

# Phytoremediation of Aquaculture Effluents

by Dr. Paul R. Adler

Aquacultural effluents are difficult to treat because they contain large volume flows carrying relatively dilute nutrients ( $< 1 \text{ mg/L P}$ ). However, it may be important to treat the nutrients in aquaculture effluents because, depending upon the receiving water, the total nutrient mass loading can contribute significantly to environmental degradation.



10

Predominant thinking regarding the use of plants to clean effluents has been that plants cannot remove nutrients in water to low levels without a reduction in productivity and quality. Because greenhouse space is expensive, maintaining maximum productivity is critical to sustaining a profitable operation. Our research has focused on using plants to remove P from aquacultural effluents. With development of the conveyor production system (Adler et al., 1996b), plants can reduce nutrients to low levels concurrent with the production of a high-value product. Conventional hydroponic production of lettuce and basil using thin-film technology, also known as NFT - Nutrient Film Technique, was investigated as a method to remove P to low levels from an aquaculture effluent. Thin-film technology is a hydroponic crop production system in which plants grow in water that flows continuously as a thin-film over their roots. Water flow across the roots decreases the stagnant boundary layer surrounding each root which, in turn,

enhances the mass transfer of nutrients to the root surface and permits crops to maintain high productivity at steady-state (continually maintained) P levels above  $0.3 \text{ mg/L}$  (A.D.M. Glass, personal communication). The rainbow trout effluent in this study contained between  $0.5$  and  $0.7 \text{ mg P/L}$ . So, using conventional hydroponic technology, P could be removed to about  $0.3 \text{ mg/L}$  or about 50% of the P could be removed from the effluent while producing a marketable product. Although lettuce can remove P to  $< 0.3 \text{ mg/L}$ , a reduction in growth will coincide with a further reduction in solution P concentrations. The objective of our research was to develop a production system that would allow plants to remove  $> 95\%$  of the P in the rainbow trout effluent while producing a marketable product.

Rainbow trout effluent characteristics. The effluent to be treated was from the recirculating system used to produce rainbow trout at The Conservation Fund's Freshwater Institute. The bulk effluent typically has a pH of 7.2 and contains around  $6 \text{ mg/L}$  total suspended solids (TSS) and the following macronutrients (mg/L):  $\text{NO}_3\text{-N}$  (25), P (0.7), K (5), Ca (55), Mg (20), and S (9). In contrast, the spring water that supplied the fish culture system typically contained (mg/L):  $\text{NO}_3$  (3), P ( $< 0.001$ ), and K (3). In this effluent, nutrients most limiting to plant's productivity is determined by the nutrient present in lowest supply relative to its requirements. When other nutrients limit plant growth, P removal can be increased by adding those nutrients that are most limiting. To maximize P removal, the following nutrients



*Paul Adler examines young lettuce seedlings which are grown for about 3 weeks in a separate hydroponic system before they are set in the "conveyor production system" to remove nutrients from the rainbow trout effluent. (Photo by Keith Weller, USDA-ARS)*

were added to make P the most limiting nutrient: 0.1 mg/L Fe-EDDHA (LibFer SP, Allied Colloids Inc.<sup>1</sup>, Suffolk, VA), 0.1 mg/L Mn-EDTA (Librel Mn, Allied Colloids Inc., Suffolk, VA), 0.004 mg/L Mo (as  $(\text{NH}_4)_6\text{Mo}_7\text{O}_{24}$ ), and 15 mg/L K (as  $\text{K}_2\text{SO}_4$ ).

**Seedling growth conditions.** 'Ostinata' lettuce and sweet basil were seeded into Oasis cubes (Smithers-Oasis, Kent, OH). The lettuce and basil seedlings were placed into thin-film troughs and watered for the first 16 or 20 days, respectively, with a recirculated complete nutrient solution. Seedlings could grow on effluent from the beginning if a hole in the Oasis cubes was extended down through the bottom to

permit immediate entry of roots into effluent upon germination. Without the hole, plants became nutrient starved because mass transfer of nutrients was poor without the roots directly in the solution. Due to relatively large diffusion distances, the only nutrients delivered to the root surface before they emerged from the cube were due to evapotranspiration or mass flow. At 16 and 20 days, lettuce and basil, respectively, were moved to a nonrecirculating thin-film system configured with the conveyor production sequence. Rainbow trout

effluent was pumped with peristaltic pumps (model no. 7520-35 Cole Parmer Instrument Co., Chicago, IL) at a constant flow rate of 250 and 300 ml/min for basil and lettuce, respectively.

