SHRIMP AQUACULTURE & OLIVE PRODUCTION - SUSTAINABLE INTEGRATION

By

Dennis McIntosh[1*], Kevin Fitzsimmons[1], Jose Aguilar[2] and Craig Collins[2]

[1] University of Arizona, Environmental Research Lab
2601 E. Airport Dr.
Tucson, Arizona 85706

[2] Wood Brothers' Farm
Gila Bend, Arizona

*Phone: (520) 626-3318
*Fax: (520) 573-0852
*E-mail: dmcintosh1@hotmail.com

Introduction

The efficient utilization of resources, be it man power, fertilizer, water or even light and heat, has long been the aim of agriculture. Countless agricultural methods have been developed and perfected over the years to maximize production. Innovations such as greenhouses and genetic engineering have enabled agriculture to be successful even in areas where it might not otherwise be possible.

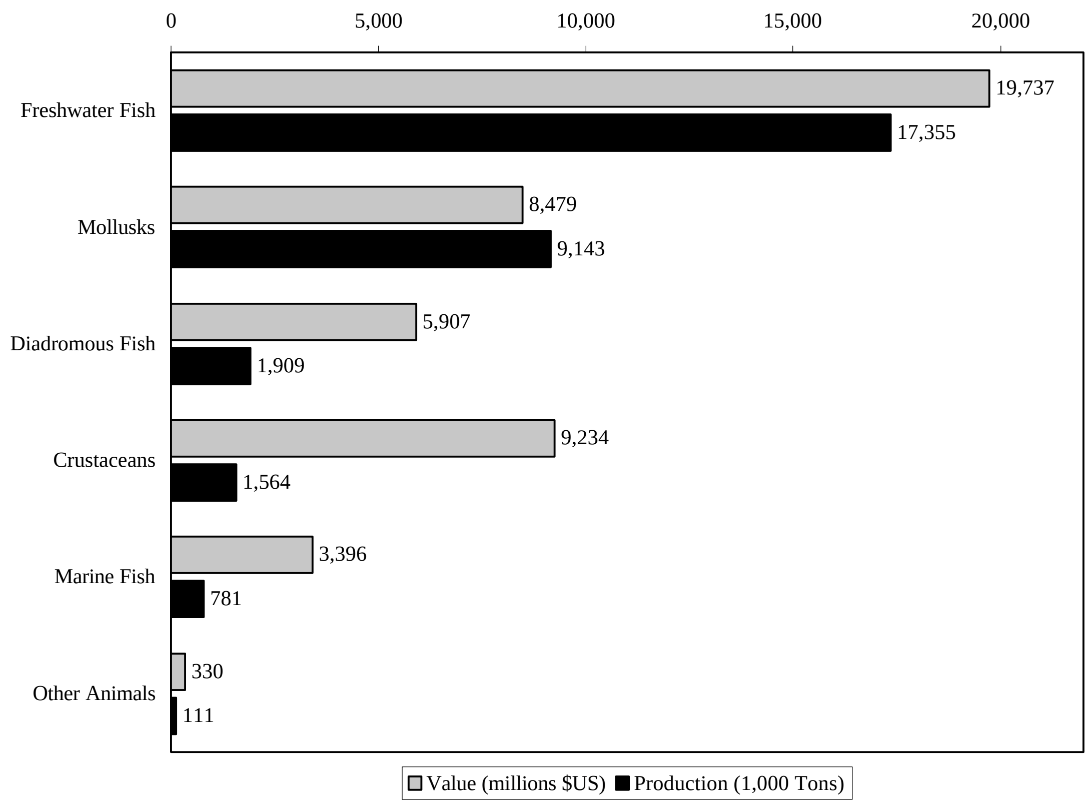
Prior to the widespread use of commercial farming, the integration of various aspects of farm production was commonplace (Fernando and Halwart 2000). Today, as consumers and producers alike become more environmentally conscience, we are seeing a renewed interest in more efficient and better utilization of resources. By integrating aquaculture production into traditional agriculture, the impact of farming on already limited water resources (Prinsloo and Schoonbee 1993; Ingram et al. 2000) and the reliance on chemical fertilizers can be reduced (Fernando and Halwart 2000).

Various methods have been proposed over the years to merge the farming of aquatic animals with field crops and/or terrestrial animals (Prinsloo and Schoonbee 1987; Ruddle and Zhong 1988; Fernando and Halwart 2000). To date, much effort has gone into small-scale (subsistence level) sustainable production of plants and animals (Lightfoot et al. 1993; Gupta et al. 1997), with one common approach being the use of agriculture wastes (manures and plant wastes for example) as a fertilizer for fish ponds, effectively converting unusable proteins into a usable commodity (Prinsloo and Schoonbee 1987; Prinsloo and Schoonbee 1993). More recently, similar ideas are being applied on a larger scale, where alternative protein sources are being explored as a component in aquaculture feeds. Traditionally, fish feeds required large amounts of fishmeal as the primary source of protein (Debault et al. 2000). In catfish feeds, for example, soybean meals commonly replace 45% of the fishmeal in the diet formulation (Lim et al. 1998). Other alternative proteins are also being explored, including canola meal (Lim et al. 1998), corn gluten meal (Kikuchi 1999), lupin meal (Sudaryono et al. 1999), soybean/poultry meal (DeBault et al. 2000) and blood meal (Johnson and Summerfelt 2000).

