Water Resources Research Institute
of The University of North Carolina

Report No. 461

LAND APPLICATION OF AQUACULTURE EFFLUENTS TO PREVENT SURFACE WATER EUTROPHICATION AND PROMOTE GROUNDWATER RE-INFILTRATION IN COASTAL NORTH CAROLINA

By
Harry V. Daniels[1], Elizabeth G. Nichols[2] and Dennis W. Hazel[2]

[1]Department of Applied Ecology
[2]Department of Forestry and Environmental Resources
North Carolina State University
Raleigh, NC

UNC-WRRI-461

The research on which this report is based was supported by funds provided by the North Carolina General Assembly and/or the US Geological Survey through the Water Resources Research Institute; and by funds provided by the North Carolina General Assembly and/or the National Oceanographic and Atmospheric Administration through the North Carolina Sea Grant Program.

This report fulfills the requirements for a project completion report of the Water Resources Research Institute of The University of North Carolina. The authors are solely responsible for the content and completeness of the report.

WRRI Project No. 14-07-WSG
May 2016

Project #2014-NCSG-03

Land Application of Aquaculture Effluents to Prevent Surface Water Eutrophication and Promote Groundwater Re-infiltration in Coastal North Carolina.

H. V. Daniels, E.G. Nichols, and D.W. Hazel, North Carolina State University

Introduction: Current production practices for hybrid striped bass require annual pond draining to harvest and move fish and to avoid infestations by the parasitic yellow or white grub. These practices create large volumes of effluent from April to October and have led to complaints from the general public about stream eutrophication and habitat degradation. Effluents released from the North Carolina fish farms are slow-moving and drain into wide, shallow coastal creeks that empty into waters such as the Pamlico Sound – part of the nutrient sensitive Tar-Pamlico River Basin (sub basin No. 7). In North Carolina, these streams are classified as zero-flow waters, which severely restricts their use for receiving effluents. The Albemarle Sound system and the Cape Fear River are also potentially impacted.

Although many studies have shown that the nutrient content of the effluents is low relative to other animal production systems, the high volume of water presents an engineering challenge that overwhelms surface water systems as well as traditional land application to row crops. Based on preliminary studies at the Tidewater Research Station, we developed a fish-water-tree system that has the potential to absorb the pond effluents and divert this wastewater to woody biomass production for carbon storage (managed forest plantations), sustainable wood products, or sustainable bioenergy such as wood pellets, a fast-growing renewable energy market in coastal North Carolina. This system re-infiltrates pond water back to groundwater systems allowing for groundwater recharge. Ideally, these systems could be designed to land-apply pond effluents on managed forest systems up-gradient of source wells to better manage groundwater resources and limit surface water impact.

This purpose of this study was to evaluate nutrient removal efficiency, water use and tree growth of this system during an entire production season. We found that the trees and soil microorganisms removed more than 80% of the water added to the site including precipitation and irrigation, which effectively doubled the amount received through precipitation. Approximately 90% of the chlorophyll-a, 25% of the Total Kjeldahl Nitrogen (TKN) and Total Organic Carbon (TOC) were removed and 50% of the Total Suspended Solids (TSS) were removed by this system. Overall, the reductions in these parameters meant that the water leaving the site, as subsurface export, was well below the regulatory limits required for discharge to Nutrient Sensitive Waters.

Materials and Methods: Clones of hybrid poplar (*Populus spp)* were planted (over 1,400 trees) on a 1.2-acre field site (Figure 1). Drainage tile was installed under one half of the field, while the other half (negative control) did not have additional drainage structures. Six shallow groundwater monitoring wells were installed in March 2014 on tiled (n=3) and non-tiled (n=3) areas. The entire field has perimeter drainage ditches typical of lower Coastal Plain agricultural fields. A 4-ft deep trench with a vertically-oriented polycarbonate sheet bisects the field and prevented the passage of water between the two halves. Water samples were collected according to the following schedule: (1) biweekly ground and surface water for nitrogen species, total suspended solids or chlorophyll a (Center for Applied Aquatic Ecology); (2) biweekly ground and surface water monitoring and gauging of physical characteristics for hydrological modeling; and (3) end of growing season productivity and survival for Fall 2015. The site required weekly maintenance for irrigation and weed control. Aluminum irrigation pipe was placed throughout the field with sprinklers spaced at 100-ft intervals to evenly distribute water and minimize overlap. The ponds were stocked with hybrid striped bass (*Morone chrysops X M. saxatilis*) and were managed according to standard commercial practices. The trees were irrigated to field capacity (maximum water absorption of soils), which corresponded to approximately one-inch of water per week. Weekly water irrigation volumes along with related meteorological data (rainfall, evaporation, wind speed and relative humidity) were collected to calculate permissible water application rates and evapotranspiration.

