Treatment of Dairy Manure Effluent Using Freshwater Algae:
Elemental Composition of Algal Biomass at Different Manure Loading Rates

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The cultivation of algae on nitrogen (N) and phosphorus (P) in animal manure effluents presents an alternative to the current practice of land application. However, the use and value of the resulting algal biomass as a feed or soil supplement depend, in part, on whether the biomass contains any harmful components such as heavy metals. The objective of this study was to determine how the elemental composition of algae changed in response to different loading rates of anaerobically digested flushed dairy manure effluent. Algal biomass was harvested weekly from laboratory-scale algal turf scrubber (ATS) units using four manure loading rates (2, 4, 6, or 9 L m⁻² day⁻¹) corresponding to daily loading rates of 0.8–3.7 g of total N and 0.12–0.58 g of total P. Mean N and P contents in the dried biomass increased 1.6–1.8-fold with increasing loading rate up to maximums of 6.5% N and 0.84% P at 6 L m⁻² day⁻¹. Concentrations of Al, Ca, Cu, Fe, Mg, Mn, and Zn showed similar 1.4–1.8-fold increases up to maximums at a loading rate of 6 L m⁻² day⁻¹, followed by plateaus or decreases above this loading rate. Concentrations of Cd, Mo, and Pb initially increased with loading rate but then declined to levels comparable to those at the lowest loading rate. Concentrations of Si and K did not increase significantly with loading rate. The maximum concentrations of individual components in the algal biomass were as follows (in mg kg⁻¹): 1100 (Al), 9700 (Ca), 0.43 (Cd), 56 (Cu), 580 (Fe), 2300 (Mg), 240 (Mn), 3.0 (Mo), 14,700 (K), 210 (Si), and 290 (Zn). At these concentrations, heavy metals in the algal biomass would not be expected to reduce its value as a soil or feed amendment.

KEYWORDS: Algal turf scrubber; dairy manure; phytoremediation; algae; composition

INTRODUCTION

Off-farm losses of nutrients from manure during storage in lagoons and subsequent land application can pose a threat to environmentally sensitive watersheds. Cultivating algae on nutrients in animal manure offers an alternative to the current practice of land application. Suspended algae can be cultivated and harvested using wastewater in slowly mixed, shallow raceways (1–5). Alternatively, attached algae can be grown in rapidly mixed, shallow raceways lined with a suitable attachment surface (6–9). Both types of systems are highly productive and yield algal biomasses that are potentially valuable as soil amendments or feed supplements (10).

Removal of nutrients from raw and anaerobically digested dairy manure using attached algae has been recently studied in laboratory-scale algal turf scrubber (ATS) units (9). However, with the exception of N and P, there has been no examination of how the elemental composition of the algal biomass changes as a function of manure loading rate. This is important because use of the algal biomass as a feed or soil supplement depends, in part, on whether the biomass contains any harmful components. Previous research has shown that freshwater algae can accumulate heavy metals to levels far above levels found in their aqueous environment (11–13). The objective of this study was to determine how the elemental composition of harvested algal biomass changes using different loading rates of anaerobically digested flushed dairy manure.

MATERIALS AND METHODS

Experiments were conducted using anaerobically digested flushed manure effluent from the Dairy Research Unit of the University of Florida in Gainesville, FL, as previously described (9). The flushed dairy manure underwent mechanical solids separation and settling prior to being pumped into a 400 m³ fixed-film anaerobic digester operating at ambient temperature with a 2-day retention time (14). All tests were performed on one batch of digested manure effluent that was shipped to Maryland in 200 L barrels and stored at 4 °C. The digested manure effluent concentrations of ammonium-N, nitrate-N, total N (TN), soluble reactive phosphorus, and total P (TP) were 233, <1, 412, 55.8, and 64.5 mg L⁻¹, respectively. The elemental composition of the manure effluent is shown in Table 1. Three laboratory-scale ATS units (each
Effluent (2, 4, 6, or 9 L per day) was added daily to the recirculating scrubber before draining back into the plastic drum. Digested dairy manure effluent pulses of effluent that wash over the attached algal turf every 10 days and dried at 70 °C prior to analysis for total Kjeldahl nitrogen (TKN) and phosphorus (TP), as well as elemental composition using inductively coupled plasma (ICP) analysis (15).

RESULTS

ATS units were operated at loading rates of 2, 4, 6, and 9 L m⁻² day⁻¹. Algal production varied from 5 to 23 g of DW m⁻² day⁻¹ with mean values ranging from 7.6 to 19.1 g of DW m⁻² day⁻¹ at the different loading rates (9). The relative content of ash-free dry weight (% DW) for algal biomass grown under all treatments was fairly constant, between 90 and 93%. Mean N and P contents in the dried biomass increased 1.6-1.8-fold with increasing loading rate up to 6.5% N and 0.84% P, at 6 L m⁻² day⁻¹ (Figure 1, Table 1). Above this loading rate, algae N content increased slightly (to 6.9%) and P decreased slightly (to 0.8%) (9). Levels of Al, Ca, Cu, Fe, Mg, Mn, and Zn showed similar 1.4-1.8-fold increases up to maximums at a loading rate of 6 L m⁻² day⁻¹, followed by plateaus or by changes of <10% above this loading rate. Levels of Mo and Pb initially increased with loading rate but then declined to levels comparable to those at the lowest loading rate. Cd levels decreased slightly at 4 L m⁻² day⁻¹, increased at 6 L m⁻² day⁻¹, but then declined to levels comparable to those at the lowest loading rate. Concentrations of Si and K did not increase significantly with loading rate (Figure 2, Table 1).