As aquaculture faces continued pressure from the environmental community and increased governmental regulations, efforts are being made to further improve production efficiency and decrease the environmental impacts of the industry. In the United States, perhaps the most important environmental concern facing the aquaculture industry is the disposal of the nutrient rich effluent water produced during the culture of aquatic animals (Goldburg and Triplett 1997). Great steps have already been taken toward reducing the impact that these effluent waters have by reducing nutrient loading through the manipulation of feeds and feeding practices (Ketola and Harland 1993; Cho and Bureau 1997), improved water treatment enabling water reuse (Rosati and Respicio 1999; Jones et al. 2001; Kinne et al. 2001) and reducing the volume of water used in animal production (Hopkins et al. 1993). While each of these methods can effectively reduce the impact that aquacultural effluents will have on the receiving water, they do not eliminate aquaculture effluents entirely.

In freshwater systems, these nutrient rich effluents can and are being used to irrigate any number of crops (Prinsloo and Schoonbee 1987). However, freshwater fish account for 41.9% of world aquaculture production by value and 56.2% of the total production by weight (FAO 2000). The remainder of world aquaculture production is attributed to marine organisms, including fish, mollusks and crustaceans, with farmed shrimp accounting for only 5.1% of the total aquaculture production by weight in 1998 but 19.6% of the total value (Fig. 1). Disposal of waste water from the production of marine organisms is not so straight forward, as the salinity of the water

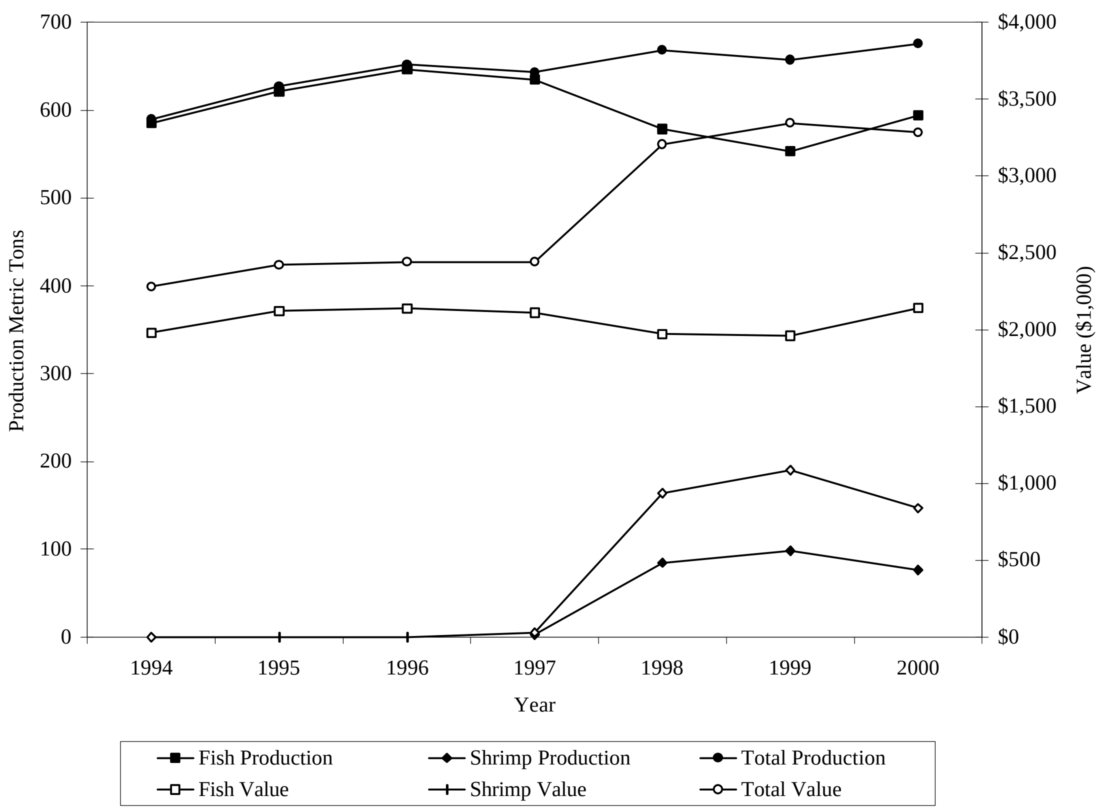
Figure 1. 1998 world aquaculture production and value (FAO 2000).



prohibits its use as a source of irrigation water, except in select cases. Saline effluents have been used successfully to irrigate halophytes (Brown and Glenn 1999; Brown et al. 1999), although commercial scale production of these crops is limited (Glenn et al. 1991; Glenn et al. 1998). While low-salinity waters have been used successfully to grow numerous marine species including; red drum, *Sciaenops ocellatus* (Fosberg et al. 1996; Fosberg and Neill 1997), white shrimp, *Litopenaeus vannamei* (Samocha et al. 1998) and tiger prawns, *Penaeus monodon* (Cawthorne et al. 1983; Flaherty and Vandergeest 1998), integration with agriculture has been limited to the addition of manures to increase pond productivity and the secondary culture of seaweeds (De La Cruz 1994).

Recent expansion of the aquaculture industry in Arizona has enabled us to study the integration of olive groves with marine shrimp culture. There are currently four aquaculture facilities in the state growing the pacific white shrimp, *L. vannamei*. As of 1999, production of marine shrimp was close to 100 metric tons, with a farm gate value of over one million dollars (Fig. 2) (Toba and Chew 2001). Each of these farms is using brackish (1.3-5.0 ppt) groundwater and in many instances, effluent generated at these farms is being used to irrigate field crops including wheat, sorghum, cotton, alfalfa and olives. The major objective in undertaking the current study was to quantify the effects of irrigating olive trees with low-salinity shrimp farm effluent.

Figure 2. Quantity and value of aquaculture products grown in Arizona between 1994 and 2000 (Toba and Chew 2001).