**Thin-film technology production system.** In our first study, lettuce plants were grown in long (72 feet, 126 plants) troughs on rainbow trout effluent flowing from one end of the trough to the other. This system removed P from an inlet concentration of about 0.7 mg/L to an outlet concentration in the low parts per billion (ppb). However, as solution P concentrations dropped below about 0.3 mg/L, tissue P concentrations decreased. Even so, the plant growth rate was sustained until the P concentration within the plant

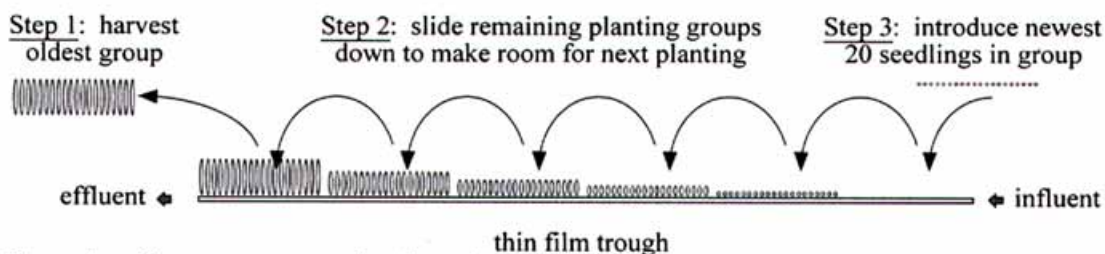


Figure 1 — Conveyor crop production schematic.



dropped below the critical deficiency level (0.35-0.4% P on a dry weight basis for lettuce). At that point, P deficiency symptoms appeared, plant growth decreased, and the plant quality became unmarketable. We developed the conveyor production strategy (described below) to sustain plant productivity and health while removing dissolved P levels to less than 0.01 mg/L.



*Lettuce and basil plants growing in the "conveyor production system" in Shepherdstown, WV*

### **Development of the Conveyor Crop Production System**

Fundamental concepts of plant nutrition were utilized to develop the conveyor production system, which produced healthy lettuce and basil without an apparent reduction in growth while simultaneously removing P to very low levels (ppb). For a mechanistic understanding of plant nutrient uptake see Adler et al. (1996c,d). A phenomenon called luxury consumption allows plants to absorb and store much higher levels of nutrients than are required by metabolism. The conveyor crop production strategy enables plants to store P early in their growth cycle. This stored reservoir of P can be remobilized to meet current plant needs and supplement the lower P influx rate, which occurs as P drops below about 0.3 mg/L in the effluent. Phosphorus remobilization will maintain growth as long as the tissue P concentration remains above the critical deficiency level (about 0.35-0.4% P on a dry weight basis in lettuce). With the conveyor production strategy, seedlings introduced at time intervals near the inlet of a thin-film system were progressively moved in sequence as they matured towards the outlet where they were harvested (Figure 1). At the front end of the thin-film troughs, where nutrient concentrations were highest, young plants absorbed and stored nutrients in excess of

their immediate needs. Luxury consumption of nutrients during this early growth phase sustained the plants later when they were moved towards the trough outlet where nutrient concentrations in solution were too low for absorption kinetics to meet their growth needs. Cellular nutrient concentrations were sufficient to sustain growth even after nutrients within the flow were limiting. This conveyor crop production scheme permitted the removal of P to very low levels (ppb), without an apparent reduction in plant productivity. This is in contrast to a conventional production scheme where a gradient in growth would accompany the reduction in nutrient levels.