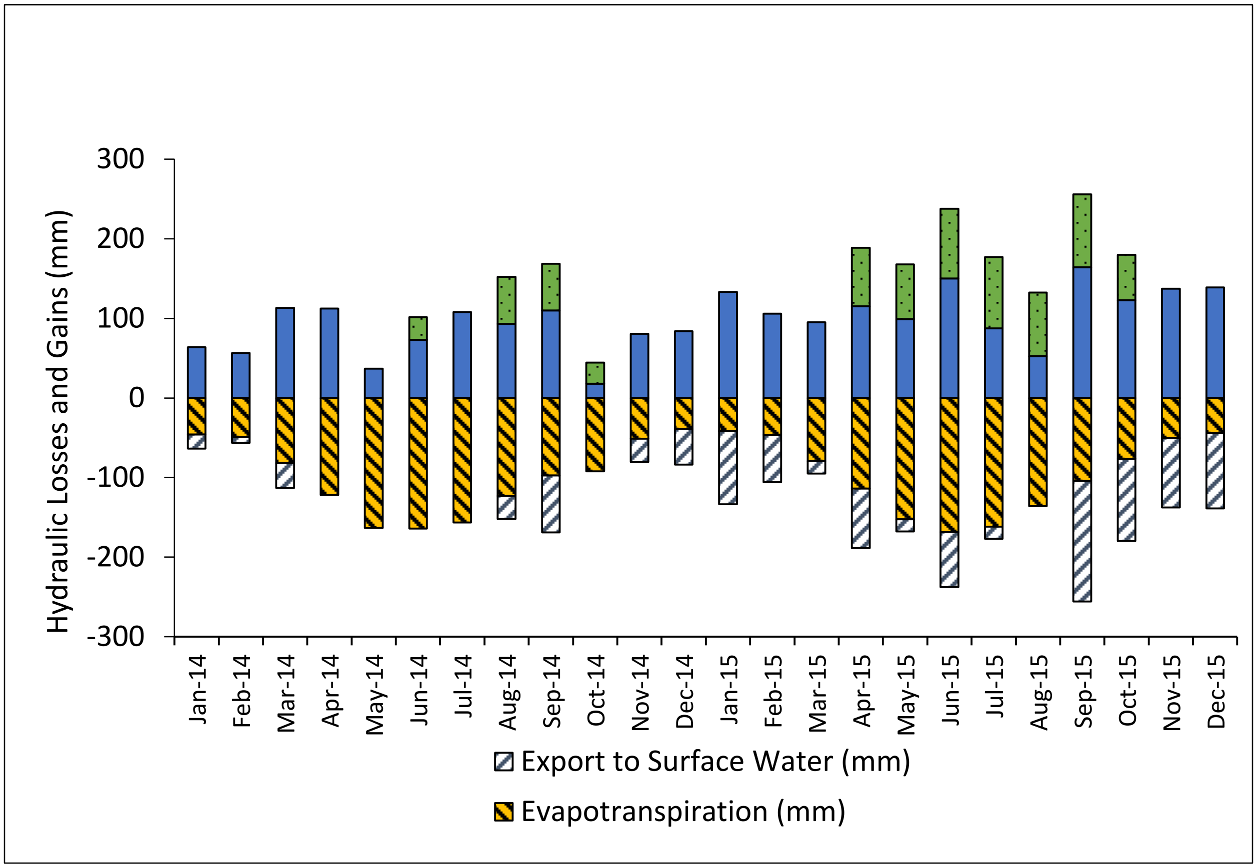
Figure 1. Planting design for Spring 2014 for eleven *Populus* clones from ArborGen and GreenWood

Results and Discussion:

Water budget

The majority of the effluent applied to the field was lost through evapotranspiration by the trees (Fig. 2). Percent removal through evapotranspiration was highest during the peak growing season in summer and declined beginning in early fall then remained low during the winter months. Water additions through irrigation nearly doubled the amount of water that the field received through precipitation during the summer months. Since the principal means of evapotranspiration is through leaves, we did not irrigate when leaves were not present on the tree limbs to avoid excessive water loss through subsurface export.

