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SURFACE IRRIGATION OF COTTON USING AQUACULTURE EFFLUENT

M. W. Olsen*, K. M. Fitzsimmons*, D. W. Moore**

ABSTRACT

In field trials at the University of Arizona, fish and crop production systems have been combined to determine the benefits and constraints of the multiple use of water and utilization of wastes in fish effluent as fertilizer. Nutrients in fish effluent that are available to plants, the effects of application of fish effluent on soil nutrient levels, and crop yields were determined in replicated plots of cotton irrigated with fish effluent at two different catfish production sites in 1992. Control plots were irrigated with well water. Fish effluent contained more nitrogen than well water, but the same amount of chemical inorganic fertilizer was needed in all plots based on initial soil nitrate nitrogen, cotton petiole analyses, and nitrogen demand curves for cotton. Average yields of cotton in replications of the two treatments were the same. First year results demonstrated that the effluent water can be applied easily, and that some nutrients were contributed by fish effluent.

Keywords: catfish, cotton, irrigation, nutrients, reuse

INTRODUCTION

The reuse of effluent water from fish culture to irrigate plant crops may reduce the cost of water and the use of chemical fertilizers. It may also reduce ground water contamination and solve waste water disposal problems. However, there are few published reports detailing the effects of using effluent from commercial fish culture to irrigate plant crops (Redding & Midlen, 1990; Budhabhatti, 1991). There is little information on costs benefits of water reuse, the actual amounts of nutrients that can be expected to be available to plant crops, and the timely application of water for irrigation to maximize use of available fish effluent.

Fish farmers may recover a high percentage of their pumping costs by selling effluent to farmers, especially in fish tank systems in which there is little evaporation or seepage loss of water (McClintic, 1991). Water costs can be reduced and water enriched with nutrients from the fish culture. For example, in catfish production tanks, measured ammonia production can be 0.03 kg ammonia for every kg fed to fish. If fish consume 3% of their body weight a day, 1000 kg of fish fed 30 kg per day would

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* Associate Research Scientist and ** Research Specialist, Environmental Research Laboratory, University of Arizona, Tucson, AZ 85706

excrete 0.9 kg of ammonia. Fecal matter and uneaten feed also contribute organic matter and other nutrients to the effluent water. Huat and Tan (1980) report that rice yields increased up to 14% when fish were grown in paddies with the rice, and farmer income was increased 26% from fish sales.

Intensive recycling fish culture systems can raise individual nutrient levels several ppm above source water (Jensen, et al., 1986; Parker, et al., 1990; Siddiqui et al., 1991). Nitrogenous waste, the majority of which is ammonia, is a primary nutrient source. Data from greenhouse trials at the University of Arizona have shown that nitrate levels in intensive fish culture units can reach 181 ppm and averaged 21.6 ppm (Lightner, et al., 1988). Ammonia and nitrogen excretion rates of 0.1 g/kg of body weight/day were typical for farm raised fish. Phosphorus levels of 21 ppm and potassium levels of 57 ppm were common in effluent.

Greenhouse vegetable production integrated with intensive fish production may require little or no added nutrients other than those provided in fish discharge waters (Rakocy, et al., 1989; Roy, et al., 1990; Sanders and McMurtry, 1988; Watten and Busch, 1984; Zweig, 1986). Plants clean the water by removing wastes, and the water can then be recycled back into fish production (Jacquez and Zachritz, 1985). This cycle is the basis for much of the Controlled Ecological Life Support System developed by NASA (Huffaker et al., 1982; Leigh et al., 1987). Traditional oriental fish production likewise involves a high degree of integration and recycling of nutrients (Cruz, 1980; Pantulu, 1980; Pullin and Shehadeh, 1980). Human, livestock, and inedible plant wastes are often put into a pond as either fertilizer for phytoplankton or direct feed for fish (Woynarovich, 1980; Lee and Schleser, 1984).