**Conveyor production system.** Six connected troughs, each 12 feet long, formed the foundation for the conveyor production scheme. The troughs, roughly 4 inches x 12 feet (Genova Products, Inc., Davison, MI), were covered with 1.6 mm PVC having 1.25 inch holes evenly spaced at 6.9 inches, and planted with 20 seedlings. Plants were grown from the beginning of June through mid-July in a greenhouse maintained at 80-93°F during the day and 70-75°F during the night. With this production strategy, the rate of biomass production per unit area, hydraulic loading rate, and effluent P concentrations were relatively constant. Lettuce and basil were harvested every 4 days. Each of

the 6 sections represented 4 days in the system, so both lettuce and basil were in the system for 24 days. The lettuce and basil production cycles were 40 and 44 days, respectively. Every 4 days, plants were harvested at the outlet end of the system, the plants in the remaining 5 sections were moved down one position, and 16-day lettuce or 20-day basil plants were set into the system at the inlet end (Figure 1). This cycle was repeated 5 times to move a given set of plants completely through the system to harvest. The number of sections can be greater or less than 6. An increase in the number of sections will decrease the percentage of biomass removed with any one harvest and result in a more stable outlet concentration.

### Greenhouse Studies

After steady-state planting and harvesting was achieved, the conveyor production strategy maintained plant productivity and health while removing 99% of the dissolved P and 60% of the nitrate from the flow (Adler et al., 1996b). Basil and lettuce removed P to 0.003 mg/L and less than 0.001 mg/L, respectively, from an influent concentration of greater than 0.5 mg/L. Rate of P removal was greater than 60 mg P/m<sup>2</sup>-d and nitrate removal was 980 mg N/m<sup>2</sup>-d. Plants absorb nutrients 24 h a day; N absorption varies with the day/night cycle while P has very little diurnal variation (Adler et al., 1996a). Because plants remove nutrients continuously, effluent storage facilities are not necessary to treat effluents that are generated 24 h a day.

### Can All Water in Aquaponic Systems be Evapotranspired?

In warmwater aquaponic systems, water is recycled to conserve water. Hydroponic production of crops has been used as a way to remove nutrients added by fish from water. But will water which has passed through the plant system always be lower in nutrients? In the example below, if P is higher than 20 ppm, water will be returned to fish with more P because relatively more water is evapotranspired than P absorbed. Phosphorus needs to be lower than 20 ppm for plants to “clean” the water, i.e., remove it to lower levels. If the effluent entering the plant production system contains 20 ppm P, the effluent leaving it will also contain 20 ppm P and all the effluent could be evapotranspired.

#### Example

- Crop: lettuce
- Nutrient: phosphorus: 0.5% in plant
- Water use efficiency: 0.25 L water evapotranspired per g dry matter produced

0.5% P = 5 mg P/g dry matter  
or 5 mg P/0.25 L water  
or 20 mg P/L water



*Water quality in the 7,400-gallon recycled-water system must be monitored closely. Here, culture assistant Eric Leonard (right) and system manager Joe Hankins check levels of acidity and solids. (Photo by Scott Bauer, USDA-ARS)*

## Balancing Fish and Plant Production

In this fish production system, solids are removed with a triangle filter. The triangle filter is able to remove about 80% of the P excreted by the fish with the biosolids, leaving about 20% of the P in the effluent. With the production of 10 lettuce crops/year spaced at 48 inch<sup>2</sup>/plant and an average head size of 6 to 8 oz., the biomass production rate would be between 8 and 10.6 g/m<sup>2</sup>·d. At a biomass production rate of 8-10.6 g/m<sup>2</sup>·d and a tissue P concentration of 0.5%, 40-53 mg P/m<sup>2</sup>·d would be removed. This would be equivalent to a mass loading rate of about 30-40 pounds per year for a 10,000 ft<sup>2</sup> greenhouse. With an effluent concentration of 0.5 mg P/L and a mass loading rate of 40-53 mg P/m<sup>2</sup>·d, a hydraulic loading rate of 80-106 L/m<sup>2</sup>·d or 0.02 to 0.026 MGD (million gallons per day) could be treated in a 10,000 ft<sup>2</sup> greenhouse.