Water Quality



Nutrient Removal: Trees and soil microbiota removed approximately 20 – 92% of most water quality variables, such as chrolophyll-a, TSS, TOC and TKN (Table 1 and Figure 2). However, inorganic nitrogen levels either remained unchanged or increased markedly after water passed through the system. It is likely that the water added through irrigation was removing residual nitrogen that had accumulated through bacterial nitrification and was not bound to soil clays or organic matter.

Seasonal comparisons of nutrient export (Table 2) show that concentrations are markedly higher during the winter months versus the summer months when irrigation occurs. These values likely represent the normal water quality in subsurface waters after precipitation moves through soils when plants are inactive or dormant. The mean chlorophyll-a value during winter is particularly interesting because this value, 39.3 µg/L, is very close to the EPA limit of 40 µg/L for receiving streams in Nutrient Sensitive Waters.

Table 1: Mean water quality concentrations during irrigation

Parameter	Pond	Published Effluent Values*	Irrigation Ditch	Subsurface Export
Chl a (µg/L)	73.0 ± 3.0		73.3 ± 24.5	5.9 ± 1.4
TSS (mg/L)	42.3 ± 9.4	49*	44.5 ± 10.9	15.8 ± 2.0
TOC (mg/L)	12.4 ± 1.1		16.5 ± 1.3	12.6 ± 0.8
TKN (mg/L)	2.9 ± 0.4	7.1*	2.4 ± 0.2	1.6 ± 0.1
NO_2-N&NO_3-N (mg/L)	0.26 ± 0.11	0.43*	0.09 ± 0.02	0.75 ± 0.21
NH_3-N (mg/L)	0.47 ± 0.2	0.95*	0.39 ± 0.11	0.33 ± 0.07

*Values from Tucker et al. 1998 [33], a sampling of 20 HSB ponds in South Carolina.

