DOI: 10.3856/vol46-issue1-fulltext-8

Research Article

Production and management of shrimp (*Penaeus vannamei*) in co-culture with basil (*Ocimum basilicum*) using two sources of low-salinity water

Juan F. Fierro-Sañudo[1], Gustavo A. Rodríguez-Montes de Oca[2], Jesús A. León-Cañedo[1]
Suammy G. Alarcón-Silvas[3], M. Martin Mariscal-Lagarda[4]
Tomás Díaz-Valdés[5] & Federico Páez-Osuna[6,7]
[1]Posgrado en Ciencias Agropecuarias, Colegio de Ciencias Agropecuarias
Universidad Autónoma de Sinaloa, Culiacán Rosales, Sinaloa, México
[2]Facultad de Ciencias del Mar, Universidad Autónoma de Sinaloa, Mazatlán, Sinaloa, México
[3]Posgrado en Manejo de Recursos Acuáticos, Facultad de Ciencias del Mar
Universidad Autónoma de Sinaloa, Mazatlán, Sinaloa, México
[4]Universidad Estatal de Sonora, Villa Juárez, Sonora, México
[5]Facultad de Agronomía, Universidad Autónoma de Sinaloa, Culiacán, Sinaloa, México
[6]Instituto de Ciencias del Mar y Limnología, Universidad Nacional Autónoma de México
Mazatlán, Sinaloa, México
[7]Miembro de El Colegio de Sinaloa
Corresponding author: Federico Páez-Osuna (paezos@ola.icmyl.unam.mx)

ABSTRACT. The aim of this study was to evaluate the production of an aquaponic culture of white shrimp (*Penaeus vannamei*) and basil (*Ocimum basilicum*) using two sources of low-salinity water (1.7 g L^{-1}): diluted seawater (DSW) and groundwater (GW) with zero water exchange at a stocking ratio of 4.9 shrimp per basil plant. Six aquaponic treatment systems were constructed: three individual aquaponic systems for DSW-basil, three for GW-basil, and a control (per triplicate) of basil with a hydroponic solution. Stock densities for shrimp were 75 post-larvae m^{-2} and 16 plants m^{-2} for basil. With the exception of the yield in the shrimp culture (kg m^{-2} or ton ha^{-1}), no significant differences ($P > 0.05$) were found for the final individual weight, survival, growth rate and feed conversion ratio between DSW and GW, whereas for basil, lower yields were found with DSW. No significant differences in the basil production between the control and the treatment GW were found. Feed consumption per kg of total harvested basil was significantly lower ($P < 0.05$) in GW treatment, while for feed intake in the shrimp farming, where no significant differences were found ($P > 0.05$). The aquaponic culture of shrimp and basil using these two types of low-salinity water sources showed promising results. The estimates of both crop yields were compared with those recorded in the literature and for commercial field crops from northwest Mexico.

Keywords: aquaponic culture, *Penaeus vannamei*, groundwater, *Ocimum basilicum*, production, management.

INTRODUCTION

Aquaponics are integrative systems of aquatic animals and plants production where the waste of the aquaculture units is used in the vegetable production. This food production system has been successfully developed with fish. Great advantages have been found, including reducing the use of water for both cultures (Ingram *et al.*, 2000). The economic return per cubic meter of water is greater because it is used to produce two or more products at once (McIntosh & Fitzsimmons, 2003) and the use of fertilizers is lower due to the contributions of nutrients from the aquaculture effluent (Fernando & Halwart, 2000). Aquaponic systems can be implemented in areas of high poverty for subsistence or family businesses, and the environmental impact from aquaculture is significantly reduced due to the use of the effluents as a nutrient source.

With the expansion of the culture of Pacific white shrimp (*P. vannamei*) *Penaeus vannamei* (= *Litopenaeus vannamei*) in fresh and low-salinity water, effluents from such farms can be utilized for the production of

Corresponding editor: Jesús Ponce-Palafox

plant biomass, which reduces environmental impact while producing more food with less water. For good growth and survival in shrimp culture using low-salinity water, concentrations, and ratios of ions in the water should be similar to the concentrations and ratios present in the diluted seawater at the same salinity (Roy *et al*., 2010). There are two ways to achieve this: diluting seawater (or brine solution) with fresh water (Samocha *et al*., 1998; Limsuwan *et al*., 2002), or using groundwater and supplementing deficient salts (Boyd *et al*., 2002; Saoud *et al*., 2003; McNevin *et al*., 2004). In both cases, when working with low salinity water (approx. <2 g L^{-1}), it is possible to irrigate plants. In this context, there are few studies on the integration of shrimp (*P. vannamei*) with tomato plants (*Lycopersicon esculentum*), evaluating produc-tion and management (Mariscal-Lagarda *et al*., 2012), water quality (Mariscal-Lagarda *et al*., 2014), the mass balance of nitrogen and phosphorus (Mariscal-Lagarda & Páez-Osuna, 2014), and the production and management of shrimp (*P. vannamei*) integrated culture with tomato plants (*L. esculentum*) and lettuce (*Lactuca sativa*) (Fierro-Sañudo, 2013).

