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Effects of two different nutrient loads on microalgal production, nutrient removal and photosynthetic efficiency in pilot-scale wastewater high rate algal ponds

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ABSTRACT

When wastewater treatment high rate algal ponds (HRAP) are coupled with resource recovery processes, such as biofuel production, short hydraulic retention times (HRTs) are often favoured to increase the microalgal biomass productivity. However, short HRT can result in increased nutrient load to the HRAP which may negatively impact on the performance of the microalgae. This paper investigate the effects of high (NH_4–N mean concentration 39.7 ± 17.9 g m^{-3}) and moderate ((NH_4–N mean concentration 19.9 ± 8.9 g m^{-3}) nutrient loads and short HRT on the performance of microalgae with respect to light absorption, photosynthesis, biomass production and nutrient removal in pilot-scale (total volume 8 m^3) wastewater treatment HRAPs. Microalgal biomass productivity was significantly higher under high nutrient loads, with a 133% and 126% increase in the chlorophyll-*a* and VSS areal productivities, respectively. Microalgae were more efficient at assimilating NH_4–N from the wastewater under higher nutrient loads compared to moderate loads. Higher microalgal biomass with increased nutrient load resulted in increased light attenuation in the HRAP and lower light absorption efficiency by the microalgae. High nutrient loads also resulted in improved photosynthetic performance with significantly higher maximum rates of electron transport, oxygen production and quantum yield. This experiment demonstrated that microalgal productivity and nutrient removal efficiency were not inhibited by high nutrient loads, however, higher loads resulted in lower water quality in effluent discharge.

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1. Introduction

High rate algal ponds (HRAP) are a component of enhanced pond systems first developed in the 1950s for the treatment of wastewater and resource recovery (Oswald and Golueke, 1960). These shallow (typically < 500 mm deep), well mixed ponds allows for the proliferation of microalgal biomass which, in turn, enhances nutrient removal from the wastewater via assimilation. In New Zealand, pilot-scale and full-scale research on HRAPs has shown that they provide improved and more consistent wastewater treatment and higher microalgal productivity than traditional facultative ponds (Craggs et al., 2011). In addition to enhanced nutrient removal, HRAPs have the added benefit of recovering assimilated nutrients from the wastewater, as harvested algal biomass, for use as fertiliser, feed or biofuel (Craggs et al., 2012). The use of HRAPs for biofuel production alone is currently not financially viable, however, the ability to recover resources from wastewater treatment HRAPs makes biofuel production economically feasible (Benemann, 2003; Rawat et al., 2011).

One of the main objectives of coupled wastewater treatment and resource recovery is to maximise microalgal productivity in the shortest possible time while meeting nutrient discharge objectives. Light absorption and utilisation (photosynthesis) is the driving force in the uptake of nutrients and formation of biomass and its efficiency is central to the mass cultivation of microalgae (Grobbelaar, 2010). Factors that negatively impact on this include: physical factors such as light, turbulence and temperature; chemical factors such as nutrient load, pH and salinity; and biological factors such as competition between species, grazing by invertebrates and viral infections (Grobbelaar, 2000; Larsdotter, 2006). A number of these factors can be managed through modifications in pond operation. The hydraulic retention time (HRT) is considered one of the main operational control variables for HRAPs as it determines both the nutrient load into the pond and the water quality of the effluent discharge, by affecting the amount of nitrogen removed by the microalgae (Garcia et al., 2000). Longer HRTs are favoured during winter minima growth periods to ensure sufficient nutrient removal to meet discharge consent conditions, however, when wastewater treatment is coupled with resource recovery, shorter HRTs during summer maxima are considered more desirable to achieve higher microalgal areal productivity (Cromar and Fallowfield, 1997; Garcia et al., 2000; Park and Craggs, 2010).

