

protocol (SFP) and slight variations ($\pm 10\%$ -20%) showed similar survival, FCR, and economic returns across treatments, indicating that well-calibrated manual tables can support satisfactory growth and profitability without high feed surpluses. At nursery scale in biofloc systems, reducing manual feeding frequency from six to one meal per day did not significantly affect final weight, survival, or FCR, suggesting that in early stages, growth performance can be maintained even with relatively simple manual schedules when water quality is stable (Wasielesky et al., 2020).

Nevertheless, comparative trials consistently show that manual feeding underperforms more intensive or automated strategies in terms of growth and yield. In intensive tanks, a manually fed control group at six meals per day achieved lower final body weight and poorer FCR than groups fed at similar frequencies with automatic feeders, underscoring the limitations of human-timed delivery in matching shrimp appetite patterns (Liang et al., 2025). Large-pond comparisons of manual hand feeding versus automatic timer and acoustic systems also showed the lowest average daily growth, final body weight, and yield under manual regimes, even though survival remained comparable, highlighting that manual feeding is robust but less efficient for maximizing production.

8.2 Production benefits of multiple small-meal feeding regimes

Case studies comparing low versus high feeding frequencies demonstrate clear production gains from multiple small meals. In recirculating systems, automatic feeding 6-12 times per day, with the same total ration as a manual six-meal control, significantly increased final body weight and specific growth rate, while improving FCR; regression analysis indicated an optimal automatic frequency around 7.8 meals per day (Liang et al., 2025). Similarly, post-larval trials showed that feeding six times daily yielded higher final weights than two or four meals, confirming that distributing the ration more finely better matches the shrimp's continuous feeding behavior.

Pond-scale work reinforces these findings by linking increased feeding frequency to higher growth and crop value. In a 16-week pond trial, moving from two daily feedings under an SFP to six feedings via timer feeders raised final individual weights and improved economic returns, even though overall FCR and survival remained similar (Ullman et al., 2019). Subsequent studies in semi-intensive ponds confirmed that higher numbers of meals allow greater total feed inputs and higher yields, with growth responses linked more strongly to the number of meals than to the specific day-night schedule, emphasizing that multiple small meals are a key lever for enhancing production efficiency.

8.3 Economic and environmental assessment of intelligent automatic feeding systems

Intelligent automatic systems—including timer feeders, acoustic demand feeders, and model-based “smart” feeders—offer both economic and environmental advantages over traditional methods. In pond case studies, acoustic demand systems (AQ1) produced the highest final weights, yields, and crop values compared with standard twice-daily SFP and timer-based protocols, while maintaining similar FCR and survival, thereby increasing revenue per hectare without extra feed cost per kilogram of shrimp. Another semi-intensive trial similarly found that on-demand AQ1 feeding yielded larger shrimp and higher production than several fixed over-SFP timer regimes, demonstrating that real-time feedback can outperform pre-set schedules in economic terms (Reis et al., 2020).

Environmental and labor-cost benefits arise from more precise control of ration size and timing. Water-quality monitoring in ponds fed by hand, timers, and AQ1 showed that the acoustic system achieved the greatest yield but also higher late-season ammonia and nitrite, indicating that automated strategies must be matched to system nutrient-processing capacity to avoid water-quality deterioration. In recirculating systems, intelligent feeders using machine-learning biomass prediction can calculate appropriate feed amounts from sensor data in real time, supporting stable water quality while reducing waste and labor, and IoT-linked solar feeders further cut long-term labor and energy costs, achieving large percentage reductions in annual and 10-year operating expenses compared with manual feeding (Boonraksa and Boonraksa, 2025).

9 Conclusions and Future Perspectives

Across culture systems, feeding strategies can be viewed along a spectrum from fixed schedules and ration tables to fully intelligent, sensor-driven control. Fixed-time, fixed-ration approaches remain the backbone of many farms