14

Production of 50,000 pounds of rainbow trout (will consume about 60,000 pounds feed at a feed conversion ratio of 1.2 pounds feed/pound gain) generates 98.4 Kg P. Of that 98.4 Kg P, 22.6 Kg P is in the effluent and the rest (77%) is in the biosolids (Heinen et al., 1996). It will take 12,600-16,700 ft<sup>2</sup> greenhouse space to remove 22.6 kg of P from the effluent. Each 6-8-oz. head of lettuce will contain 45-60 mg P. For each pound of trout produced and each kilogram of feed fed, about 450 and 800 mg P, respectively, will be excreted in the effluent. This means that it will take 7.5 - 10 heads of lettuce to remove the P excreted by the production of 1 pound of trout or 13 - 18 lettuce heads for each kg of feed consumed.

## Advanced Wastewater Treatment Technology

If all nutrients in the water being treated are equally limiting or balanced, all nutrients can be removed to very low levels (ppb) by plants. Water of this quality can only be

regenerated by the most advanced water treatment technology, such as ion exchange, reverse osmosis, or electrodialysis. The most elaborate chemical and biological P removal systems are expensive and can only remove P to about 0.1 mg/L. In addition, chemical and biological P removal systems generate large amounts of sludge waste. Ion exchange generates a waste with regeneration of the resins, and reverse osmosis and electrodialysis clean a portion of the wastewater with membranes and concentrate ions removed into a waste stream. In contrast, the conveyor production system generates income while nutrients are removed to a very low level (Adler et al., 1996e,f).

## References

- Adler, P.R., S.T. Summerfelt, D.M. Glenn, and F. Takeda. 1996a. Evaluation of a wetland system designed to meet stringent phosphorus discharge requirements. *Water Environ. Res.* 68(5):836-840.
- Adler, P.R., S.T. Summerfelt, D.M. Glenn, F. Takeda. 1996b. Evaluation of the effect of a conveyor production strategy on lettuce and basil productivity and phosphorus removal from aquaculture wastewater. In J. Staudenmann, A. Schönborn, and C. Etnier (Eds.): *Recycling the Resource - Ecological Engineering for Wastewater Treatment. Proceedings of the Second International Conference, Waedenswil - Zurich, Switzerland; 18-22 September 1995.* Trans Tech Publications, Switzerland. *Environmental Research Forum* 5-6:131-136.
- Adler, P.R., F. Takeda, D.M. Glenn, E.M. Wade, S.T. Summerfelt, and J.K. Harper. 1996c. Phytoremediation of wastewater using lettuce and basil. *Proceedings of the American Society for Plasticulture* 26:253-258.
- Adler, P.R., F. Takeda, D.M. Glenn, E.M. Wade, S.T. Summerfelt, and J.K. Harper. 1996d. Conveyor production strategy enhances nutrient byproduct recovery from aquaculture wastewater, p. 431-440. In *Successes and Failures in Commercial Recirculating Aquaculture*

(conference proceedings). NRAES-98. Northeast Regional Agricultural Engineering Service: Ithaca, New York. July 1996.

Adler, P.R., F. Takeda, D.M. Glenn, and S.T. Summerfelt. 1996e. Enhancing aquaculture sustainability utilizing byproducts. *World Aquaculture* 27(2):24-26.

Adler, P.R., F. Takeda, D.M. Glenn, E.M. Wade, S.T. Summerfelt, and J.K. Harper. 1996f. Nutrient removal: ecological process sows a cost-saving idea for enhancing water quality. *Water Environment & Technology*. 8:23-24.

Heinen, J.M., J.A. Hankins, and P.R. Adler. 1996. Water quality and waste production in a recirculating trout-culture system with feeding of a higher-energy or a lower-energy diet. *Aquaculture Res.* 27:699-710.

*About the Author: Dr. Paul Adler is a Research Scientist with the United States Department of Agriculture's Agricultural Research Service. He conducts research on minimizing the environmental impact of the aquaculture industry. He can be reached by email at PADler@afrs.ars.usda.gov.*

AJ