The recovery rate for a particular element is a function of algal production and the elements content in the biomass. The absolute amounts of different elements recovered in the algal biomass generally increased with increasing loading rate because of increasing production (not shown). However, percentage recovery for a number of elements (K, P, Ca, Mg, Fe, Mn, Mo, and Cd) peaked at a loading rate of 6 L m⁻² day⁻¹ corresponding to the point of their maximum respective concentrations in the algal biomass (Table 1). Individual loading rates and percentage recoveries of different elements in the algal biomass at the highest manure loading rate (9 L m⁻² day⁻¹) are also shown in Table 1. At this loading rate, average recoveries generally varied from values of <10% (Ca, Cd, Mg) to values of 33–36% (N, P, Zn). In contrast, calculated recovery values for Pb were variable and very high relative to recoveries for the other elements. Mean Pb recoveries ranged from 70 to 80% at the two highest loading rates and exceeded 100% at the two lower.

### Table 1. Elemental Composition of Dairy Manure and Dried Algal Biomass Grown Using Four Different Manure Loading Rates

<table>
<thead>
<tr>
<th>Element</th>
<th>Dairy manure (mg/L)</th>
<th>Algal biomass (mg/kg)</th>
<th>Recovery in algal biomass at max loading rate (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>35200 ± 5000</td>
<td>6400 ± 5200</td>
<td>1.6±0.01</td>
</tr>
<tr>
<td>K</td>
<td>12300 ± 4800</td>
<td>14720 ± 2500</td>
<td>1.4±0.01</td>
</tr>
<tr>
<td>P</td>
<td>7500 ± 1300</td>
<td>8300 ± 1070</td>
<td>1.4±0.01</td>
</tr>
<tr>
<td>Ca</td>
<td>241 ± 1800</td>
<td>6400 ± 1000</td>
<td>1.6±0.01</td>
</tr>
<tr>
<td>Mg</td>
<td>617 ± 3500</td>
<td>1800 ± 2000</td>
<td>1.6±0.01</td>
</tr>
<tr>
<td>Al</td>
<td>9.8 ± 100</td>
<td>1070 ± 1900</td>
<td>1.6±0.01</td>
</tr>
<tr>
<td>Fe</td>
<td>350 ± 40</td>
<td>530 ± 100</td>
<td>1.6±0.01</td>
</tr>
<tr>
<td>Mn</td>
<td>1.8 ± 1</td>
<td>222 ± 32</td>
<td>1.6±0.01</td>
</tr>
<tr>
<td>Zn</td>
<td>1.6 ± 15</td>
<td>299 ± 61</td>
<td>1.6±0.01</td>
</tr>
<tr>
<td>Si</td>
<td>3.8 ± 2</td>
<td>210 ± 46</td>
<td>1.6±0.01</td>
</tr>
<tr>
<td>Cu</td>
<td>0.39 ± 6.1</td>
<td>55.7 ± 11.1</td>
<td>1.6±0.01</td>
</tr>
<tr>
<td>Mo</td>
<td>0.024 ± 0.03</td>
<td>1.6 ± 0.26</td>
<td>1.6±0.01</td>
</tr>
<tr>
<td>Pb</td>
<td>0.010 ± 0.02</td>
<td>0.12 ± 0.01</td>
<td>1.6±0.01</td>
</tr>
<tr>
<td>Cd</td>
<td>0.011 ± 0.004</td>
<td>0.21 ± 0.43</td>
<td>1.6±0.01</td>
</tr>
</tbody>
</table>

**a** Values are means ± SD of measurements over five to nine harvest cycles. **n** = number of harvests. **b** Values calculated using a manure loading rate of 9 L m⁻² day⁻¹.
The maximum tolerable dietary levels (MTDL) in dairy cow feed for elements measured in this study are as follows (in mg kg\(^{-1}\)): Al (1000), Cu (100), Cd (0.5), Fe (1000), Mo (5), Mn (1000), Pb (30), and Zn (500) (17). These levels are based on the use of highly bioavailable soluble salts of these metals. In this study, only levels of algal Al (with a mean value of 1070 mg kg\(^{-1}\)) at the highest loading rate) exceeded the MTDL. We have no information about the solubility or bioavailability of any of the constituents in the algal biomass. However, as a potential feed component, dried algal biomass would constitute only a small portion of the total feed (18), and thus Al in the product would be unlikely to reduce its value as a feed.

With regard to using the algal biomass as a fertilizer, rough application rates can be calculated on the basis of available N or P fertilizer equivalents. In Maryland, algal production could be expected to operate 9 months of the year at average production values of 15 g of DW algal biomass m\(^{-2}\) day\(^{-1}\) (equivalent to 150 kg of DW ha\(^{-1}\) day\(^{-1}\) or 40.5 mt of DW year\(^{-1}\)). At these loading rates, algal biomass would contain approximately 7% N and 1% P (9). The volume of algal biomass from a 100-cow dairy would provide available N fertilizer equivalents for 6 ha of corn at 150 kg ha\(^{-1}\) (19). As a P fertilizer used for amending soils at 100 kg of P ha\(^{-1}\), this volume of algal biomass would support 4 ha of production. At these amendment rates (6.5–10 mt of biomass ha\(^{-1}\)), loadings of heavy metals from the algal biomass would be well below regulatory limits (20).

**ABBREVIATIONS USED**

ATS, algal turf scrubber; TP, total phosphorus; TN, total nitrogen; DW, dry weight.

**ACKNOWLEDGMENT**

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**LITERATURE CITED**


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