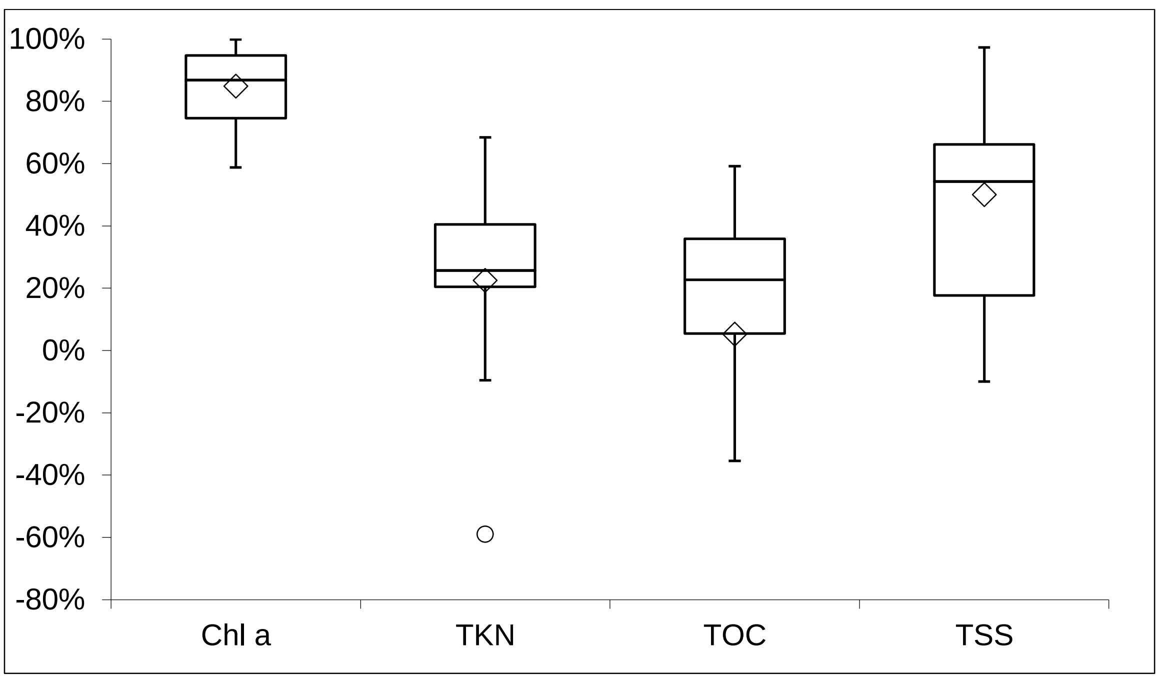


Fig 2. Percent removal efficiency of hybrid poplar biofilter for chlorophyll a (Chl a), total Kjehldahl nitrogen (TKN), total suspended solids (TSS), and total organic carbon (TOC).

Table 2: Mean (± standard error) water quality values in subsurface export water during months without irrigation (winter) versus months with irrigation (summer).

Subsurface Export	Winter	Summer
Chl a (µg/L)	39.05 ± 1.76	5.9 ± 1.4
TSS	88.25 ± 2.88	15.8 ± 2.0
TOC	68.54 ± 0.79	12.6 ± 0.8
TKN	8.61 ± 0.16	1.6 ± 0.1
NO3-N&NO2-N	9.23 ± 0.36	0.75 ± 0.21
NH3-N	0.86 ± 0.04	0.33 ± 0.07

Tree Productivity: Mean height, mean diameter at breast height (DBH), and mean volume all differed significantly between the twelve genotypes (Fig. 3). Four of the genotypes (356, 373, 140, 312) are currently exceeding the productivity level needed to meet the sustainability criteria (established by USDA) for carbon neutrality and woody biomass demand. These *Populus deltoides* genotypes had much greater productivity, although slightly average survival, and in some cases lower survival than the other clones. These findings suggest that not only the species, but the actual clone and genotype of that tree species is important to the success of a crop under this type of irrigation regime. It is clear that each clone responds very differently to the amount of water applied and the constituents of that effluent. This information is critical to the future success of land application research and/or demonstration studies because the economic feasibility of this system will be directly influenced by the specific tree genotype. Given these results, the productivity values, for these four clones of P. deltoides, is an encouraging outcome.

Outreach:

In addition to the presentations at State meetings to producer groups and scientific presentations at National and International meetings (shown below), we have taken several groups of undergraduate students (total of 12 Doris Duke Conservation Scholars from NC State University) to the study site for educational tours. Given the remote location of the study site, transportation of producers to the site is challenging. Instead, we have presented annual updates of our work for two consecutive years at the

North Carolina Aquaculture Development Conference, where the audience consists of a variety of producers from around the state.

Shifflett, S.D., **Culbreth, A.** Hazel, D. Daniels, H., Nichols, E.G. (2016). Integrating freshwater aquaculture and forest productivity for F.E.W. nexus resiliency in the mid-Atlantic Coastal Plains. North Carolina Sea Grant Graduate Student Workshop. New Bern, N.C. April 6-7, 2016. Poster.

Culbreth, A. (2016). Evaluation of the Treatment Efficiency of a Vegetative Filter on Hybrid Striped Bass (*Morone chysops x Morone saxatilis)* Pond Effluents. Aquaculture America 2016, Las Vegas, NV. February 23-26, 2016. Presentation.

Shifflett, S.D., **Culbreth, A.** Hazel, D. Daniels, H., Nichols, E.G. (2016). Using land application systems to address the F.E.W. nexus: managing aquaculture effluents and growing woody biomass for bioenergy. The Food-Energy-Water Nexus: 16th National Conference and Global Forum on Science, Policy and the Environment. Washington, D.C. January 19-21, 2016. Poster.

Culbreth, A., Shifflett, S.D., Hazel, D., Nichols, E., Daniels, H. 2015. The Food, Energy, Water Nexus: Using Wastewater from Aquaculture Operations to Fertilize Energy Crops. 2015 Stewards of the Future Conference. Raleigh, NC, November 2, 2015. Poster.

Culbreth, A., Hazel, D., Nichols, E.G., Daniels, H. Land Application of Aquaculture Effluent. Water Resources Research Institute Annual Conference. Raleigh, NC. March 18-March 19, 2015. Poster.

