Sustainability of Inland Shrimp Production

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Paddlewheels in one of the shrimp ponds


Litopenaeus vannamei, the Pacific white shrimp


Irrigating the test plot


Olive tree (*Olea europaea* var Manzanillo)


Watering the test plot from storage tanks


Flood irrigation of rows in test plot


One treatment row


Established olive trees elsewhere on farm

Introduction:

Motivation:
Demand for shrimp and high market value have led to rapid expansion in shrimp aquaculture. Use of coastal areas for aquaculture often conflicts with other users, or impacts sensitive mangrove habitat. The high concentration of farms in coastal areas also leads to a self-polluting industry, as nutrient rich waters or disease exit one farm near the intake of the next. As a result of these factors, inquiries into the feasibility of inland low-salinity aquaculture operations are becoming more common.

Several studies have focused on water quality parameters and acclimation of marine shrimp for inland growth in low salinity water. Reusing aquaculture effluent disposes of a nutrient-enriched waste stream, while making multiple uses of water, improving sustainability of both agriculture and aquaculture practices. Land application on agricultural crops is a preferred method of aquaculture effluent disposal, but few studies have investigated the contributions of irrigation with inland shrimp culture effluent.

Objectives:
1. Determine benefits of irrigating olives with low-salinity aquacultural effluents by measuring growth of trees.
2. Determine any detrimental effects on soil caused by the application of saline irrigation water through the monitoring of soil salinity.
3. Reduce the reliance on chemical fertilizers through the application of nutrient rich aquacultural effluents.
4. Quantify efficient utilization of scarce water resources through the multiple use of water for shrimp production and irrigation.
5. Initiate an integrated aquaculture/agriculture extension program in Arizona by hosting an integrated agriculture field day, distributing a newsletter, and developing a bulletin and website reporting findings.

Methods:

A randomized complete block experimental plot was laid out on a commercial shrimp farm growing *Litopenaeus vannamei*, the Pacific white shrimp, in Gila Bend, Arizona. Olive trees (one year old from cuttings) were planted in ten rows of twelve trees, on a 0.133 ha (0.329 acres). Trees were planted in the bottom of a single furrow 30 cm wide and 30 cm deep, and watered by flood irrigation. Tree height was measured monthly. The experimental plot was isolated from other olive groves, and managed in accordance to standard farm procedures.

During shrimp production (June to October), effluent was used for irrigation. The well water + fertilization treatment groups received urea fertilizer applications (March through April) at rates of half (year one) and full (year two) the rate recommended in the literature for full grown olive trees. The rate in year one was reduced due to the initial size of the trees. Urea was mixed with well water before application in irrigation water. The rest of the year, all trees received well water.

Duplicate water samples were taken for each treatment during every irrigation event, to determine levels of ammonia-nitrogen (NH_3-N), nitrite-nitrogen (NO_2-N), nitrate-nitrogen (NO_3-N) total nitrogen, and salinity. Soil salinity was measured from 30 cm soil increments to 120 cm in depth at the beginning and end of the experiment. Analyses of water use, costs, and efficiency were incorporated into the final conclusions

Table 1: Mean water quality parameters per treatment.