From an international survey of aquaponics practi-tioners worldwide (Love *et al*., 2015), basil (*Ocimum basilicum*) was identified as the most cultivated plant in aquaponic systems. This plant belongs to the family Lamiaceae. It is native to India, and is widely used in Vietnam, Thai and Italian food, due to its unique flavor and aroma. There are various studies that describe obtained yields, of integrated basil production with tilapia (Rakocy *et al*., 2004; Hanson *et al*., 2008), river prawn (Ronzón-Ortega *et al*., 2012), and carp (Roosta, 2014), with no available information for low-salinity shrimp co-culture.

Basil's main characteristics that make it a good candidate for integration with shrimp farming using low salinity water are: i) it is tolerant to the high concentration of dissolved salts in the water because it can be grown in water up to 4 dS m^{-1} of electrical conductivity (salinity of 2.5 g L^{-1}), without showing deficiencies in development and production (Ramírez *et al*., 2001; Reyes-Pérez *et al*., 2013), ii) the climatic conditions of the study area (southern Sinaloa, Mexico) are compatible with the requirements of the plant (temperature of 24-30°C during the day and 16-20°C during the night, altitude from 0 to 1,000 m and relative humidity of 60-70%) (Briseño-Ruiz *et al*., 2013), and iii) it has excellent market acceptance due to it essential oils contribution to the food preparation, perfume, and medical industries. Based on the above, the aim of this study was to evaluate the production of an aquaponic culture of shrimp *P. vannamei* and basil *O. basilicum*, using two sources of low-salinity water, groundwater (GW), and diluted seawater (DSW), at an approximate electrical conductivity of 2.7 dS m^{-1} (1.7 g L^{-1}) with zero water exchange at a stocking ratio of 4.9 shrimp per basil plant.

MATERIALS AND METHODS

Experimental system

The present study was carried out in the experimental module YK located in Mazatlan, Sinaloa, Mexico (23°12'11.9"N, 106°25'41.29"W). The experimental system consisted of six tanks for the shrimp culture (2 m diameter × 1.2 m height, with a working volume of 3.14 m^3 each). Three tanks were filled with GW with an electrical conductivity of 2.7 dS m^{-1}, from a shrimp farm located in southern Sinaloa, and three tanks were filled with DSW to the same electrical conductivity prepared with seawater (34 g L^{-1}) and freshwater (0.2 g L^{-1}) from the domestic supply. Each tank was connected to one tank of 180 L, one biological filter of 120 L with HDPE (high-density polyethylene) plastic beads and gravel as a substrate for fixing nitrifying bacteria and a deep flow technique system (DFT) for the basil crop. The DFT system consisted of beds constructed with cement blocks covered with plastic (3.0 m long × 1.0 m wide × 0.2 m high) with a slope of 1% (Fig. 1).

The basil seedlings (10-15 cm high) were put to float in their corresponding DFT systems above plates of polystyrene (1.0 m long × 1.0 m wide × 1.0" thickness). Water was transferred by gravity from the shrimp culture tanks to the rest of the system using a ½" diameter HDPE hose. At the end of the DFT system, the water was received in a 50 L tank, and then pumped back into the shrimp culture tanks by a ½ HP peripheral pump. Three additional DFT systems were constructed to grow basil using a nutritive hydroponic solution (Marulanda-Tabares, 1999; Samperio-Ruiz, 2000) as the control treatment, the chemical major components of the nutritive hydroponic solution are summarizing in Table 1. Aeration was supplied by a 1 HP regenerative air blower and aeration tubing (Aerotube) in each tank.

The water recirculation through the aquaponic system was a constant flow of 2 L min^{-1}. The water lost through evaporation, evapotranspiration of the plants and the draining of the settlement tanks was replaced from a 450 L tank connected to the pump reservoirs where water was replaced after reaching a predeter-mined level. During the culture cycle, the water exchange was zero.

Analysis of major components, pH and electrical conductivity per water source

At the time of shrimp culture tanks setup, water samples were collected directly from the tanks (25 cm