Shifflett, S.D., **Culbreth, A.,** Begue, P., Hazel, D., Nichols, E.G., Daniels, H. Land Application of Aquaculture Effluents to Meet Dual Objectives: Grow Woody Biomass and Prevent Surface Water Eutrophication. Aquaculture America 2015. New Orleans, LA, February 18-February 22, 2015. Poster.

Conclusion and Future Research: The current fish-water-tree effluent treatment system continues to show promise as a viable method for effective water removal, nutrient reduction and economic potential for biomass production. The trees in this system will reach their peak maturity during the 2016 production season. We anticipate that water removal, through evapotranspiration, and nutrient removal will increase as a result of the greater leaf area and establishment of associated root systems and soil microbes. Combined with projected biomass production, these results should allow us to objectively evaluate the economic benefits of this system.

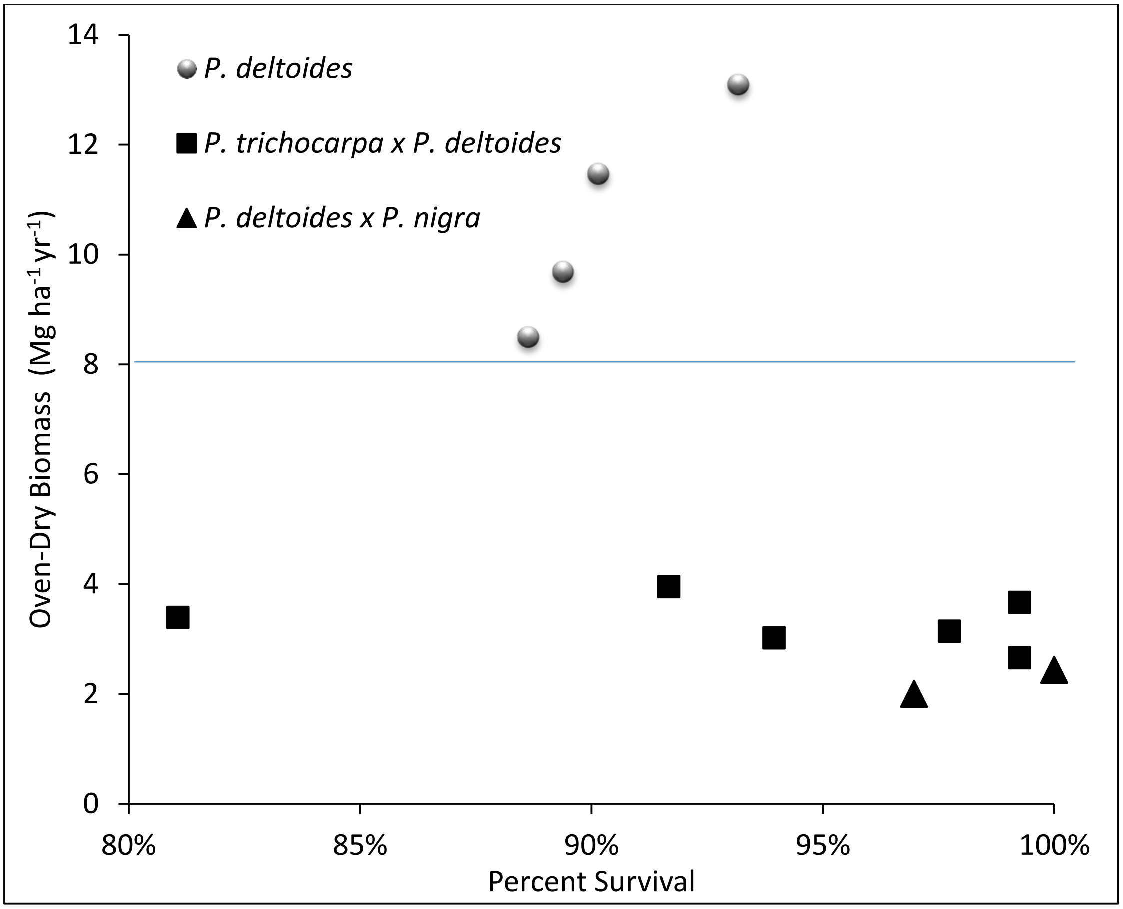


Fig 3. *Populus spp.* clone productivity measured in Mg/ha/yr of oven-dried biomass.