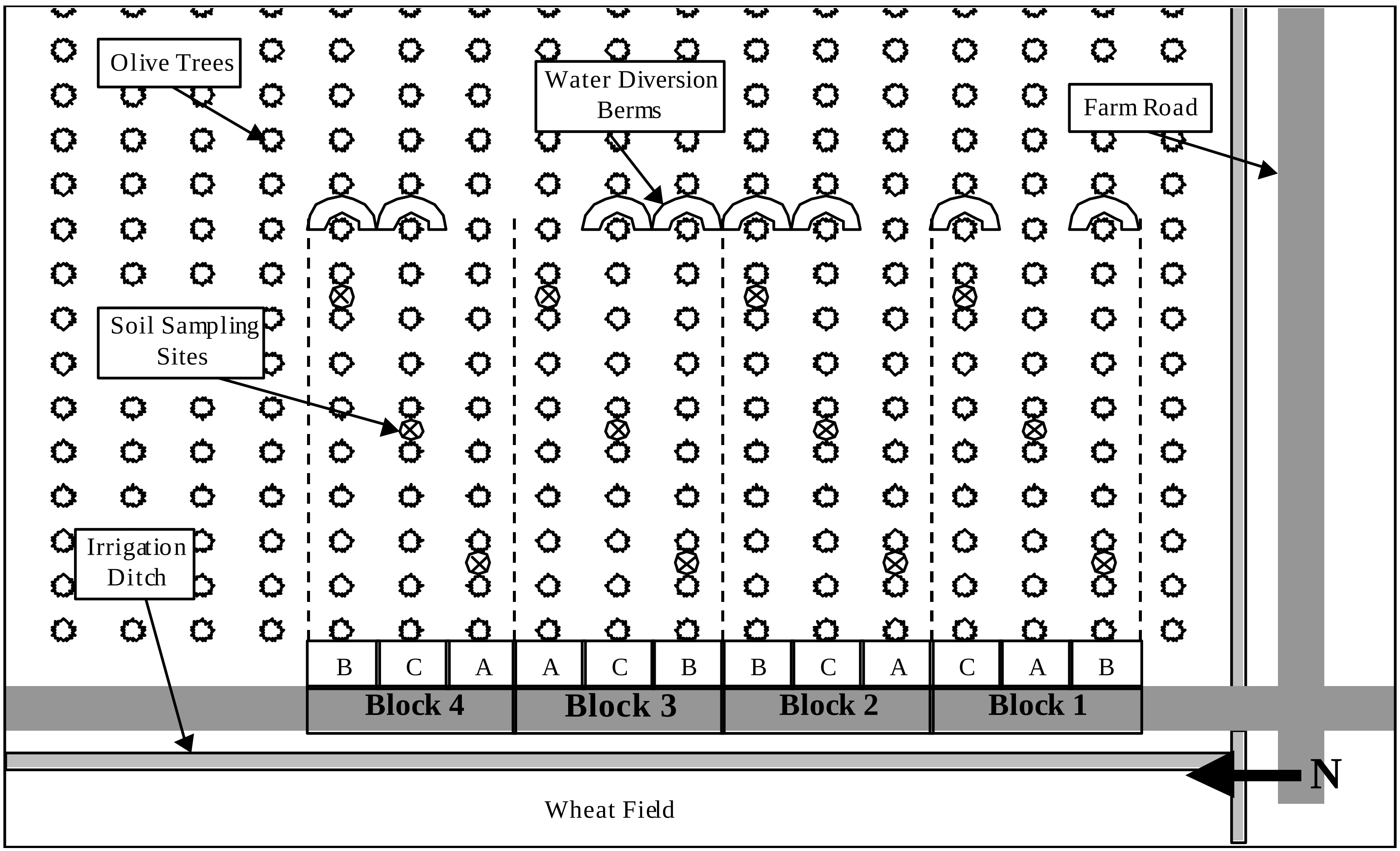
Methods

A field study utilizing a randomized block design was chosen to quantify the effect of low-salinity shrimp farm effluent on olive trees. This preliminary trial examined three effluent/well water/fertilizer combinations; 1) normal farm management, 2) 100% effluent water irrigation and 3) 100% well water irrigation. Each treatment was applied to 40 olive trees (*Olea europaea* var. Manzanillo), planted in rows for four months beginning in March 2001.

As olive trees are long lived, with much of the growth occurring in the early years, a young orchard was chosen as the study site. The selected grove is the southern most of all and as a result, is situated closet to the shrimp farm. Trees are planted in rows running in an east-west direction, approximately 10 m on center. Trees in the grove are flood irrigated every 10 - 12 days, as needed, with irrigation water applied from the eastside of the grove. The space between adjacent rows is commonly planted to wheat or sorghum while the trees are immature.

Due to its proximity to the service road, the southwestern corner of the field was chosen as the study site (Fig. 3). The southern most row of trees was not included in the study area to avoid the potential of an edge effect. Four blocks were laid out, each containing three rows of 10 trees. Rows were randomly assigned to one of three pre-selected treatments: 1) normal farm management, which included irrigation with well water and the application of anhydrous ammonia as fertilizer; 2) 100% shrimp farm effluent water as the sole irrigation and fertilizer source; and 3) a negative control consisting of 100% well water with no additional fertilizer applied.

Figure 3. Experimental plot at Wood Brother's farm in Gila Bend, AZ used to test the effect f irrigating with low-salinity shrimp farm effluent. 'A' indicates normal farm management, 'B' is irrigation with 100% effluent water and 'C' indicates the negative control 100% well water.