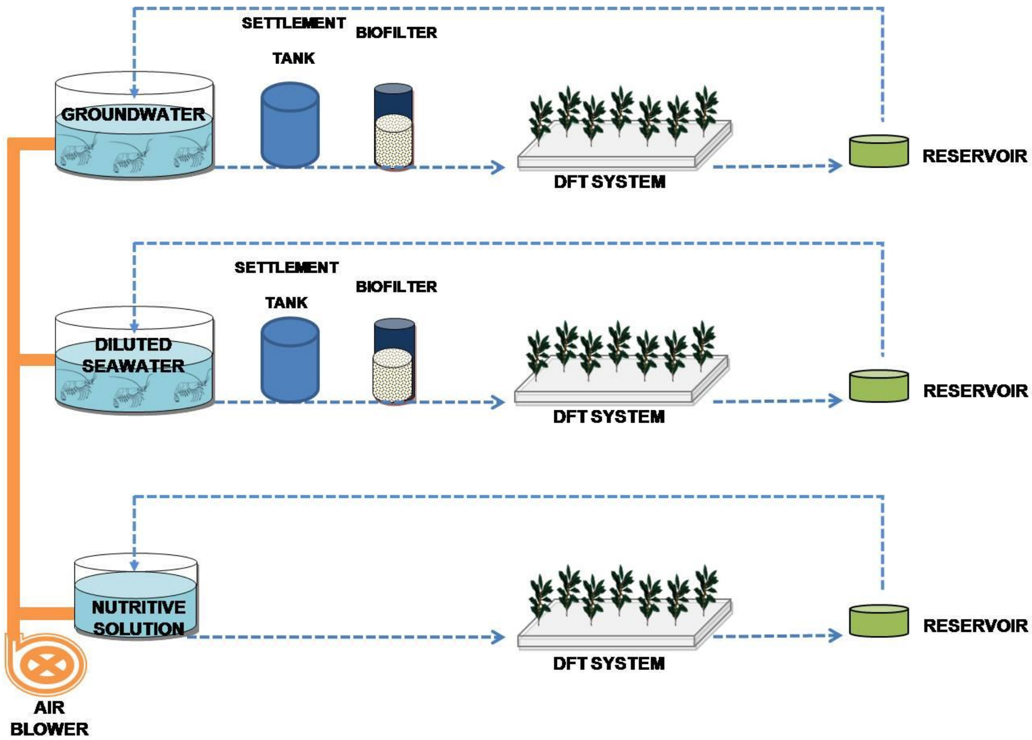

Figure 1. Scheme of the experimental system used. Each treatment was performed in triplicate.

Table 1. Major chemical components of hydroponic nutritive solution used in the trial.

Component	Concentration (mg L^{-1})
N	190.3
P	45.6
K	211.6
Ca	131.2
Mg	49.6
S	65.7
Fe	2.9
Mn	0.4
Zn	0.1
Cu	0.1
B	0.5

below the surface water) and were filtered using Whatman GF/F filters. The filtered water samples were stored in clean plastic bottles (120 mL) and transported to the laboratory at low temperature (4°C). The groundwater and diluted seawater used in this trial were analyzed in duplicate for Cl^-, Mg^{+2}, K^+, $Ca^{+2,}$ and Na^+, as well as total alkalinity using standard techniques (APHA, 2012). The precision for each major component varied from 3.5 to 7.8%. The dissolved oxygen and temperature values were determined with a dissolved oxygen meter (YSI, model 58, USA), and pH and electrical conductivity (EC) with a meter (Hanna Instrument model HI 98129). The salinity was estimated from the EC readings (in µS cm^{-1} at 25°C × 0.00063) (Boyd, 2002). The precision, estimated as the coefficient of variation, was 5.5, 2.2 and 4.1% for the dissolved oxygen, pH and conductivity, respectively.

Shrimp culture

Shrimp post-larvae (PL-53) used in the experiment system was provided by Fitmar Proveedora de Larvas S.A. de C.V. The organisms were transported to the YK module inside an ice chest at 23°C and 10 g L^{-1} of salinity. Upon arrival, PL´s were stocked in 450-L tanks for complete the acclimatization process to selected working salinity according to Van Wyk (1999) and McGraw & Scarpa (2004) until the electrical conductivity levels were reached (2.7 dS m^{-1}). During the acclimatization process, the post-larvae were fed with Flake (52% protein, 9% lipids, 3% fiber, 3% ash, 10% humidity; Brine Shrimp Co., Providence, Utah, USA) five times a day (7:00, 10:00, 13:00, 16:00, and 19:00 h). At the completion of acclimatization, shrimp culture tanks were stocked at a density of 75 PL-58 m^{-2} with an individual mean weight of 0.69 ± 0.19 g.

During the first two weeks, the post-larvae were fed manually *ad-libitum* form the border of the shrimp culture tanks with Camaronina (35% protein, 3.5%

lipid, 5% fiber, 11% ash, 12% humidity; Nestlé Purina, St. Louis Missouri, USA) three times a day (8:00, 13:00 and 16:00 h). For the remaining culture cycle, the organisms were fed with feeding trays using the same feed, and the amount of feed was adjusted considering the biomass and the remnant observed in the feeders (Cook & Clifford, 1997). The shrimp culture had a duration of 50 days; shrimp were harvested, but working water (or shrimp effluent) was maintained in recirculation to continue with the basil culture 81 days more.

Basil crop

The basil seeds were sown in polystyrene seedbeds of 200 cavities with peat moss as the substrate and were irrigated three times a day (8:00, 13:00 and 16:00 h) (Samperio-Ruiz, 2000). The seedlings were transplanted in the aquaponic system 30 days after the seed was sown and 15 days after the shrimp were stocked. In this period, the shrimp tanks are expected to generate sufficient levels of concentrated nutrients (Mariscal-Lagarda *et al*., 2014), and the registered temperatures are compatible with the basil culture. The crop density used was 16 plants m^{-2} in the DFT systems; each tank had contained 235 shrimp and was coupled with 48 plants (*i.e.*, 4.9 shrimps per plant). The control hydroponic DFT systems were stocked in the same plant density as the aquaponic treatments. Once the plants reached a height of 35 cm, the first pruning was done; the cut was made at 15 cm from the stem base upwards to preserve the basal buds of the stems and promote the regrowth of the plants (Briseño-Ruiz *et al*., 2013), the remaining pruning was performed following the same criteria. The duration of the basil crop was 115 days, when the final pruning was done.

