Utilizing Microalgae to Remediate Nitrate-Contaminated Groundwater

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Background

Nutrient contamination of local groundwater sources is often a problem in areas with concentrated agricultural and animal production. Due to its high permeability, nitrates from runoff can be found in groundwater at concentrations exceeding EPA limits of 10 mg/L N as NO_3^-, thereby reducing the amount of useable drinking water.

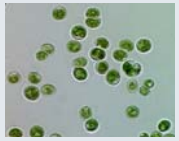
High concentrations of nitrate in drinking water may be linked to a number of health problems. Infants less than one year old are at the highest risk because nitrates in the body are converted into a form that decreases the ability of blood to carry oxygen.

Reverse osmosis, distillation, and anion exchange can remove nitrates from water, but currently there are no cost-efficient methods employed by water companies to remove nitrate contamination on a large scale. We have examined the cultivation of microalge in contaminated groundwater as a sustainable, cost-efficient approach to remove nitrates.

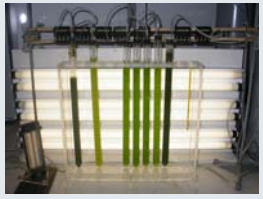
Methodology

Laboratory

Several strains of green algae and cyanobacteria were isolated from local water sources and grown in nitrate-contaminated groundwater. For algae to be successfully grown in groundwater, small amounts of phosphate were added. Laboratory screening experiments were conducted with several strains to identify the organisms with the highest rates of growth and nitrate removal.



Chlorococcum sp.



Samples were collected over a period of two days. Cell density was measured using a spectrophotometer at 730nm, and nitrate concentration was determined using a Bran-Luebbe TrAAcs 800 Autoanalyzer.

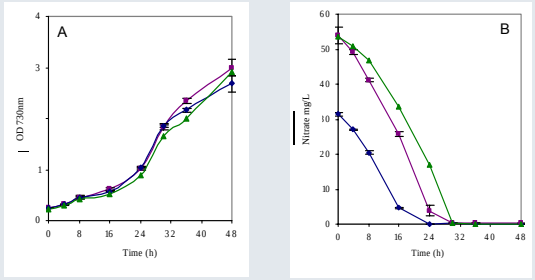
Field

Experiments were conducted in a 400 L capacity outdoor bioreactor using a strain of *Chlorococcum* sp. The bioreactor contained twelve 33 L Plexiglas columns for culturing the algae. The columns were exposed to full sunlight during the day, with no additional lighting during the night. The culture was aerated with CO_2 from the bottom of the columns. Initial experiments were conducted in early September when temperatures ranged from 24–40°C (76–104°F). When the temperature approached 40°C, an automatic cooling system released water down the outer surface of the columns, providing evaporative cooling until the temperature dropped below 30°C.

Outdoor photobioreactor

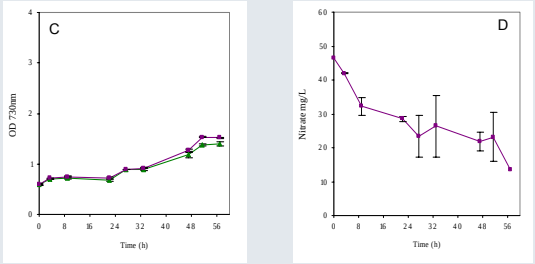
Findings

Microalge are capable of very rapid growth, requiring only light, carbon dioxide, and nutrients. Under laboratory conditions, some strains could remove nitrates at a rate of 2 mg/L/hr. *Chlorococcum* sp. grew well in the local groundwater and had the highest nitrate removal rates. This organism was able to remove 30 mg/L NO_3^- within 24 hours.



(A) Cell density and (B) nitrate uptake of *Chlorococcum* sp. grown in the laboratory in groundwater containing 30 mg L^{-1} N-NO_3^- (♦), 50 mg L^{-1} N-NO_3^- (■), and in BG11 growth medium with 50 mg L^{-1} N-NO_3^- (▲). Locally collected groundwater was enriched with 4.5 mg L^{-1} phosphate and 50 mg L^{-1} nitrate. Cultures were inoculated at an initial OD of 0.3. The 300 mL columns were aerated with 1.7% CO_2, and illuminated with 185 µmol $s^{-1}m^{-2}$ by continuous fluorescent lighting.

The *Chlorococcum* sp. was then moved outdoors to be tested in the photobioreactor. Preliminary results were slightly lower than those in the laboratory. However, there are a number of factors that may have contributed to a lower daily nitrate uptake when compared to the laboratory environment. First, the photobioreactor relies only on sunlight, with no supplemental or additional lighting during the night. Since phototrophic algae require light to grow and take up nitrate, these processes will be halted during the night. This affect is apparent in figures C and D, where growth and uptake rates are reduced. Also, high temperatures during the summer can cause physiological stress that may reduce cell function and performance. Finally, the diameter of the columns in the photobioreactor was much larger than those used in the lab, so algal cells in the photobioreactor may have been exposed to lower light fluxes than in the laboratory.



(C) Growth of *Chlorococcum* sp. grown in the bioreactor in groundwater containing ~ 50 mg L^{-1} N-NO_3^- (■), and in BG11 growth medium with ~ 270 mg L^{-1} N-NO_3^-(▲). (D) Nitrate uptake in groundwater containing ~ 50 mg L^{-1} N-NO_3^-. Columns were aerated with 2% CO_2 and received full daytime sunlight, but no lighting at night.

Applications

Many local wells are contaminated with nitrates at concentrations of approximately 25 mg/L NO_3^-. If the algae can remove nitrates at a rate of 2 mg/L/hr, levels could be reduced to or below the EPA maximum allowable levels within 8 hours.

As an example, if a well pumped 1,000 gallons/minute, the water could be held in the photobioreactor for the 8 hour treatment period and then released into storage to be used. The average household in Arizona uses 126,632 gallons of water in a year. At this level, a photobioreactor on the site of a well could treat enough contaminated water each year for 4,000 households. This process may be especially useful to small communities in remote areas where conventional water treatment methods are too expensive.

The algal biomass produced by the reactor can become a valuable product for a number of applications. The high protein content and nutritional value of the algal biomass makes it an ideal health or food supplement for humans or domestic animals. It can also be used as a fertilizer or converted to biofuels. The photobioreactor can maintain a high cell density. If the bioreactor processes 300 million gallons of water in one year, the amount of dry biomass produced could approach 60,000 pounds. The sale of this biomass could help offset the costs of operating and maintaining the photobioreactor for groundwater cleanup.

Future Work

The photobioreactor must be extensively tested throughout the year to determine its seasonal and annual capacities to remove nitrate contamination. A continuous-flow photobioreactor design that can handle the quantities of water pumped from wells is essential.

Additional strains of algae should be examined for unique characteristics, such as tolerance to high and low temperatures, to maximize nitrate uptake rates throughout the year.

Efficient methods for harvesting and processing the algal biomass for potential commercial use must be developed.

Photobioreactor growing algae

Photobioreactor Valve System

Photobioreactor Air System

Back view of photobioreactor

Acknowledgements

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