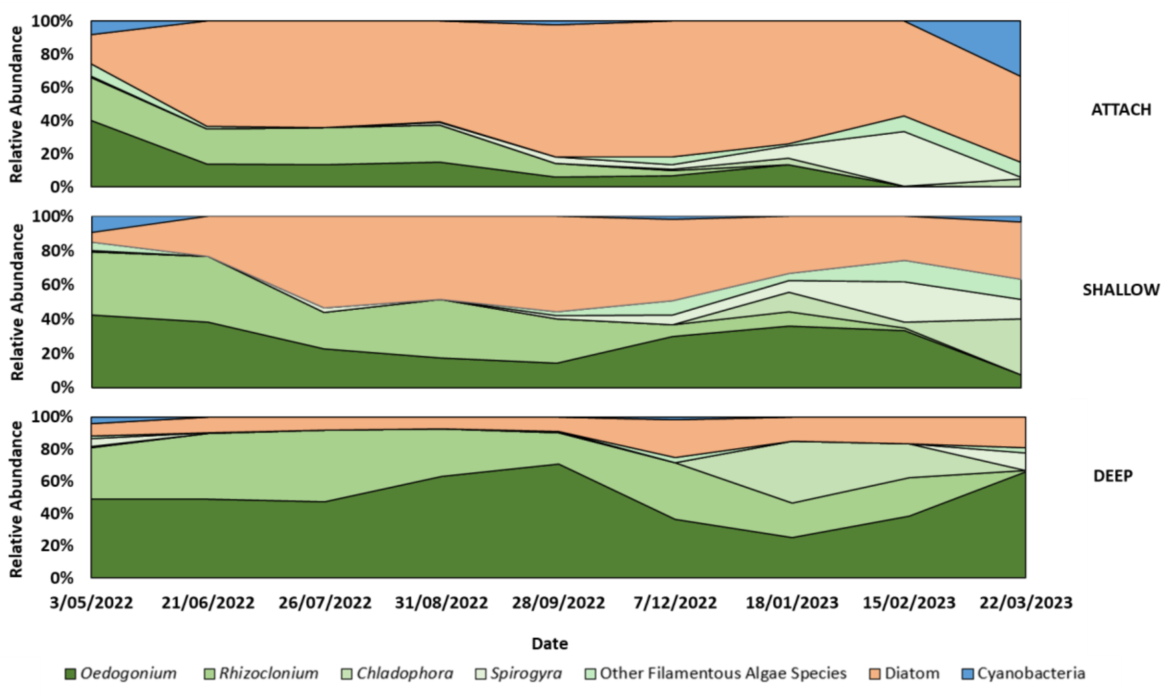

Figure 7: Algal species establishment based on species relative abundance (%) across one-year trial period

The study underscores the impact of FANS operational modes on overall performance. These modes influence algae growth, nutrient reduction, and biomass quality. The shallow suspended FANS highest overall biomass productivity and nutrients reduction, likely benefited from an optimal depth that facilitated sufficient light penetration for efficient algae photosynthesis (Sutherland et al., 2020; Hariz et al., 2023a). Hence, the shallow suspended FANS emerges as a promising choice for year-round FANS operation. Factors such as hydraulic retention time (HRT) and algae contact time (ACT) also play crucial roles in nutrient assimilation while minimizing carbon limitations (Park et al., 2022). In summary, understanding the interplay between operational modes, algae composition, and system performance is essential for optimizing FANS technology in treating agricultural drainage water under varying seasonal conditions.

Acknowledgements

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