Project Number:	**1830-352-0501-I**
Project Title:	**Automated Feeding Systems for Improved Shrimp Production**
Organization:	Auburn University, School of Fisheries, Aquaculture and Aquatic Sciences
Principal Investigator Name:	D. Allen Davis
Project Status - Completed	
See next pages…	

Did this project meet the intended Key Performance Indicators (KPIs)? List each KPI and describe progress made (or not made) toward addressing it, including metrics where appropriate.

Long Range Strategic Plan Objective: Increased Meal use

Target Area: Domestic and International Opportunities

Strategy Focus: Support research related activities that will enhance marketing efforts to increase value and volume of soy products in shrimp feeds in a sustainable manner.

Expected Outputs/Deliverables - List each deliverable identified in the project, indicate whether or not it was supplied and if not supplied, please provide an explanation as to why.

The primary outcomes of this research include 1) increased knowledge and demonstration of the efficacy of automated timed feeding systems, 2) increased knowledge and demonstration of automated feedback feeding systems based on acoustic feedback (AQ1 acoustic on demand feeder), and 3) demonstration of high soy feed formulations under optimized growing conditions. Results have been directly transferred to the industry thought industry training (USSEC supported technical support as well as industry supported presentations), presentations at scientific meetings as well as publications through a range of outlets (e.g., newsletters, trade journals and peer reviewed journals). Results have been presented in conjunction with USSEC technology support in Mexico, Ecuador and Peru. Results have been presented at technical meeting in the US including a training program sponsored by Skretting Ecuador and 37th Fish Feed and Nutrition Workshop. Additionally, one of my students was able to attend and present at the European Aquaculture Meeting.

Presentations

"Improving Automatic Feeding Protocols in Semi-Intensive Pond Culture of Pacific White Shrimp (*Litopenaeus vannamei*)" João Reis, Melanie Rhodes, and D. Allen Davis. Aquaculture Europe 2019, Berlin, Germany. October 7-10, 2019.

"Acoustics and Feed Management" Silvio Peixoto and Melanie Rhodes. 37th Fish Feed and Nutrition Workshop, September 18-20, 2019. Auburn, AL.

"Improving Feed Management by Utilizing Automatic Feeding Systems in the Pond Production of Shrimp, *Litopenaeus vannamei.* Melanie A. Rhodes and D. A. Davis. Ecuadorian Aquaculture Congress (XX CEA). September 9-12, 2019. Guayaquil Ecuador.

"Sustainable feeds and improved feed management for the continued success of aquaculture". CIAB. May 8-9, 2019. San Juan Costa Rica.

"Optimizing feed automation: improving timer-feeders and on demand systems in semi-intensive pond culture of pacific white shrimp (*Litopenaeus vannamei*)". Reis, J., R. Novriadi, A. Swanepoel, M. Rhodes and D. A. Davis. Aquaculture America 2019, New Orleans, LA. March 7-11, 2019

"Use of soy and corn protein concentrate as replacement for fishmeal in practical diets for the pacific white shrimp *Litopenaeus vannamei".* Guo, J., Y. Huang, H.G. Arachchige and D. A. Davis. Aquaculture America 2019, New Orleans, LA. March 7-11, 2019.

*"Sustainable Feeds and Improved Feed Management for the Continued Success of the Shrimp Industry". Aquacultura de Camaron. January 24-25, 2019. Machala, Mexico.

Popular article

Reis, J.T., Swanepoel, A., Novriadi, R., Rhodes, M., Davis, D.A., 2019. Testing soy-optimized feeds and automated feeding systems in shrimp pond production, Global Aquaculture Advocate. https://www.aquaculturealliance.org/advocate/testing-soy-optimized-feeds-automated-feeding-systems-shrimp-pond-production/

Describe any unforeseen events or circumstances that may have affected project timeline, costs, or deliverables (if applicable.)

The primary issue relative to costs is that my Research Associate took an excellent position with a commercial company. Given the hiring process of the University we were unable to replace him so the work was picked up by me and others resulting in a shuffling of personnel.

What, if any, follow-up steps are required to capture benefits for all US soybean farmers? Describe in a few sentences how the results of this project will be or should be used.
We are and will continue to use this data in training and industry presentations. The data fits very well into USEC international presentations for industry training and promotion. We will continue working on publications and releases to trade journals. If there are any USB outlets that you would like a popular article for, we are happy to help.
List any relevant performance metrics not captured in KPI's.