However, most fish farms are not intensive recycling systems and would not be expected to contribute these high levels of nutrients. With higher water flow rates, nutrient levels are diluted and the actual amounts of nutrients are a function of the amount of feed and the metabolic functions of the fish. Therefore, a nutrient increase contributed by the fish culture may be difficult to measure. However, concentration of nutrients in soils at the irrigation site over time may become significant. Low levels of nitrogen fertilizer applied more frequently allows the crop to more efficiently utilize available nitrogen and to reduce nitrate leaching (Yates, et al., 1992).

The dual use of water also reduces or eliminates the need and cost for treatment of the discharge water by the fish farmer. For example, in Arizona, irrigation with aquaculture discharge water has been approved by the Arizona Department of Environmental Quality, and Aquifer Protection and NPDES Permits are not required (Fitzsimmons, 1992). Currently, farmers must have EPA-NPDES permits for discharge of fish effluent into natural waterways.

There are several potential constraints on these systems. Fish wastes may plug drip irrigation systems. Also, the fish farm may require a nearly constant supply of water, and water distribution from the fish to the field crops must be carefully coordinated on a daily and seasonal basis. Geothermal waters used in some fish production systems may be too saline for direct irrigation. If so, the discharge water may need to be diluted with another water supply. If an intensive fish farm were to have a discharge high in nitrogen and not diluted into other waters, it is possible that too much nitrogen could be applied to plants.

The University of Arizona has incorporated commercial fish production into operation of its demonstration farm at the State Agriculture Experimental Station in Maricopa, AZ. The demonstration farm is operated as a separate farm, for profit, which is used to collect applicable data on a scale for commercial operations in the Southwest. An integrated system is also underway at United Fisheries, a commercial fish farm that uses a high density tank system. Discharge waters from United Fisheries have been sold to nearby cotton farmers.

Field trials integrating fish and cotton production began at these sites in 1992. Cotton was irrigated with fish effluent or with standard irrigation water, usually well water, in replicated plots to (1) determine available nutrients and organic matter content of fish farm discharge waters; (2) determine the effect of discharge waters on soil nutrient levels, soil organic matter, fertilizer requirements and cotton yields.

METHODS AND MATERIALS

Site descriptions. One site, United Fisheries and T&C Farms, is located near Safford in southeastern Arizona. United Fisheries is a commercial fish farm using geothermal well water, pumped into a series of round tanks. The farm has utilized dual water use on a trial basis by selling water to T&C Farms for gravity fed furrow irrigation of up to 120 ha of cotton and grain.

Channel catfish (Ictalurus punctatus) and tilapia (Oreochromis aureaus and O. mossambicus) were grown in 40,000 liter above ground fiberglass tanks located on a plateau above the field. Periodic flushing was used to keep total dissolved ammonia levels below 0.1 ppm and to remove settled solids. The range of standing crops was 2050 kg to 4350 kg, mostly fingerlings and broodstocks, between April and October 1992. Daily feeding ranged from 34 to 59 kg. Approximately 200,000 liters of water were used to flush the tanks to a discharge pond, either daily or every two days. The discharge pond is an unlined pond (surface area of 0.2 ha and average depth of 1.8 m). The experimental plots of cotton were irrigated by mixing 380 liter/min from the discharge pond with 3300 liter/min of well water. The control plots received water directly from the well.

Cotton was planted in 0.4 ha plots in April, 1992 and irrigated with equal amounts of either effluent from fish tanks or with well water. There were 3 replications of each treatment. All plots were identically cultivated and fertilized according to standard practice.

The second site is at the Maricopa Agricultural Center (MAC) of the University of Arizona near Casa Grande in central Arizona. The MAC is a demonstration as well as research site, and the University of Arizona has made a large commitment for demonstration of fish production in ponds and ditches used in irrigation water delivery. Facilities include a series of ponds, canals and ditches stocked with catfish, tilapia and carp. All water originates from the Central Arizona Project aqueduct or from wells.

The fish effluent water used for irrigation of cotton came from a 0.7 ha unlined pond stocked with approximately 7,000 kg/ha of channel catfish. These fish were fed a daily ration of 32% protein, floating pellets at a rate of 3% of biomass/day.

Between January and October of 1992, water in the pond ranged from 12.4 to 33.0° C, pH of 7.6 - 9.0, NH3-N of 0 to 1.2 ppm and dissolved oxygen of 4.5 to 12.5 ppm. The catfish pond was supplied with rainwater and a mixture of surface and well water from the local irrigation district.