Evaluation of the production system

At the end of the shrimp culture, the individual mean weight was estimated by weighing a sample of 100 shrimp for each shrimp culture tank and dividing the weight by the number of shrimp weighed. The survival was calculated by the following equation (Esparza-Leal *et al*., 2010): Survival (%) = (number of shrimp harvested/number of shrimp stocked) × 100. The growth in grams per week was estimated according to Araneda *et al*. (2008): Growth (g $week^{-1}$) = (Wf - Wi)/t, where Wf is the mean final weight of the shrimp at the time of harvest, Wi is the mean initial weight, and t is the duration of culture expressed in weeks. The specific growth rate (SGR) was calculated as follows: SGR (% d^{-1}) = (ln(Wf) - ln(Wi)) × 100/t, where t is the duration of culture expressed in days. The yield in kilograms per square meter (kg m^{-2}) of shrimp harvested was calculated and then extrapolated to tons per hectare (ton ha^{-1}). For the basil crop, the fresh weight was determined using a Shimadzu TX223L top-loading analytical balance (Shimadzu Scientific Instruments, Columbia, USA), and the yield expressed in kilograms per square meter (kg m^{-2}) was estimated for each treatment. Feed consumptions were estimated according to Love *et al*. (2015). The amount of feed supplied to the tanks during the shrimp culture was recorded and summed to estimate the feed consumption per kg of each crop harvested.

Statistical analysis

The data obtained were subjected to normality and homogeneity of variance tests. For the data of shrimp farming and feed consumption, Student's t-test was used. For the data of basil production, one-way ANOVA and Tukey's *a posteriori* test were used. The software employed was Statistica 7 (Statsoft Inc., Tulsa, USA). All tests were analyzed with a confidence interval of 95% (Zar, 2010).

RESULTS

Characterization of the water sources

The ionic composition of the two types of water used in this study is summarized in Table 2. Groundwater (GW) showed higher concentrations of Mg^{+2} and Ca^{+2} than diluted seawater, and the opposite results for Cl^-, K^+, and Na^+. The pH values were similar in both waters (8.4 ± 0.1 and 8.6 ± 0.2 for GW and Diluted seawater (DSW), respectively), and the Mg/Ca ratio were 2.9 and 3.4 for GW and DSW treatments, respectively.

Production of shrimp culture and basil crop

The data obtained are summarized in Table 3. With the exception of shrimp yield (kg m^{-2} and ton ha^{-1}) with a higher production for GW than Diluted seawater (DSW), respectively), no significant differences were found in the remaining variables evaluated for the shrimp culture.

The two types of low-salinity water, DSW, and GW, did not differ significantly in terms of most of the variables examined. The production data recorded for the basil crop are presented in Table 4. No significant differences in the yield were found ($P > 0.05$) between GW treatment and the control, whereas DSW basil was significantly ($P < 0.05$) lower yield than the control and the basil that grew with groundwater (GW).

No significant difference ($P > 0.05$) were found in the feed consumption of shrimp culture, otherwise to feed consumption in basil crop where significant difference ($P < 0.05$) were found (0.11 ± 0.01 and 0.12 ± 0.01 kg of feed per kilogram of basil harvested for GW and DSW, respectively).

Table 2. pH and major components (mg L^{-1}) of the groundwater and the diluted seawater used to fill the tanks for the integrated culture shrimp-basil. The units EC are dS m^{-1} and pH is dimensionless.

Variable	Groundwater	Diluted seawater
pH	8.4 ± 0.1	8.6 ± 0.2
Cl^-	706 ± 128	986
Mg^{+2}	179 ± 22	70
K^+	16.7 ± 1.4	19.1
Ca^{+2}	61.4 ± 13.1	20.8
Na^+	252 ± 18	545
Alkalinity as $CaCO_3$	171 ± 13	-
EC	2.6 ± 0.2	2.7 ± 0.2
Ratios		
Na/K	15.1	28.5
Ca/K	3.7	1.1
Mg/Ca	2.9	3.4

Table 3. Mean production data for shrimp farming using two sources of low-salinity water (1.7 g L^{-1}) in aquaponic culture with basil. Mean with different letters between the lines are significantly different ($P < 0.05$) between sources of water.

	Groundwater	Diluted seawater
Initial weight (g)	0.69 ± 0.09	0.69 ± 0.10
Final weight(g)	9.05 ± 1.71^a	8.69 ± 1.51^a
Survival (%)	89.53 ± 1.90^a	85.20 ± 3.60^a
Growth (g $week^{-1}$)	1.17 ± 0.06^a	1.13 ± 0.06^a
Specific growth rate (% d^{-1})	5.02 ± 0.15^a	4.97 ± 0.11^a
Yield (kg m^{-2})	0.63 ± 0.01^a	0.53 ± 0.02^b
Yield (ton ha^{-1})	6.24 ± 0.29^a	5.29 ± 0.26^b

Table 4. Mean production data for basil crop integrated with two types of low-salinity water (1.7 g L^{-1}) in aquaponic culture with shrimp. Means with different letters between the lines are significantly different ($P < 0.05$) between sources of water.