Shorter summertime HRT can result in increased nutrient load to the HRAP which may affect the performance of the wastewater microalgae. While a number of studies have looked at the effects of changes in HRT and nutrient loads (e.g. Cromar and Fallowfield, 1997; Garcia et al., 2000) on the microalgal biomass productivity and nutrient removal, there has been no published studies, to date, assessing the effects of different nutrient loads, under summertime HRT, on the light absorption and utilisation by wastewater microalgae. The aim of this study was to investigate the effects of nutrient load on the performance of microalgae with respect to light absorption, photosynthesis, biomass production and nutrient removal in wastewater treatment HRAPs.

2. Methods

2.1. *High rate algal pond operations and environmental variables*

This study was conducted outdoors over the summer-time period (December–March), at the Ruakura Research Centre Hamilton, New Zealand (37°47′S, 175°190′E). The pilot-scale system consisted of two adjoining single-loop, raceway HRAPs, each with a surface area of 31.8 m^2, operating depth of 0.3 m and a total volume of 8 m^3. In each of the HRAPs, a single paddlewheel mixed the wastewater around the pond at an average horizontal water velocity of 0.2 m s^{-1}. Further description of the design and construction of the HRAPs are described in Park and Craggs (2010).

The HRAPs received primary settled domestic wastewater which was pumped into the ponds at hourly intervals to give the required flow rate over a 24 h period. Nutrient and suspended sediment concentrations of the primary influent are presented in Table 1. The HRAPs were both operated on a 4 day hydraulic retention time (HRT). HRAP 1 received 100% primary influent to represent high nutrient load (HNL), while HRAP 2 received 50% primary influent: 50% tap water, to represent moderate nutrient load (MNL). To avoid daytime carbon limitation, CO_2 gas was sparged into both ponds via gas diffusers placed on the bottom of the ponds in the turbulent zone. The addition of the CO_2 was pH controlled, with addition commencing when pH > 8 and stopping when pH < 7.8.

Table 1 – Summer-time environmental variables, microalgal productivity, nutrient removal and light climate in pilot scale HRAPs operated at moderate nutrient load (MNL) and high nutrient load (HNL) on a 4 day retention time. Data are means ± standard deviations of the three month period.

Variable	MNL	HNL
Pond temperature (°C)	19.2 ± 3.2	19.4 ± 3.6
Pond dissolved oxygen (% saturation)	164 ± 73	144 ± 69
Pond pH	7.4 ± 0.7	7.5 ± 0.8
Pond conductivity (μS cm^{-1})	454 ± 197	689 ± 235
Influent NH_4–N (g m^{-3})	19.9 ± 8.9	39.7 ± 17.9
Effluent NH_4–N (g m^{-3})	5.1 ± 4.7	12.3 ± 9.3
% NH_4–N removed	74 ± 15	75 ± 21
NRE – NH_4–N	1.11 ± 0.61	2.35 ± 0.82
Influent DRP (g m^{-3})	3.2 ± 1.0	6.3 ± 1.9
Effluent DRP (g m^{-3})	0.7 ± 0.7	2.7 ± 1.9
% DRP removed	79 ± 22	58 ± 29
NRE – DRP	0.20 ± 0.06	0.24 ± 0.12
Influent VSS (g m^{-3})	19 ± 11	39 ± 23
Pond VSS (g m^{-3})	184 ± 22	233 ± 42
Pond Chl-*a* (mg m^{-3})	3053 ± 281	4064 ± 774
Areal productivity VSS (g m^{-2} d^{-1})	17.4 ± 3.0	13.8 ± 2.6
Areal productivity Chl-*a* (mg m^{-2} d^{-1})	229 ± 21	305 ± 58
VSS:Chl-*a*	61 ± 7	58 ± 9
K_d (m^{-1})	31.5 ± 2.5	40.6 ± 7.0
$Z_{euphotic}$:Z_{total}	0.49 ± 0.04	0.39 ± 0.06
E_{mix} (mmol d^{-1})	5.24 ± 1.15	4.14 ± 1.07
E_{mix}:pond surface PAR	0.11 ± 0.01	0.08 ± 0.01
Light conversion efficiency (mg Chl-*a* μmol photon)	0.69 ± 0.29	1.19 ± 0.55