Background: The shrimp aquaculture industry has continued to expand and intensify production making this sector the third largest consumer of feeds in aquaculture. The Pacific white legged shrimp is the dominant culture species, which is extremely accommodating in terms of acceptance of plant base feed formulations. Hence, our continued efforts to refine and improve soy base feeds. This species is an exceptional opportunity to expand the use of sustainable plant-based feed formulations through improved nutrition. However, equally as important is feed management and we have found that improved feed management is the key to expanding the demand for feed. Hence, we have also spent considerable efforts refining and developing new technologies.

Shrimp have developed as "grazers" in that they have evolved to consume small quantities of food frequently. One option would be to use a water stable feed, but this has proven ineffective primarily due to leaching of nutrients. The other option is to provide more frequent small feedings. It is well documented that shrimp have shown increased performance with multiple feedings spread throughout the day. However, the labor required to increase the feedings can be prohibitive in most operations. Utilizing automatic feeding systems can allow farmers to spread out the feeding without increasing the labor required to do so. Based on previous work, we have demonstrated the shifting to automated feeding systems results in faster growth and consequently the need to feed more feed. This can be further enhanced by adding acoustic monitors which allow feeding activity to be monitored to provide real time adjustment of feed input based on demand. This means improved feed application during times of active and inactive feeding.

Over the previous years we have transitioned from two feedings per day running a 120-day production cycle to the use of automated feeding systems running a 90-day production cycle. Despite reducing the production cycle by 30 days we are production a larger biomass and shrimp of larger size resulting in improved economic efficiencies. In short, we have reduced the day to market and increased production by 50% which also means a 50% increase in feed demand. During the 2018 production cycle we geared the work towards increasing pond productivity for timer feeder treatment through increased feed inputs and number of meals. Results for this experiment suggested that although higher feed inputs and meals result in higher growth rate, there seems to be a growth limit for different stages of the production cycle regardless of the feed inputs. Hence, we were able to confirm that there are upper limits to feed inputs for which the shrimp did not increase their growth rates. We now have a standardize protocol that we can recommend for timer feeders. Albeit timer feeders feeding protocols have been improved and standardized, on-demand acoustic feeding system still provided the best performing strategy.

This year's production: Building on previous research, the goal of this work was to continue the development of feed management recommendations for standard feeding protocol for automatic feeding systems (SPAF) and demonstrate the applicability of soy-optimized feed formulations (Table 1). Feeds were commercially produced by Zeigler Feeds Inc providing an industry link to demonstrate the efficacy of commercial feed manufacturing. Protocols were designed to maximize growth rates in semi-intensive pond production of Pacific White Shrimp, *Litopenaeus vannamei*. This year's pond work concentrated on looking at the time of feed application which is one of the commonest questions that I am asked for which there is very limited data.

Table 1. Feed formulations for trials.

Ingredient	%
Soybean meal	**50.00**
Poultry by-product meal	8.00
Corn Gluten meal	8.00
Wheat	23.10
Dicalcium phosphate	3.13
Fish Oil Top dress	3.00
Fish Oil Mixer	2.00
Bentonite	1.50
Lecithin	1.00
Vitamin premix	0.12
Mineral premix	0.12
Tiger C	0.02
Copper sulfate	0.01
Protein	37.22
Lipid	7.01
Fiber	2.56
Moisture	10.18
Ash	8.55
Phosphorus	1.20

Pond Production

Each pond was stocked at a density of 35 shrimp/m^2 and we targeted a standard 90-day (13 week) production trial in 16, 0.1 ha outdoors ponds, and fed a 35% protein soy-optimized feed. Four treatments including: three SPAF treatments for which feed was offered during the day, night or over 24 hr (SFAF-Day, SPAF-Night, SPAF-24, respectively) were offered using automatic timer-feeders (Biofeeder, Guayaquil Ecuador) delivering 36 feedings per day, with gradual increasing of feed amounts of the standard feeding protocol (SFP) as suggested for last year's data. The SFP was calculated an expected weight gain of 1.3 g/wk, a feed conversion ratio (FCR) of 1.2 and a mortality rate of 1.5%/wk. All ponds with timer feeders were offered 130% of the SFP (SFP130) from day 1 through 45, SFP145 from 45 through 60 and SFP160 from 60 until harvest with exception for SPAF- 24 which was further increased to SFP175 from day 75 until harvest

A fourth treatment utilized on-demand AQ1 acoustic feeding system (AQ1, Tasmania, Australia) which offered feed on demand.