	Groundwater	Diluted seawater	Nutritve hydroponic solution
Production per plant (kg $plant^{-1}$)	0.53 ± 0.04^a	0.42 ± 0.02^b	0.58 ± 0.02^a
Yield (kg m^{-2})	8.49 ± 0.61^a	6.73 ± 0.28^b	9.22 ± 0.42^a

DISCUSSION

The yields obtained in our study are promising and demonstrate the feasibility of this integrated culture system of shrimp-basil using low-salinity water of 2.7 dS m^{-1} of electrical conductivity. The basil crop can be considered as an added value to the shrimp harvested, where the effluent is reused and thereby achieves two advantages: i) the nutrients in the shrimp culture effluent are assimilated and converted into plant biomass, and ii) the discharge of the shrimp culture effluent to natural ecosystem receptors is avoided, thereby preventing the harmful impacts associated with the addition of nutrients, such as the deterioration of water quality and eutrophication. In addition, this secondary crop could help to improve the crop profitability due to the extra income from the sale of basil. Basil plants are economically important at local, national, and worldwide levels (Reyes-Pérez *et al.*, 2013). Furthermore, it has a wide range of biological activities including antioxidant properties (Lee *et al.*, 2005).

The electrical conductivity (EC) of used GW was 2.7 dS m^{-1}, whereas dilution of seawater (34.0 g L^{-1}) and freshwater (0.2 g L^{-1}) allows reaching the same EC reading as GW for DSW treatments. This EC was selected because for the shrimp *P. vannamei*, it is equivalent to a salinity of 1.7 g L^{-1}, which is reasonable and within of the acceptable range for shrimp culture of 0.5 to 40 g L^{-1} (Van Wyk, 1999). On another hand, such EC value is below the maximum tolerance of basil, which is 4.0 dS m^{-1} (Reyes-Pérez *et al.*, 2013). The alkalinity (as $CaCO_3$) measured in GW exceeds the minimum concentration required (75 mg L^{-1}) for the good development of *P. vannamei* in low-salinity water

(Roy *et al*., 2010). The high concentration of Ca^{+2} and the low concentration of Cl^- are characteristic of most groundwater around the world (Boyd & Thunjai, 2003; Roy *et al*., 2010; Mariscal-Lagarda *et al*., 2012). DSW obviously shows the ionic proportions of typical seawater; in contrast, the GW was an ionic ratio different to seawater, particularly for Ca/K and Na/K; Cl^- and Na^+ were in deficiency, and Mg^{+2} and Ca^{+2} in excess in comparison to seawater (Table 2). For the temperature (30.5 ± 1.9; 27.0-33.2ºC) and dissolved oxygen (6.1 ± 1.7; 4.2-8.1 mg L^{-1}) of the waters registered during the culture of both shrimp and basil, the means were within the acceptable range for typical shrimp monoculture (Van Wyk, 1999) and the recommended environment for basil culture (Briseño-Ruiz *et al*., 2013).

The yields of shrimp culture obtained with both treatments (6.24 ton ha^{-1} for GW and 5.29 ton ha^{-1} for DSW) are comparable to those recorded for shrimp monoculture using fresh and low-salinity water. Samocha *et al*. (1998) estimated a yield of 5.2 ton ha^{-1} with a mean weight of 19 g and a survival rate of 98% during a 77-day culture cycle using diluted seawater at 2 g L^{-1}. Mariscal-Lagarda *et al*. (2010) found a yield of 1.3 ton ha^{-1} with a final mean weight of 15.6 g and survival of 61.5%, employing groundwater at 1.7 g L^{-1} from the coast of Hermosillo, Sonora, Mexico, while Araneda *et al*. (2008) obtained a yield of 7.8 ton ha^{-1} with organisms of 11.4 g mean weight and a 76.1% survival rate using water from a cenote (spring water associated to carbonated deposits) at 0.6 g L^{-1} in Yucatan, Mexico.