In rows assigned to the 100% effluent treatment and the negative control, water diversion berms were constructed (Fig. 3). Soil was dug from between the number 10 and 11 trees in these rows to connect the irrigation furrows on either side. Removed soil was subsequently used to create diversionary berms, effectively isolating the treatment trees from the main field's flood irrigation by directing this water into the inter-row spaces that had been planted to wheat during this trial. Rows assigned to the normal farm management treatment, did not have diversionary berms.

Trees in the experimental plot were flood-irrigated every 10 to 12 days as needed, following the schedule of the main field. Observation of the irrigation methods and conversations with the farm management were used to determine the volume of water applied during each irrigation event. It was determined, based on the size of the experimental rows, that each would need to receive approximately 3500 L of water per irrigation event. Due to the distance from the shrimp production ponds it was not practical to pump water to the study site, therefore water for both the 100% effluent and the negative control treatments was hauled from their respective sources to the experimental rows in a 3800-L polyethylene tank. Water for the 100% effluent water treatment was collected from the shrimp farm's drainage ditch with a portable pump. Well water for the negative control treatment was taken from the shrimp farm's water supply lines.

During each irrigation event, duplicate irrigation water samples were collected corresponding to the three treatments for macronutrient analysis. Water was collected from both the shrimp farm's drainage ditch and water supply lines as well as from the irrigation ditch supplying the main olive grove. Samples were analyzed for total nitrogen, nitrate-nitrogen, total phosphorus, potassium and salinity. The method used to test each parameter is listed in the Table 1. A HACH DR-890 (HACH Co., Loveland, CO) was used to measure total nitrogen, nitrate-nitrogen and total phosphorus. Potassium was measured with a Turner Model 340 (Sequoia-Turner Corp., Mountainview, CA) spectrophotometer and salinity was measured with a YSI Model 32 Conductance Meter (Yellow Spring Instruments, Yellow Springs, OH).

Table 1. Analytical methods used to test the macronutrient levels of irrigation water.

Parameter	**Method**
Total Nitrogen	HACH Method # 10071
	Persulfate Digestion Method
Nitrate-Nitrogen	HACH Method # 8039
	Cadmium Reduction Method
Total Phosphorus	HACH Method # 8190
	Acid Persulfate Digestion
Potassium	HACH Method # 8049
	Tetraphenylborate Method
Salinity	Standard Method # 2520 B
	Electrical Conductivity Method

In addition to the chemical analysis of the three irrigation water sources, tree growth, soil salinity and soil macronutrients were also monitored. Individual trees were measured for height and stem diameter each month. Tree heights were measured from the ground to the apical meristem of the longest branch, leaves were not used in measuring tree height. Stem diameters were measured 20 cm above the ground with dial calipers. Diameters were taken at the widest point at this height.

Soil samples were collected at the beginning and end of the study to measure nitrate and phosphorus concentrations and soil salinity. Samples were taken with a 1.5-cm soil corer to a depth of 0.5 m. One sample was collected from each of the experimental rows, in a staggered pattern (Fig. 3). Nitrate was extracted from the soil with a 2 M KCl solution. Phosphorus was extracted with Olsen's Solution (0.5 M $NaHCO_3$). For both nitrate and phosphorus, the filtrate was collected and analyzed with the same techniques used for the irrigation water (Table 1).

Irrigation water samples (six per sample date) were analyzed separately and results were grouped by source (shrimp farm drainage ditch, shrimp farm supply line or olive grove irrigation ditch) for statistical analysis. Soil data and tree growth data were grouped by treatment for statistical analysis. The statistical software package JMP IN v4 (SAS Institute Inc., Pacific Grove, CA) was used to analyze all data. A one-way ANOVA was applied to the irrigation water data, followed by a linear contrast to separate the means. Tree growth data was analyzed using a repeated measures ANOAVA. Soil salinity and nutrient data were analyzed using a paired sample *t*-test.

Results

Irrigation Water

Of the irrigation water quality parameters measured, statistically significant differences were only found in total nitrogen ($F_{2,31} = 30.413$, $p<0.0001$). Total nitrogen levels in the negative control (100% well water taken from the shrimp farm supply line) averaged 20 mg/L N, 10 mg/L higher than the effluent water ($t = 6.228$, $p<0.0001$) and 12 mg/L higher then the irrigation ditch water ($t = 7.096$, $p<0.0001$). The 2 mg/L N difference between the effluent water and the irrigation ditch water was not statistically significant ($t = 1.157$, $p = 0.2559$). Levels of nitrate-nitrogen, total phosphorus, potassium and salinity were not statistically significant among the three water sources used in this research (p>0.05 for all parameters) (Table 2).

Table 2. Nutrient levels (means) of the water used to irrigate the experimental plot with the respective *F*-statistics and *p*-values. Numbers in parenthesis are the standard errors of the means.

	Water Source				
Parameter	**Well**	**Effluent**	**Ditch**	***F*-Statistic**	***p*-Value**
Total Nitrogen (mg/L)	20 (1)	10 (1)	9 (0)	30.413	<0.0001
Nitrate-Nitrogen (mg/L)	8.0 (1.6)	8.3 (0.6)	5.9 (0.6)	1.5496	0.2274
Total Phosphorus (mg/L)	0.52 (0.12)	0.69 (0.05)	0.59 (0.10)	0.9114	0.4124
Potassium (mg/L)	7.35 (0.97)	6.51 (0.86)	8.62 (0.21)	1.9537	0.1578
Salinity (ppt)	1.95 (0.30)	1.38 (0.21)	1.22 (0.20)	2.5782	0.0911

Tree Growth

Height

Tree height increased an average of 40.1 cm over the four month study period, from 172.1 to 212.2 cm (Fig. 4). Trees subjected to the normal farm management treatment grew 41.4 cm during the study and trees irrigated with 100% shrimp farm effluent water grew 41.1 cm during the study (Table 3). Trees irrigated with 100% well water grew 37.9 cm between March and July. Neither height differences nor the growth as measured by height was statistically significant among the three treatments investigated in this study ($F_{2,109}$ = 1.3241, p = 0.2704 and $F_{2,109}$ = 0.6438, p = 0.5273, respectively).