Cotton was planted in April, 1992 in 0.04 ha plots and irrigated with fish effluent or well water. There were 4 replications of each treatment. Because the soil nitrate levels were between 17 and 26 ppm, no fertilizer was applied at planting. Petiole analyses were done periodically beginning the first week in June and used to determine fertilizer need.

At both sites, cotton was planted and harvested according to standard field practices. Yields were determined by mechanically harvesting the middle two rows of each plot using a two row commercial picker.

Analyses. Effluents from fish ponds or tanks were analyzed at each irrigation to determine pH, electrical conductivity (EC), nitrate nitrogen, ammonia nitrogen, phosphate, and total organic carbon according to established procedures (Greensberg, et al., 1985). Soil nitrate nitrogen and phosphate, EC, pH, total organic carbon, total nitrogen and soil texture were determined before planting and at harvest. Soil sampling methods and numbers of samples per plot or treatment were determined by using established methods (Brown, 1987; Klute, 1986; Page, 1982).

RESULTS AND CONCLUSIONS

United Fisheries in Safford, AZ had a low fish density, and there were no significant differences in the amount of nutrients in fish effluent as compared to well water. Average yields of cotton before ginning, 4146 kg/ha and 36[illegible]2 kg/ha for well water and fish effluent respectively, were not significantly different. However, there was an actual cost benefit to the cotton farmer and fish farmer in water costs. The cost to the fish farmer of pumping water from the well was offset by the purchase of all the water that flowed through the tanks by the cotton farmer. Both farmers benefitted. Also, because discharge of the fish effluent at this site to the nearby river requires a special exclusion permit, the problem of discharge disposal was alleviated.

At the MAC, the fish effluent contained slightly more nitrogen (total application equivalent to 15.1 kg/ha) than the well water (12.1 kg/ha), more phosphate (2.6 kg/ha) than well water (0.7 kg/ha), more ammonia (4.6 kg/ha) than well water (0.8 kg/ha) and a slightly lower pH (8.0 in fish effluent and 8.3 in well water). The average EC readings were not different (0.85 mmhos/cm). Petiole analyses were not significantly different in treatments throughout the season. Nitrogen application to cotton was based on results from petiole analyses in nitrogen demand curves, and 45 kg/ha nitrogen was applied as ammonium sulfate (21-0-0) to all plots uniformly in mid June.

There were no significant differences between treatments in soil nitrate nitrogen, available phosphate or soil organic matter in samples taken at harvest at MAC. Nitrate nitrogen and phosphate from 30 cm depth were less than 5 ppm and soil organic matter was 0.1% in all samples. Soils in both treatments had very similar mechanical analyses in initial soil samples compared to samples after cotton was harvested. The average sand/silt/clay composition of plots was 67/14/19% at one foot depth, 62/13/25% at two foot depth in fish effluent plots and 67/12/21% at one foot and 53/16/31% at two foot depth in the well water plots.

Total solids in fish effluent made up about 0.02% by weight, on a dry weight basis, the water applied and contained 0.57% total nitrogen. Average cotton yields before ginning, 3506 kg/ha and 3455 kg/ha for well water and fish effluent respectively, were not statistically different .

Farmers in Arizona commonly apply 50 to 300 kg/ha nitrogen and about 1.2 m total water to a cotton crop in a single year (Doerge, et al., 1991). However, by using best management practices including preplant soil analyses, petiole analyses, and fish effluent, only 45 kg/ha nitrogen and 0.9 m of water was applied to plots at the MAC site. At the Safford site, water pumped to the fish tanks was gravity fed to the cotton plots, so both the fish and cotton farmer shared the cost of pumping, and the fish farmer did not have a waste water disposal problem. Even though there were no differences in soil nutrients in treatments at the end of the first growing season at either site, repeated applications of fish effluent on the same plots may result in nutrient savings in subsequent crops. Since these field trials will continue for at least two more years, and higher fish densities are expected in the fish ponds, further reduction in application of inorganic fertilizer may be possible.

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