Outdoor tank trials

Building on previous research that showed improvement in production when increasing from 2 to 6 feedings/day, this outdoor tank trial aimed to test shrimp productivity under different feeding schedules and rations. Thus, validating pond data and providing additional treatment to allow further refinement of feed management. Toward this goal, an 11-week growth trial was performed in 32, 750 L tanks in green water recirculation system housed in a greenhouse. The shrimp were stocked at 30 shrimp/tank (35 ind/m^2), fed a 35% protein soy-optimized feed. Water in tank systems was obtained from a semi-intensive shrimp production pond. All tanks were hand-fed the same feed ration four meals a day for the first 3 weeks after which a set of 8 treatments was designed to compare growth performance at different feeding schedules and feed levels. Five treatment were fed during the day from 7am-7pm with different number of feedings per day. One treatment was fed at night from 7pm-7am and two treatments fed the daily ration over 24 hours. Standard ration (SR) was calculated assuming a doubling of weight weekly until reaching 1.3g then calculated on an expected weight gain of 1.3 g/wk, a feed conversion ratio (FCR) of 1.2. Feed inputs mirrored those used in the ponds with shrimp initially being the SR which was then increased to 130% SR for weeks 4-5, 145% SR weeks 6-7 then 160% for weeks 8-11. One treatment (SR 175 24h) gradually reaching 175% at week 7 and the SR175 Day only 175% during the last two weeks. All treatments were fed using belt feeders using lines of feed, except 4 meals per day treatments which were hand-fed.

Statistics

Data presented are the means of 4 replicated systems. One-way ANOVA and Student-Newman-Keuls test were used to distinguish significant differences within and between means.

Results

Production data is summarized in Table 2. Analysis of the results indicate that AQ1 System resulted in statistically higher feed inputs which resulted in higher yields. However on-demand feeding system did not result in larger shrimp nor higher weekly weight gain that shrimp fed SR 160 during Daytime. Survival ranged between 69.2 and 77.0% and FCR between 0.99 and 1.03, no statistical differences were found among these parameters.

Table 2. Production results for *Litopenaeus vannamei* cultured in 0.1 ha ponds stocked at 35 shrimp/m^2 over a 13-week culture period using varying feeding techniques including levels our Standard Feeding Protocol (SFP) of feed input using standard automatic feeders and varied schedules, 160% Daytime, 160% Nighttime and 175% 24 hours of and acoustic demand feeding using the AQ1 system.

Treatment (n=4)	Final Weight (g)	Survival (%)	Weight Gain (g/wk)	Yield (kg)	Feed Input (kg)	FCR
SPAF-Day	26.13[ab]	69.2	2.01[ab]	625.4[b]	641.7[b]	1.03
SPAF-Night	24.81[b]	69.6	1.91[b]	602.9[b]	613.6[b]	1.01
SPAF-24	24.56[b]	71.8	1.89[b]	615.9[b]	617.7[b]	0.99
AQ1 System[1]	29.65[a]	77.0	2.28[a]	800.6[a]	790.1[a]	0.99
P-value	0.0500	0.4123	0.0500	0.0057	<0.0001	0.8951
PSE[2]	1.120	3.205	0.0862	30.90	13.9822	0.0355

[1] n=3 due to electrical issue
[2]PSE – Pooled Standard Error

Feed costs and economic value of shrimp produced is summarized in Table 3. The AQ1 system resulted in significantly higher feed inputs and feed cost, however also resulted in significantly higher shrimp value and partial income.

Table 3. Economic information for the pond production trial.

Treatments (n=4)	Feed Input (kg/ha)	Feed Cost ($/ha)	Shrimp Value ($/ha)	Partial Income ($/ha)[3]	Electrical Use (kWh/ha)
SPAF-Day	6,416.7[b]	7,044.4[b]	52,134[b]	45,365[b]	21,060[bc]
SPAF-Night	6,135.8[b]	6,819.6[b]	48,640[b]	42,086[b]	26,730[a]
SPAF-24	6,177.1[b]	6,809.1[b]	49,928[b]	43,384[b]	24,678[ab]
AQ1 System[1]	7,901.0[a]	8,826.3[a]	68,978[a]	60,510[a]	18,320[c]
P-value	<0.0001	<0.0001	0.0051	0.0082	0.0025
PSE[2]	139.82	154.21	3096.6	2988.3	1155.8

[1] n=3 due to electrical issue
[2]PSE – Pooled Standard Error
[3] Calculated as Shrimp value minus feed cost

Results from the outdoor tank trials are presented in Table 4. Similar to the pond trial, there was no significant difference in FCR or survival in any of the treatments. There was significant improvement in growth with increasing the number of daily feeding. There was no significant improvement in the night feeding or the increased levels of feed compared to the daytime 8 and 12 feedings/day.