Figure 4. Monthly height of olive trees at the Wood Brothers' farm in Gila Bend, Arizona.

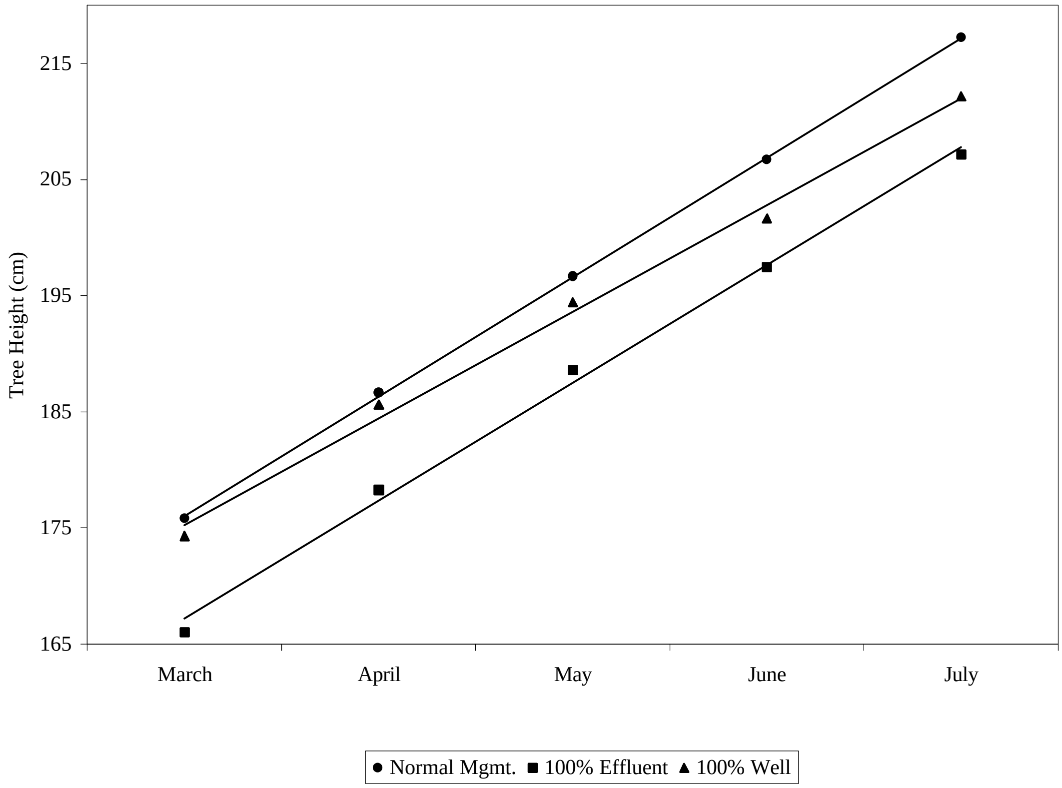


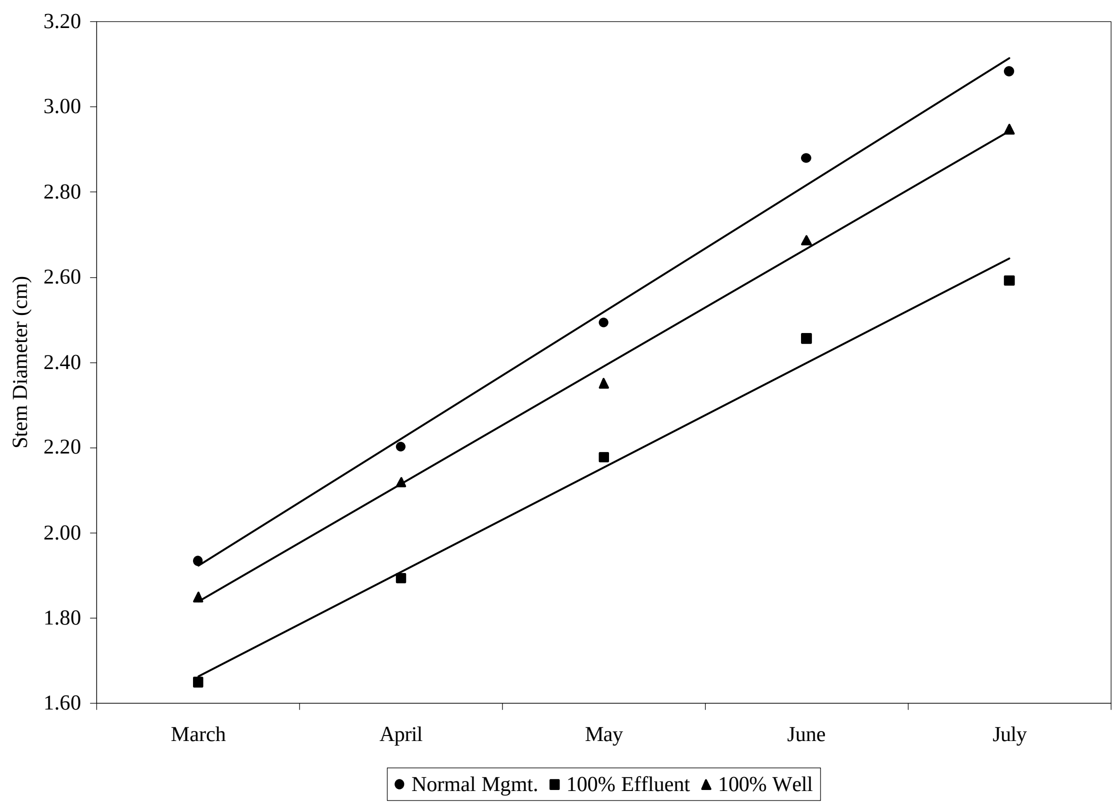
Table 3. Mean height and diameter of olive trees irrigated with various sources of water as measured between March and July 2001 at the Wood Brothers' farm in Gila Bend, AZ.