Effluents of shrimp farming have been tested in the irrigation of some plants, such as rice in Thailand (Flaherty *et al*., 2000), olive trees in the United States (McIntosh & Fitszimmons, 2003) and melon and forage in Brazil (Miranda *et al*., 2008); thus, the potential of shrimp farming effluent for use in agricultural irrigation has been demonstrated. In these three cases, the crops were sown directly in soil, which did not allow better management of water and shrimp production, and data were not presented. In contrast, Mariscal-Lagarda *et al*. (2012) recorded a yield of 3.9 ton ha^{-1} of shrimp with a stocking density of 50 PL m^{-2} using low-salinity groundwater (0.9 g L^{-1}) in an integrated culture of shrimp (*P. vannamei*) and tomato (*L. esculentum* Mill) in an intermittent recirculation system. Such yield is less than that estimated in this study, mostly due to the lower density culture employed and lower survival obtained (56.3%). Fierro-Sañudo (2013) calculated yields of 3.8 and 6.2 ton ha^{-1} testing diluted seawater at 1.2 and 1.9 g L^{-1}, respectively, with the same stocking density used in the present work (75 PL m^{-2}) in an integrated culture of shrimp (*P. vannamei*) and two types of tomato (*L. esculentum*) and two types of lettuce (*L. sativa*). Note that the results obtained are also comparable to the yields (0.8-4.5 ton ha^{-1}) and feed conversion ratio (0.7 to 2.0) regularly obtained in commercial shrimp monoculture production in northwestern Mexico using saline water (including both, hypersaline and brackish water) (Ruiz-Fernandez & Páez-Osuna, 2004; Lyle-Fritch *et al*., 2006; Miranda-Baeza *et al*., 2007).

Additionally, according to Briseño-Ruiz *et al*. (2013), the yields registered in basil monocultures in soil range between 1.8 and 2 kg m^{-2}, which are lower than that found in this study. Ramírez *et al*. (2008) indicated that during a crop cycle of basil in aquaponics, it is possible to obtain up to four cuts over five weeks, with variable quality and yielded quantities, for crops whose magnitude depends on the irrigation frequency and the nutrient absorption by the basil plants. Rakocy *et al*. (2004) calculated a yield of 8 kg m^{-2} of fresh basil in an aquaponic culture with tilapia (*O. niloticus*), which is slightly lower than those found in the GW treatment of our study, although the yield reported by Rakocy *et al*. (2004) was achieved in a shorter period of time (28 days). Meanwhile, Roosta (2014) recorded basil yields of 1.4, 4.9, and 5.9 kg m^{-2} in an aquaponic system with three varieties of carp and a culture period of 42 days.

The feed needed to produce one kilogram of harvested shrimp and vegetables can be taken as an indicator of the efficiency of the system itself. The feed required to produce one kilogram of shrimp in the present work were 1.41 ± 0.01 and 1.49 ± 0.06 kg of feed kg^{-1} of shrimp harvested in GW and DSW, respectively. Green (2008) estimated feed consumptions of 1.2, 1.9 and 3.0 kg of feed kg^{-1} of shrimp harvested for shrimp monoculture of *P. vannamei* using fresh water of 0.7 g L^{-1} in 65, 55 and 112 days of culture. Mariscal-Lagarda *et al*. (2012) calculated a feed consumption of 1.6 kg of feed kg^{-1} of shrimp harvested in an integrated culture of *P. vannamei* with tomato (*L. esculentum* Mill); while Fierro-Sañudo (2013) obtained a feed consumptions of 1.6 and 2.3 kg of feed kg^{-1} of shrimp harvested in an integrated culture of *P. vannamei* with tomato (*L. esculentum* Mill) and lettuce (*L. sativa*) using diluted seawater at 1.9 and 1.2 g L^{-1}, respectively.

The commercial feed consumption calculated in this study to produce one kilogram of fresh basil (0.11 ± 0.01 and 0.12 ± 0.01 kg feed kg^{-1} of basil harvested in GW and DSW, respectively) is lower than that found by Love *et al*. (2015) of 0.4 and 0.5 kg of feed kg^{-1} for different crops. These last authors do not detail the crops harvested, which may be because the major crops that produce fruit (tomato, cucumber, pepper, etc.)

require more nutrients than smaller plants that produce only leaves (lettuce, basil, mint, etc.) (Samperio-Ruiz, 2000), such as is in the present study where only basil was cultures.

CONCLUSIONS

From this study, it is evident that the culture of shrimp-basil using low-salinity groundwater (GW) and diluted seawater is feasible. Overall, the GW treatment showed the best development in terms of yield of shrimp and basil as well as feed consumption. The estimated yields, as well as the water and feed consumption of both crops, were comparable to those registered in both shrimp monoculture and integrated shrimp-tomato and integrated shrimp-tomato-lettuce cultures (Fierro-Sañudo, 2013) as well as those that involve basil crops in the field. These results demonstrate the efficiency of the proposed aquaponic system for shrimp-basil in low-salinity waters of 2.7 dS m^{-1}.

For the near future, the main research question in this shrimp-basil co-culture has to be focused on the finding of a better balance between the number of shrimp and the plants to grow so that the most nutrients would be produced by the shrimp culture and the discharge would be minimized as an output from the aquaponic farming. Another challenge is to extrapolate our findings at a commercial scale and demonstrate both its technical and economic viability.

ACKNOWLEDGEMENTS

The authors thanks the support from Proveedora de Larvas S.A. de C.V. (FITMAR) to facilitate the larvae used in the experiment. To H. Bojórquez-Leyva, J. Ramírez-Rochin, G. Valencia-Castañeda, M. Fregoso-López, for your help in the chemical analysis, field work and during the harvest.