Table 4. Response of Pacific white shrimp to different feed management protocols in tanks

Treatments (n=4)	Mean Wt (g)	Survival (%)	Weight Gain (g/wk)	Final Biomass (g)	Feed Input (g)	FCR
4 Meals SPAF-Day	15.89[a]	92.53	1.43[a]	439.85[ab]	570.9[a]	1.32
6 Meals SPAF-Day	16.00[a]	78.87	1.44[a]	379.27[a]	570.9[a]	1.52
8 Meals SPAF-Day	16.88[ab]	86.68	1.52[ab]	438.75[ab]	570.9[a]	1.31
12 Meals SPAF-Day	16.82[ab]	86.65	1.52[ab]	437.85[ab]	570.9[a]	1.32
6 Meals SPAF-Night	15.92[a]	86.65	1.44[a]	414.20[ab]	570.9[a]	1.40
12 Meals SPAF-24hr	16.81[ab]	86.68	1.52[ab]	436.55[ab]	570.9[a]	1.33
12 Meals SPAF-175 24h	18.41[b]	88.35	1.67[a]	485.83[b]	627.1[c]	1.33
6 Meals SPAF-175 Day	16.76[ab]	87.53	1.51[ab]	439.90[ab]	585.0[b]	1.34
P-value	0.049	0.200	0.044	0.042	<0.0001	0.256
PSE[1]	0.366	1.951	0.033	12.296	0	0.04

[1]PSE: Pooled Standard Error

Discussion

We have clearly identified advantages to automated feeding systems which have reduced the time to market through improved growth rates. This translates to more shrimp produced per unit area which corresponds to an increase feed demand. By using a commercially manufactured soy-optimized feed formulation produced by a commercial mill also helps demonstrate the commercial viability of these feeds. The primary messages from this year's production data would be that we have established a standard protocol for automatic feeders (SPAF) for future cycles which was based on 2018 data and validated the protocol this year. The identification of there being no advantage to feeding 24 hours or at night. As there are numerous technical issues with feeding at night, daytime feeding is still recommended. It is interesting to note that the nighttime feeding, had the highest electrical consumption which would make sense as the feed is one of the primary drivers of oxygen demand. Hence, feeding only at night may have increased the need for nighttime aeration.

We also evaluated the same number of feedings but spread out over 24 hrs a day. The move to feeding 24 hrs a day did not result in improved growth or feed conversion. As 24 hr feeding is likely to be accomplished through automation, there would be no added cost to feed 24 hrs a day. Based on our results feeding 24 hrs a day is not warranted. However, as this is not likely to increase costs there is also no data that clearly indicates there would be a disadvantage.

Of the timer feeding treatments, final weights, weekly growth rates and feed inputs were best for shrimp fed the SFAP applied during the day. Despite, considerable improvement in SFAP for timer feeders, this is still an educated guess or a post responsive measure of feed intake. Shrimp maintained on the AQ1 passive acoustic system still had the best production and economic returns as measured by partial income.

Results from the outdoor tank trials, validated previous reports that increasing the number of feeding increased growth rates. The tank trials also validated there was no added benefits to feeding at night or the use of increased levels of feed. All in all the tank based data confirmed and validated the pond based trials.

Conclusion

The results over four years of testing clearly demonstrated that increasing daily feedings through the use of automated feeding systems can significantly increase the production and value of *L. vannamei* produced in semi-intensive pond culture using a soy optimized feed formulations. Based on our experience real time feed management using acoustic feeders is the most efficient method of feed delivery. Irrespective of the technology, the increased production and/or reduced time to a given marketable size will offset the investment costs for equipment. It should be noted that the application of these technologies have the potential to reduce the time to market, increase production and requirements for feed inputs. Thus, as farmers adopt these technologies it will also drive the demand for feed.