Sand Culture of Vegetables Using Recirculated Aquacultural Effluents

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January 1990

Abstract

Fish production and biofiltration of sand-cultured vegetable crops were linked in a closed system of recirculating water. Blue Tilapia (sarotherodon aureus L.) were stocked as mixed-sex fingerlings at a density of 1.68kg/m-3 (0.105 lb/ft-3). Fish were fed a commercial chow. Greenhouse grown bush bean (Phaseolus vulgaris L.), cucumber (Cucumis sativus L.) and tomato (Lycopersicon esculentum Mill.) were irrigated with water drawn from the bottom of the tilapia tank for 30 minutes every three hours during the daylight hours. Drainage from the 0.5m (1.64ft) deep sand beds was returned to the fish tank. Each crop was also grown in a sandy loam soil. Feeding 1kg (2.20 lb) of fish food produced an increase of 0.76kg (1.68 lb) fish and 1.66kg (3.66 lb) of vegetables. Both water quality and nutrient content were adequate for tilapia and plant growth in sand culture with no supplemental fertilization. The feasibility of an integrated, recirculatory system for concurrent production of vegetables and fish with no additional fertilizer application was demonstrated.

1 Introduction

Benefits of integrating aquaculture and olericulture in a controlled environment include conservation of soil, water and plant nutrients, production of high-quality food products in close proximity to center of need, and reduction of operating costs. Operation of such a system is applicable wherever fish and fresh vegetables are in high demand. [7]

Dissolved and suspended organic materials accumulate rapidly in aquacultural water and must be removed for efficient fish production [13] Through water purification and reuse, recirculating systems consume less than 10per cent of the water typically used in pond culture to produce equivalent yields of fish [15] Even in filtered recirculatory fish culture systems, nitrates and phosphates accumulate to the detriment of fish production [2] Hydroponic vegetable production using recirculatory aquaculture water can control nitrate concentrations [11, 13] Although many different systems of recirculating aquacultural water have been used to grow plants, typically the suspended solids are removed prior to use of the water for plant production [3, 11, 12, 13, 18] No previous studies have directly compared aquacultural water with sand-cultured plants. The purpose of this research was to determine if vegetables growing in sand beds could provide sufficient filtration of recirculated water for fish production and receive adequate mineral nutrition only from fish wastes.

2 Materials and Methods

A schematic view of the aquaculture-olericulture integration is seen in Figure 1. Mixed sex-fingerlings of blue tilapia (Saotherodun aureus L.) were stocked at an initial density of 1.68 kg/m3 (804 ft). Fish were fed Purina Fish Cow 5140 at 0800 and 1700 hours daily. The initial feeding rate of 3 per cent of total fish biomass per day by the end of the 86-day feeding regime [2] Total feed input was 139.0 kg over the 86 day season; however, fish also grazed on algae.

Bush bean (Phaseolus vulgaris L. cv Bush Blue Lake 274) cucumber (Cucumis sativus L. cv Burpee Hybrid II), and tomato (Lycopersicon esculentum Mill. cv. Champion) were grown in a greenhouse without shading in Raleigh, NC in the summer of 1986. The crop-growing medium was a builder's grade sand composed of 98.3 per cent quartz sand and 1.7 per cent silt. No additional nutrients were added to the treatment beds. The sand beds were 1.5m wide x 7.5m long x 0.5m deep (4.9 x 24.6 x 1.6 ft), divided into five plots, and lined with a 0.15mm (6 mil.) polyethylene sheet to capture drainage for return to the fish tank. A single comparison system was built using a sandy loam soil amended with composted horse manure at a ratio of 5:1 (soil to manure v/v). No additional fertilizer was added to either the soil or sand beds. The soil bed (2.25m/2 (24.2 ft/2) was mulched with straw and watered as needed. bush bean and cucumber were grown in five sand plots and one soil plot. Tomato was grown in 10 sand plots and two soil plots. The tomatoes were pruned to a double-stem. Bush beans were grown at 12.5, 16.7 and 20.0 plants m2 (1.16, 1.55, and 1.86 plots ft2) tomatoes at 1.8, 2.6, and 4.0 plants m2 and cucumbers at 6.7 plants m2.

Water was drawn from the bottom of the tilapia tank and pumped to the sand/vegetable beds every 3 hours during the day (5 x/day). the soil bed was irrigated with fresh well water. Water was distributed across the beds in four shallow furrows. Pumping saturated the sand-bed within 5 minutes but was continued for 30 minutes to remove and distribute waste materials from the fish tank. drainage from the beds cascaded into the fish tank increasing aeration of the pond water. Drainage continued for =15 minutes after the pumping ceased. Dissolved oxygen was determined using a YSI Model 54 oxygen meter. Nitrite, nitrate, ammonia, and ph levels of the fish water were monitored 3 x daily with a Hack kit. Alkalinity was determined with methyl orange tiltration. Samples were taken from the sand medium of each plot at harvest of first mature fruit at the 0-1.6cm (0-0.63 in.), 1.6 - 3.2 cm, and 3.2 - 4.8 cm depths with three samples from each of three distances (0.5cm, 1.75cm, and 3cm) from the irrigation furrow axis for a total of 27 samples per plot (Fig. 2). A comparison sample was taken from the soil bed.