REFERENCES

American Public Health Association (APHA). 2012. Standard methods for the examination of water and wastewater, Port City Press, Baltimore. [http://www.mwa.co.th/download/file_upload/SMWW_1000-3000.pdf].

Araneda, M., E. Pérez & E. Gasca-Leyva. 2008. White shrimp *Penaeus vannamei* culture in fresh water at three densities: condition state based on length and weight. Aquaculture, 283: 13-18.

Boyd, C.E. 2002. Standardize terminology for low-salinity shrimp culture. Glob. Aquacult. Advocate, 7(1): 58-59.

Boyd, C.E. & T. Thunjai. 2003. Concentrations of major ions in waters of inland shrimp farms in China, Ecuador, Thailand, and the United States. J. World Aquacult. Soc., 34: 524-532.

Boyd, C.E., T. Thunjai & M. Boonyaratpalin. 2002. Dissolved salts in waters for inland, low-salinity shrimp culture. Glob. Aquacult. Advocate, 5: 40-45.

Briseño-Ruiz, S.E., M. Aguilar-García & J.A. Villegas-Espinoza. 2013. El cultivo de la albahaca. Centro de Investigaciones Biológicas del Noroeste, S.C., La Paz, Baja California Sur, México, 34 pp.

Cook, H.L. & H.C. Clifford. 1997. Feed management for semi-intensive shrimp culture. Part 1. Inicial feeding. Aquacult. Mag., 23: 36-43.

Esparza-Leal, H.M., J.T. Ponce-Palafox, W. Valenzuela-Quiñonez, J.L. Arredondo-Figueroa & M. Garcia-Ulloa. 2010. Effects of density on growth and survival of juvenile Pacific white shrimp, *Penaeus vannamei*, reared in low-salinity well water. J. World Aquacult. Soc., 41(4): 648-654.

Fernando, C.H. & M. Halwart. 2000. Possibilities for integration of fish farming into irrigation systems. Fish. Manage. Ecol., 7: 45-54.

Fierro-Sañudo, J.F. 2013. Cultivo integral de camarón blanco (*Litopenaeus vannamei*)-tomate (*Lycopersicon esculentum*)-lechuga (*Lactuca sativa*) con agua de baja salinidad y cero recambio: factibilidad técnica-económica y valuación ambiental. Tesis de Maestría. ICMYL-Universidad Autónoma de México, México D.F., 86 pp.

Flaherty, M., B.W. Szuster & P. Miller. 2000. Low salinity shrimp farming in Thailand. Ambio, 29: 174-179.

Green, B.W. 2008. Stocking strategies for production of *Litopenaeus vannamei* (Boone) in amended fresh water in inland ponds. Aquacult. Res., 39: 10-17.

Hanson, A., J. Yabes Jr. & L.P. Primavera. 2008. Cultivation of lemon basil, *Ocimum americanum*, in two different hydroponic configurations supplemented with various concentrations of tilapia aquaculture green water. Bios, 79(3): 92-102.

Ingram, B.A., G.J. Gooley, L.J. McKinnon & S.S. De Silva. 2000. Aquaculture-agriculture systems integration: an Australian prospective. Fish. Manage. Ecol., 7: 33-43.

Lee, S.J., K. Umano, T. Shibamoto & K.G. Lee. 2005. Identification of volatile components in basil (*Ocimum basilicum* L.) and thyme leaves (*Thymus vulgaris* L.) and their antioxidant properties. Food Chem., 91: 131-137.

Limsuwan, C., T. Somsiri & S. Silarudee. 2002. The appropriate salinity level of brine water for raising black tiger prawn under low-salinity conditions. Aquatic Animal Health Research Institute Newsletter, Department of Fisheries, Bangkok, 11: 2-4.

Love, D.C., M.S. Uhl & L. Genello. 2015. Energy and water use of a small-scale raft aquaponic system in Baltimore, Maryland. US Aquacult. Eng., 68: 19-27.

Lyle-Fritch, M.L., E. Romero-Beltrán & F. Páez-Osuna. 2006. A survey on the use of chemical and biological products in shrimp farming from Sinaloa (NW Mexico). Aquacult. Eng., 35: 135-146.

Mariscal-Lagarda, M.M. & F. Páez-Osuna. 2014. Mass balances of nitrogen and phosphorus an integrated culture of shrimp (*Litopenaeus vannamei*) and tomato (*Lycopersicon esculentum* Mill) with low salinity water: a short communication. Aquacult. Eng., 58: 107-112.

Mariscal-Lagarda, M.M., J.L. Esquer-Méndez & F. Páez-Osuna. 2010. Shrimp study uses low-salinity ground-water in Sonora, Mexico. Glob. Aquacult. Advocate, 13(E3): 42-43.

Mariscal-Lagarda, M.M., F. Páez-Osuna, J.L. Esquer-Mendez, I. Guerrero-Monroy, A. Romo del Vivar & R. Felix-Gastelum. 2012. Integrated culture of white shrimp (*Litopenaeus vannamei*) and tomato (*Lycopersicon esculentum* Mill) with low salinity groundwater: management and production. Aquaculture, 336/367: 76-84.