	Normal Mgmt.		**100% Effluent**		**100% Well**	
	Height	**Diameter**	**Height**	**Diameter**	**Height**	**Diameter**
March	175.8 (4.6)	1.93 (0.07)	166.0 (3.7)	1.65 (0.08)	174.3 (3.9)	1.85 (0.07)
April	186.6 (4.2)	2.20 (0.08)	178.3 (4.0)	1.89 (0.09)	185.6 (4.2)	2.12 (0.08)
May	196.7 (3.8)	2.49 (0.09)	188.6 (3.8)	2.18 (0.11)	194.4 (4.4)	2.35 (0.10)
June	206.7 (3.7)	2.88 (0.10)	197.5 (4.1)	2.46 (0.12)	201.6 (4.6)	2.69 (0.12)
July	217.2 (3.6)	3.08 (0.11)	207.2 (4.1)	2.59 (0.13)	212.2 (5.0)	2.95 (0.13)
Growth	41.4	1.1	41.1	0.9	37.9	1.1

Diameter

Stem diameter at 20 cm above ground increased by an average of 1.06 cm during the study period (Fig. 5). Differences in tree diameter were statistically significantly different among the three treatments ($F_{2,109}$ = 3.7764, p = 0.0260) with trees in the effluent treatment having the smallest diameters, 2.15 cm versus 2.52 cm and 2.39 cm for trees in the normal farm management and negative control treatments, respectively (Table 3). However, the differences in growth as measured by tree diameter were not statistically significantly different ($F_{2,109}$ = 2.5810, p = 0.0803) among the three treatments. Stem diameter growth averaged 1.15 cm per tree in the trees that were under normal farm management treatment, 0.94 cm per tree in the trees irrigated with 100% effluent water and 1.10 cm per tree in the negative control group.

Figure 5. Monthly measurements of olive tree stem diameter at 20 cm above ground.



Soil Salinity and Macronutrients

Soil Salinity

While soil salinity increased during the four month study period in all rows, the differences among the three treatments were not statistically significant ($F_{2,11}$ = 0.6237, p = 0.5576). The greatest difference between soil salinity in March and July was seen in the 100% effluent treatment, where salinity increased by 1.99 ppt (Table 4). Soil salinity increased by 0.54 ppt in the 100% well water treatment and 0.37 ppt in the normal farm management treatment over this same time. None of the increases in soil salinity observed within each treatment were statistically significant (p>0.32 for all, from a two-sample t-test).

Table 4. Changes in soil macronutrients and salinity from March 2001 to July 2001, as a result of irrigating with various sources of water. Numbers in parenthesis are the standard errors of the means.

		Treatment			
Parameter	**Norm. Mgmt.**	**100% Eff.**	**100% Well**	***F*-Statistic**	***p*-Value**
Salinity (ppt)	0.37 (0.95)	1.99 (1.62)	0.54 (0.54)	0.6237	0.5576
Nitrate-Nitrogen (mg/g)	9.0 (7.4)	11.0 (13.0)	-1.25 (4.9)*	0.5258	0.6082
Total Phosphorus (mg/g)	-0.15 (1.80)*	-9.08 (8.40)*	-12.18 (9.40)*	0.7181	0.5136

* Negative number denotes a decrease between March and July.

Soil Nitrate

Soil nitrate levels increased in the normal farm management and 100% effluent treatments, by 9.0 and 11.0 mg NO_3-N/g dry soil, respectively from March to July (Table 4). Levels of soil nitrate in the negative control treatment rows decreased by 1.25 mg/g. None of the differences observed within treatments were statistically significant (p>0.31 for all, from a two-sample *t*-test). Differences among the three treatment groups were also not statistically significant ($F_{2,11} = 0.5258$, $p = 0.6087$).

Soil Phosphorus

Phosphorus levels in the soil decreased across all treatments from an average of 8.10 mg PO_4/g dry soil in March to an average of 0.97 mg PO_4/g dry soil in July ($t = 1.792$, $p = 0.0868$). The normal farm management treatment rows decreased by 0.15 mg PO_4/g soil during the four month study. Decreases in soil phosphorus in the 100% effluent treatment and the 100% well water treatments were 9.08 and 12.18 mg/g, respectively (Table 4). None of the differences observed within treatments were statistically significant ($p>0.21$ for all, from a two-sample *t*-test). Differences in soil phosphorus decreases among treatments were not statistically significant ($F_{2,11} = 0.7181$, $p = 0.5136$).

Discussion

Using plants as a filtration system for aquaculture effluents has been well documented, with approaches ranging from the use of constructed wetlands (Greenberg 1991; Redding et al 1997; Rosati and Respicio 1999) to the incorporation of aquaculture effluents into hydroponic vegetable production (McMurtry et al. 1990), with the majority of the botanical approaches to aquaculture effluent treatment being aimed at freshwater systems. While the value of mariculture products is greater than that of freshwater aquaculture products (FAO 2000), botanical approaches to the treatment of mariculture effluents are not as well developed as those for freshwater aquaculture effluents, being limited to seaweeds (De La Cruz 1994; Troell et al. 1999) and halophytes (Brown and Glenn 1999; Brown et al. 1999).