Water and media samples were analyzed using a modified Kjeldahl for total N [5] , ammonium molybdate-ascorbic acid colorimetric analysis for P, and K by flame emission spectrophotometry. Ca, Mg, Fe, Mn, Zn, and Cu were determined by atomic absorption spectrophometry and a buffered ammonium chloride colorimetric analysis for S. The fourth leaf from the growing tip was collected and analyzed from each plant at the time of harvest of the first mature fruit. Plant tissue and fish food alaysis was conducted using atomic absorption spectrophometry for K, Ca, Mg, Mn, Zn, and Cu: a vanadomolybdophosphoric yellow procedure for P [9] : A salicylic acid modification of the Kjeldahl procedure for N [4] ;the curcumin method for B [6] :and a turbidimetric procedure for S [8]

3 Results and Discussion

Total fish biomasss increased from the intial 37 kg at stocking to 144 kg by the end of the 86-day feeding regime. The feed conversion ratio was 1:1.3 (76 per cent of feed converted into fish biomass). The final average fish weight was 180 g. All-male fush cultivation could increase the yield rate three fold [2]. Under more intensive stocking densitites, yearly fish production rates above 120 kg/m3 have been attained [1].

Acceptable water quality was maintained, although dissolved oxygen was low relative to requirements for good fish growth rates (Table 1). Nitrite and ammonia, which limit the production of fish in recirculating systems [11], never reached toxic levels.

Yield of edible portion for bush bean, cucumber, and tomato from both sand and soil beds are in Table 2. All crops developed rapidly and produced good yields despite the heat stress. integrated sand beds produced greater yield than in conventional soil culture beans, cucumbers and tomatoes in high density plots. Some potential tomato yield was lost due to development of bacteroal wilt (Pseudomonas solanaceaeum) in the sand-cultured tomato plants.

Although the bush beans were harvested before fully mature, the yield in the soil bed was 75 per cent of the U.S. field average. Some of this increase may have been due to the edge effect of using small plots. The medium density bush bean plots (16.7 plants m2) produced the highest yields per unit area (data not shown). The cucumber yield in the sand-beds was 111 per cent (vs soil = 70 per cent) that of a typical commercial greenhuse yield. The sand-bed tomato plants set three to four more times than the soil-bed plants, but these fruits aborted to excess heat. The increase in number may have been due to the improved growth resulting from an aerated medium.

The soil beds had greater mineral content than the sand: the mineral composition of each medium did not change. Nutrient levels within 50mm (1.97 in.) of the irrigation furrow increased when sand was irrigated with aquacultural waste water. P, K, and Mn concentrations were greatest nearest the furrow and toward the surface of the bed (Fig. 2).

Apparent cation exchange capacity (CEC) changes were greatest near the furrows as organic matter accumulated on the surface. In general, the media concentrations of P, K, Ca, Mg, Mn, Zn, and Cu were less in the sand plots than in the soil plots (Table 3). P, K, Mn, Zn, and Cu concentrations in the sand beds also increased with proximity to the irrigation furrow.

Although nutrient levels in the recirculating water were minimal and no supplemental fertilization was added to either the sand or soil beds, plant growth was adequate due to the constant replenishment characteristics of the system [11]. The following nutrients fell below sufficiency standards but were above deficiency levels: N in all the crop species: S in the bush bean foliage: K in the cucumber foliage: and P, K Ca, and Mg in the tomato crop (Table 4). The tomato crop had B and S levels below and at deficiency level respectively. All crops had mineral contents above the minimum critical level (MCL) and there were no visual deficiency symptoms. Nutrient levels could be raised by increasing the ratio of fish biomass to crop bed area, by supplemental fertilization of the medium, and/or by foliar application of the isolated (crop-specific) element(s).

Well water was used to replace that lost through evaporation and transpiration. Makeup water requirements averaged 7 per cent of the system volume per day. The pH of the water remained below 7.0 such that virtually all of the ammoniacal-N remained ionized form (relatively nontoxic to fish). Plant assimilation of N-compounds maintained nitrite and ammoniacal-N concentrations below tolerance limits for Tilapia as a result of microbial nitrogen conversions occurring in the sand beds [16] The water pH stability is due to the nitrate assimilation by plants counteracting the acidification from microbial nitrification in the sand beds. Additionally, the plant availability of both ammonium and nitrate ions tends to buffer the normal alkalinization of the nutrient solution occurring during plant growth [17] Other fish rearing systems require periodic additions of base to maintain a suitable pH. [10, 13]

Reciprocating biofiltration offers the advantages of uniform distribution of nutrient-laden water within the filtration medium during the flood cycle and improved aeration in the crop medium through complete atmosphere exchange with each de-watering [11, 13, 14] These advantages benefit both the nitrifying bacteria and the plant roots [7, 14] Uniform crop development and satisfactory performance of this system are due to the reciprocating water movement, which resulted in even distribution of nutrients and O2 to plants during the drainage period. the plant-sand filtration maintained water quality resulting in good fish weight gain and vegetable crop production. The feasibility of the integration of aquaculture using sand and crop plants to maintain water quality and fish growth was shown. The potential for increased fish biomass: vegetable production ratios enhances the economic feasibility of the system. More detailed investigations into the biological interactions and economic potential of this system are presently being conducted.

Acknowledgement. The authors gratefully acknowledge the assistance of R.L. noble, B. Noon, R.P.Patterson, S.Pulver, J.Riddle, and R.Tucker for their help on the project. This project was designed and tested by the senior author

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