Mariscal-Lagarda, M.M., F. Páez-Osuna, J.L. Esquer-Méndez, I. Guerrero-Monroy, A. Romo del Vivar, K.Y. Brito-Solano, D.N. López-Pérez & R. Alonso-Rodriguez. 2014. Water quality in an integrated cultura of white shrimp (*Litopenaeus vannamei*)-tomato (*Lycopersicon esculentum*) using low salinity groundwater in Sonora, Mexico. Exper. Agric., 50(2): 306-319.

Marulanda-Tabares, C.H. 1999. Cultivos sin tierra: hidroponía familiar. Guía técnica. Proyecto Nacional de Hidroponía, MAG-PNUD, San Salvador, 169 pp.

McGraw, W.J. & J. Scarpa. 2004. Mortality of freshwater acclimated *Litopenaeus vannamei* associated with acclimation rate, habituation period, and ionic challenge. Aquaculture, 236: 285-296.

McIntosh, R.P. & K. Fitzsimmons. 2003. Characterization of effluent from an inland, low salinity shrimp farm: what contribution could this water make if used for irrigation. Aquacult. Eng., 27: 147-156.

McNevin, A.A., C.E. Boyd, O. Silapajarn & K. Silapajarn. 2004. Ionic supplementation of pond waters for inland culture of marine shrimp. J. World Aquacult. Soc., 35: 460-467.

Miranda-Baeza, A., D. Voltolina, M.A. Brambilla-Gámez, M.G. Frías-Espericueta & J. Simental. 2007. Effluent characteristics and nutrient loading of a semi-intensive shrimp farm in NW Mexico. Vie Milieu, 57(1-2): 21-27.

Miranda, F.R., R.N. Lima, L.A. Crisóstomo & M.G.S. Santana. 2008. Reuse of inland low-salinity shrimp farm effluent for melon irrigation. Aquacult. Eng., 39: 1-5.

Rakocy, J.E., D.S. Bailey, R.C. Shultz & E.S. Thoman. 2004. Update on tilapia and vegetable production in the UVI aquaponic system. New dimensions on farmed tilapia. Proceedings of the Sixth International Symposium on Tilapia in Aquaculture, September, 12-16. Available at [https://cals.arizona.edu/azaqua/ista/ista6/ista6web/pdf /676.pdf].

Ramírez, C.J., B. Moreno & E. Murillo. 2001. Evaluación agronómica e industrial de siete variedades de albahaca en la zona cafetalera colombiana. Cenicafé, 52: 117-126.

Ramírez, D., D. Sabogal, P. Jiménez & H.G. Hurtado. 2008. La acuaponia: una alternativa orientada al desarrollo sostenible. Rev. Fac. Cienc. Bás., 4: 32-51.

Reyes-Pérez, J.J., B. Murillo-Amador, A. Nieto-Garibay, E. Troyo-Diéguez, M. Reynaldo-Escobar, E.O. Rueda-Puente & J.L. García-Hernández. 2013. Tolerancia a la salinidad en variedades de albahaca (*Ocimum basilicum*) en las etapas de germinación, emergencia y crecimiento inicial. Univ. Cienc., 29: 101-112.

Ronzón-Ortega, M., M.P. Hernández-Vergara & I. Pérez-Rostro. 2012. Producción hidropónica y acuapónica de albahaca (*Ocimum basilicum*) y langostino malayo (*Macrobrachium rosenbergii*). Trop. Subtrop. Agroecosys., 15: S63-S71.

Roosta, H.R. 2014. Comparison of the vegetative growth, eco-physiological characteristics and mineral nutrient content of basil plants in different irrigation ratios of hydroponic: aquaponic solution. J. Plant Nutr., 37(11): 1782-1803.

Roy , L.A., D.A. Davis, I.P. Saoud, C.A. Boyd, H.J. Pine & C.E. Boyd. 2010. Shrimp culture in inland low salinity waters. Rev. Aquacult., 2: 191-208.

Ruiz-Fernandez, A.C. & F. Páez-Osuna. 2004. Comparative survey of the influent and effluent water quality of shrimp ponds on Mexican farms. Water Environ. Res., 76: 5-14.

Samocha, T.M., A.L. Lawrence & D. Pooser. 1998. Growth and survival of juvenile *Penaeus vannamei* in low salinity water in a semi-closed recirculating system. Isr. J. Aquacult., 50: 55-59.

Samperio-Ruiz, G. 2000. Hidroponia comercial. Editorial Diana, México D.F., 172 pp.

Saoud, I.P., D.A. Davis & D.B. Rouse. 2003. Suitability studies of inland well waters for *Litopenaeus vannamei* culture. Aquaculture, 217: 373-383.

Van Wyk, P.M. 1999. Principles of recirculating system design. In: Production of marine shrim in freshwater recirculating aquaculture systems. Florida Department of Agriculture and Consumer Services, Tallahasse, Florida, pp. 59-98.

Zar, J.H. 2010. Biostatistical analysis. Prentice-Hall, New Jersey, 944 pp.

Received: 27 February 2017; Accepted: 30 June 2017