McMurtry and co-workers (1990), among others, have reported that aquaculture effluents from freshwater production system can supply all of the necessary mineral nutrition for vegetables, including bush beans (*Phaseolus vulgaris*), cucumbers (*Cucumis sativus*) and tomatoes (*Lycopersicon esculentum*). It seems logical, then, to assume that with the successful production of various marine species in low-salinity waters (Cawthorne et al. 1983; Fosberg et al. 1996; Fosberg and Neill 1997; Flaherty and Vandergeest 1998; Samocha et al. 1998) and the salt tolerance of certain crops, that integrating low-salinity mariculture and agriculture could result in similar findings.

In the current study, statistically significant differences were found in respect to total nitrogen levels in the irrigation water, with the 100% well water (negative control) treatment having the highest nitrogen levels. However, no statistically significant differences were found in tree growth as measured by either height or diameter among the three treatments. Looking at Figures 4 and 5, we can see that slope of the lines fitted to the data corresponding to each treatment are not the same, suggesting that while growth of trees was not statistically significant over the four month study period, a longer term study might show significant differences. In Figure 4, the slope of the line fitted to the 100% well water treatment data is less than the line for either the normal management treatment or the 100% effluent treatment. Figure 5 suggests that, when extrapolated out, growth of the normal management treatment would be greatest, followed by the 100% well water treatment followed by the 100% effluent treatment.

Our findings are in clear contrast to what has been shown in other research for vegetables (Prinsloo and Schoonbee 1987; McMurtry et al. 1990), seaweeds (Troell et al. 1999) and halophytes (Brown and Glenn 1999; Brown et al. 1999). Reasons for the apparent discrepancies could be the increases observed in soil salinity or, more likely, the high levels of nitrate present in the well water. The farm in the study is located in an area that has a long history of being planted in cotton. Our belief is that potential benefits of irrigating with nutrient rich, low-salinity shrimp farm effluents have been masked by the high nitrate-nitrogen levels present in the well water. While irrigating with 100% low-salinity effluent did not improve growth of olive trees in respect to either the normal farm management or the 100% well water (negative control) during the four month study, our results do indicate that irrigating with this low-salinity shrimp farm effluent had no noticeable negative effects.

Despite the promising results obtained in this preliminary study, many problems associated with conducting research at a commercial farm were encountered. Over the four month study period, the planned irrigation schedule was interrupted on five separate occasions due to either miscommunication and/or logistical difficulties. While these relatively minor setbacks are to be expected on a commercial farm, they do call into question the scientific integrity of the data obtained. It is for this reason that we are planning to continue this research for another season.

References

Brown, J. J. and E. P. Glenn. 1999. Reuse of highly saline aquaculture effluent to irrigate a potential forage halophyte, *Suaeda esteroa*. Aquacultural Engineering 20(2):91-111.

Brown, J. J., E. P. Glenn, K. M. Fitzsimmons and S. E. Smith. 1999. Halophytes for the treatment of saline aquaculture effluent. Aquaculture 175:255-268.

Cawthorne, D. F., T. Beard, J. Davenport and J. F. Wickens. 1983. Responses of juvenile *Penaeus monodon* Fabricus to natural and artificial sea waters of low salinity. Aquaculture 32:165-174.

Cho, C. Y. and D. P. Bureau. 1997. Reduction of waste output from salmonid aquaculture through feeds and feeding. The Progressive Fish-Culturist 59:155-160.

De La Cruz, C. R. 1994. Brackishwater integrated farming systems in Southeast Asia. Pages 23-26 in T. U. Bagarino and E. E. C. Flores, editors. Towards sustainable aquaculture in Southeast Asia and Japan: proceedings. Iloilo City, Philippines, July 26-28 1994. Southeast Asian Fisheries Development Center, Iloilo City, Philippines; Aquaculture Department, Japan International Cooperation Agency (Japan); Canadian International Development Agency (Canada).

Debault, K., T. M. Samocha and A. D. Davis. 2000. Successful replacement of fishmeal in the diet of the Pacific white shrimp *Litopenaeus vannamei* in an outdoor tank system (abstract). Page 82 in B. P. Hart and B. L. Brown, editors. Aquaculture America 2000 Book of Abstracts. New Orleans, LA, USA, February 2-5, 2000. The World Aquaculture Society, Baton Rouge, Louisiana, USA.

FAO (Food and Agriculture Organization of the United Nations). 2000. The state of the world fisheries and aquaculture 2000. FAO Fisheries Department, Rome, Italy.

Fernando, C. H. and M. Halwart. 2000. Possibilites for integration of fish farming into irrigation systems. Fisheries Management and Ecology 7:45-54.

Flaherty, M. and P. Vandergeest. 1998. “Low salt” shrimp aquaculture in Thailand: goodbye coastline, hello Khon Kaen. Environmental Management 22(6) 817-830.

Forsberg, J. A. and W. H. Neill. 1997. Saline groundwater as an aquaculture medium: Physiological studies on the red drum, *Sciaenops ocellatus.* Environmental Biology of Fishes 49:119-128.

Forsberg, J. A., P. W. Dorsett and W. H. Neill. 1996. Survival and growth of red drum, *Sciaenops ocellatus*, in saline groundwaters of West Texas, USA. Journal of the World Aquaculture Society 27:462-474.

Glenn, E. P., J. W. O'Leary, M. C. Watson, T. L. Thompson and R. O. Kuehl. 1991. *Salicornia bigelovii* Torr.: An oilseed halophyte for seawater irrigation. Science 251(4997):1065-1067.