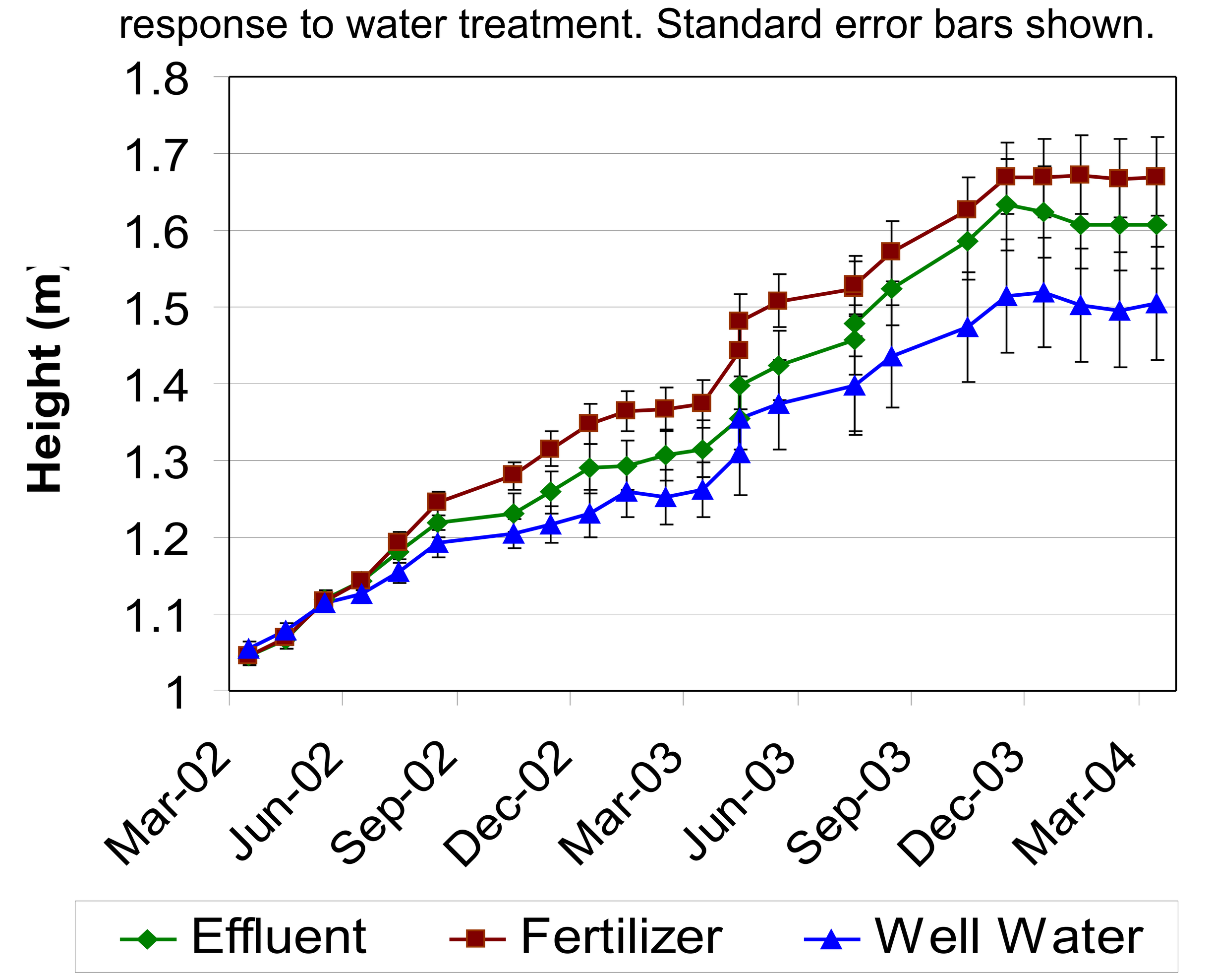
Parameter	Effluent (SEM)	Fertilizer (SEM)	Well water (SEM)
Nitrate-Nitrogen (mg/L)	8.4 (1.06)^a	9.5 (1.86)^a	8.9 (0.90)^a
Nitrite-Nitrogen (mg/L)	0.46 (0.05)^a	0.16 (0.09)^b	0.012 (0.39)^b
Ammonia-Nitrogen (mg/L)	0.49 (0.11)^a	0.96 (0.20)^a	0.01 (0.09)^b
Total Nitrogen (mg/L)	6.87 (2.66)^a	67.2 (5.12)^b	8.53 (2.26)^a
ECw (mmhos/cm)	2.9 (0.08)^a	2.5 (0.24)^a	2.9 (0.09)^a
Salinity (ppt)	1.9 (0.06)^a	1.6 (0.12)^a	1.8 (0.05)^a

Different letter superscripts designate significant differences between treatments.

Table 2: Summation of nitrogen additions per treatment.

	Fertilizer	Effluent	Well water
Nitrate-Nitrogen (kg/ha)	148	159	148
Nitrite-Nitrogen (kg/ha)	0.49	6.3	0.19
Ammonia-Nitrogen (kg/ha)	2.25	5.04	0.13

Figure 1: Mean change in olive tree height over time as a response to water treatment. Standard error bars shown.