Glenn, E. P., R. Tanner, S. Miyamoto, K. Fitzsimmons and J. Boyer. 1998. Water use, productivity and forage quality of the halophyte *Atriplex nummularia* grown on saline waste water in a desert environment. Journal of Arid Environments 38(1):45-62.

Goldburg, R. and T. Triplett. 1997. Murky waters: environmental effects of aquaculture in the United States. Environmental Defense Fund, New York, USA.

Greenberg, A. 1991. Natural Filtration for aquaculture. Pages 259-263 in D. Takiff-Smith, editor. Agriculture and the environment, yearbook of agriculture. U. S. Department of Agriculture, Washington D. C.

Gupta, M..V., M. A. Rahman, M. A. Mazid and J. D. Sollows. 1996. Integrated agriculture-aquaculture: a way for food security for small farmers and better resource management and environment. Pages 165-175 in F. Heidhues and A. Fandani, editors. Food security and innovations: successes and lessons learned: international symposium 1996. Frankfurt am Main; New York: P. Lang.

Hopkins, J. S., R. D. Hamilton, P. A. Sandifer, C. L. Browdy and A. D. Stokes. 1993. Effect of water exchange rate on production, water quality, effluent characteristics and nitrogen budgets of intensive shrimp ponds. Journal of the World Aquaculture Society 24(3):304-320.

Ingram, B. A., G. J. Gooley, L. J. McKinnon and S. S. DeSilva. 2000. Aquaculture-agriculture systems integration: an Australian prospective. Fisheries Management and Ecology 7:33-43.

Johnson, J. A. and R. C. Summerfelt. 2000. Spray-dried blood cells as a partial replacement for fishmeal in diets for rainbow trout *Oncorhynchus mykiss*. Journal of the World Aquaculture Society 31(1):96-104.

Jones, A. B., W. C. Dennison and N. P. Preston. 2001. Integrated treatment of shrimp effluent by sedimentation, oyster filtration and macroalgal absorption: a laboratory scale study. Aquaculture 193:155-178.

Ketola, H. G. and B. F. Harland. 1993. Influence of phosphorus in rainbow trout diets on phosphorus discharges in effluent water. Transactions of the American Fisheries Society 122(6):1120-1126.

Kinne, P. N., T. M. Samocha, E. R. Jones and C. L. Browdy. 2001. Characterization of intensive shrimp pond effluent and preliminary studies on biofiltration. North American Journal of Aquaculture 63(1):25-33.

Kirkuchi, K. 1999. Partial replacement of fishmeal with corn gluten meal in diets for Japanese flounder *Paralichthys olivaceus*. Journal of the World Aquaculture Society 30(3):357-363.

Lightfoot, C., M. Prein and J. K. Ofori. 1993. Potential impact of integrated agriculture-aquaculture systems on sustainable farming. Pages 51-56 in M. Prein, J. K. Ofori and C. Lightfoot, editors. ICLARM/IAB Workshop, Accra, Ghana, March 11-13 1993. International Center for Living Aquatic Resources Management, Manila, Philippines; Council for Scientific and Industrial Research, Achimota, Ghana; Institute of Aquatic Biology, Eschborn, Germany.

Lim, C., P. H. Klesius and D. A. Higgs. 1998. Substitution of canola meal for soybean meal in diets for channel catfish *Ictalurus punctatus*. Journal of the World Aquaculture Society 29(2):161-168.

McMurtry, M. R., P. V. Nelson, D. C. Sanders and L. Hodges. 1990. Sand culture of vegetables using recirculated aquaculture effluents. Applied Agriculture Research 5(4):280-284.

Prinsloo, J. F. and H. J. Schoonbee. 1987. Investigations into the feasibility of a duck-fish-vegetable integrated agriculture-aquaculture system for developing areas in South Africa. Water South Africa 13(2):109-118.

Prinsloo, J. F. and H. J. Schoonbee. 1993. The utilization of agricultural by-products and treated effluent water for aquaculture in developing areas of South Africa. Suid Afrikaanse Tydskrif vir Natuurwetenskap en Tegnologie 12(3):72-79.

Redding, T., S. Todd and A. Midlen. 1997. The treatment of aquaculture wastewaters - a botanical approach. Journal of Environmental Management 50:283-299.

Rosati, R. and P. Respicio. 1999. Culture of *Penaeus vannamei* using pond-based recirculating systems (abstract). Page 162 in C. D. Webster, editor. Aquaculture America '99 Book of Abstracts. Tampa, Florida, USA, January 27-30, 1999. The World Aquaculture Society, Baton Rouge, Louisiana, USA.

Ruddle, K. and G. Zhong (editors). 1988. Integrated agriculture-aquaculture in South China: The dike-pond system of the Zhujian Delta. Cambridge University Press, New York, NY.

Samocha, T. M., A. L. Lawrence and D. Pooser. 1998. Growth and survival of juvenile *Penaeus vannamei* in low salinity water in semi-closed recirculating systems. Israeli Journal of Aquaculture-Bamidgeh 50(2):55-59.

Sudaryono, A., E. Tsventneko and L. H. Evans. 1999. Replacement of soybean meal by lupin meal in practical diets for juvenile *Penaeus monodon*. Journal of the World Aquaculture Society 30(1):46-57.

Toba, D. R. and K. K. Chew, editors. 2001. Western regional aquaculture industry situation and outlook report. Western Regional Aquaculture Center, Seattle, Washington, USA.

Troell, M., P. Ronnback, C. Halling, N. Kautsky and A. Buschmann. 1999. Ecological engineering in aquaculture: use of seaweeds for removing nutrients from intensive mariculture. Journal of Applied Phycology 11:89-97.