Results:

Tree Growth
Growth of trees receiving effluent was not different than the fertilizer or well water treatments (Figure 2). Trees receiving effluent averaged 61.0 cm of growth over the experiment, compared to 70.4 cm for the fertilizer and 48.4 cm for the well water treatment. Trees receiving well water treatment grew substantially less than the fertilizer treatments when comparing changes in growth from the beginning to the end of the experiment (F2, 62 = 3.19, p = 0.048, one-way ANOVA).

Nutrient enrichment and water use
Mean nutrient content in irrigation waters varied greatly across treatments, causing mean TN values to differ from the summation of N constituents (Table 1). NO_3-N levels were comparable across treatments ($F_{2,73}$ = 0.127, p = 0.88), but of significance was the high levels in the groundwater. Salinity varied little among the treatments throughout the study, ranging from 1.63 ppt to 1.86 ppt.
Total water applied was 159 cm (2,460 m3 for the whole experimental plot). Total evapotranspiration (ET) over the two-year experiment was 405 cm, giving a crop coefficient (Kc) of 0.39. Effluent irrigation contributed 113 cm (71% of the total irrigation). In the first year, the fertilizer treatment received a total of 1.64 kg of urea per row (112 kg/ha) in 10 cm of well water over four applications. In the second year, 5.76 kg of urea was added per row (392 kg/ha) in 12.5 cm of well water over five applications. Water with fertilizer contributed 14.5% of the total irrigation for this treatment.

Nitrogen additions were extrapolated from water quality parameters and total water applied. Total nutrient additions - a summation of nutrients in the treatments and in the well water the rest of the year - were highest in the fertilizer treatment. NO_3-N additions were comparable across treatments, while NO_2-N and NH4-N were highest in the effluent treatment (Table 2).

Conclusions:

Benefits of irrigating olives with shrimp effluent
Effluent irrigation did not significantly increase olive tree growth over the two-year study. However, tree growth with effluent irrigation was not significantly different than with fertilizer.

Soil Salinity
Soil salinity levels were highly variable, but showed no trends of increasing with effluent irrigation.

Nutrient enrichment
Nitrogen parameters in the water were similar to those in previous studies of inland shrimp effluent. However, high nitrate-nitrogen levels in the groundwater distinguish well water at this site from other inland farms. While total nitrogen additions were highest in the fertilizer treatment, the effluent treatment contained the highest nitrate, nitrite and ammonia additions (Table 2). TN additions were not different in the well water and effluent treatments, despite nitrogen additions in shrimp feed, possibly due to phytoplankton nitrogen assimilation. The timing of these additions likely impacts tree growth more than the total nitrogen contributions. The slow addition of plant available NO_3-N and NH_4-N over the course of the growing season may allow for constant nutrient uptake and more efficient assimilation.

Water use efficiency
Effluent from low salinity inland shrimp culture can be reused as a source of irrigation water, increasing water use efficiency in arid lands as water is pumped once and used twice. On this farm, water exchange in the shrimp ponds is estimated at 1% per day. This contributes 2,725 m^3 of water for irrigation daily, or approximately 2,700 ha cm during the shrimp growing season. As the ponds are drained at harvest, another 2,700 ha cm of irrigation water is made available. This is enough water to irrigate nearly 48 ha of mature olive trees (Kc=0.75) annually. This water use is based on a ratio of approximately 15 ha of shrimp ponds, and 162 ha of olives. Reducing water consumption will lead to economic savings in electrical or water costs. So while nutrient additions from inland shrimp effluent is minimal, financial savings in water costs and increased water use efficiency make inland shrimp production a valuable option for integration with existing irrigated agriculture. Water management, from sizing optimal ratios of ponds to field crops to practices leading to availability of water for irrigation throughout the year is critical for maximizing benefits of inland shrimp effluent reuse for field crop irrigation.

Future research
Testing a broader range of water and soil nutrient parameters to include micronutrients, organic matter and ash could provide better understanding of contributions of effluent to field crops. This may help quantify contributions of algal biomass to soil nutrients and composition. Test plots of other field crops would provide more complete information on water use and production with effluent irrigation. Testing other crops will also provide yield results, which was difficult for the olive, which take up to eight years to bear fruit.

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