Aquaculture Fundamentals:

Getting the most out of your feed

Simon Wilkinson, NACA

Email simon.wilkinson@enaca.org

Feed generally represents the largest fixed cost in aquaculture systems with its importance increasing in relation to the intensity of production[1,2,3]. Feed also directly influences the capacity of the stock to realise their full growth potential. Improving the efficiency of feed utilisation in terms of reducing costs and increasing performance therefore represents a significant opportunity to increase the profit margin of the farm.

From a nutritional perspective the major elements of the culture system that influence productivity are the quality of the feed, the feeding strategies that are employed and the culture environment itself. These elements are considered below in the context of evaluating on-farm management practices to increase profit.

Records and sampling

Accurate records assist farmers to adjust feeding rates and to evaluate the results of different diets or feeding regimes[4]. Records also enable farmers to improve performance and the reliability, quality and predictability of yields. A systematic approach to the collection and analysis of feeding records is very important to maximising efficiency. Evaluation of the feeding and management practices on the farm should begin with an assessment of the monitoring and record keeping systems to determine if they are adequate to effectively manage the facility.

Evaluating the performance of feed

The efficiency of the feed should be evaluated in terms of its biological performance in promoting growth (or other culture objectives), and its economic performance in terms of feed cost per unit production.

Evaluating biological performance

The quality of feed is a function of how well it meets the nutritional requirements of the cultured animal[3]. This is in turn a function of the nutritional profile of the food and the bioavailability of the nutrients in the feed components[4]. Measurements of digestibility such as the digestible energy content or retained energy in carcass can be determined through laboratory studies[3]. However, practical on-farm assessments of diet quality are frequently made on the basis of the observed growth rates or on the observed conversion ratios of nutrients to end products. The main parameters assessed on-farm are included in Table 1.

FCR is a widely used parameter as it provides a convenient rule of thumb guide for general management purposes[6]. Indices of protein utilisation (PER and NPU) are also employed as the protein component is of greatest interest to the farmer in most instances. These parameters allow the performance of the feed to be assessed by comparing current production records with historical values for the farm, published data and with the results of other farms in the area.

However, conversion ratios are not precise measures of feed efficiency as they are affected by feeding practices and environmental factors and the availability of natural feeds[6]. With the exception of NPU they also do not give any indication of the relative conversion of energy, protein, fat and other nutrients. The interpretation of conversion ratios can be greatly assisted by simultaneous evaluation of carcass composition and quality[7].

Nutritional requirements also vary with the aims of culture. As a result, an evaluation of feed performance may need to take into account objectives other than growth such as increased larval suvivorship for larval feeds or increased fecundity in broodstock diets[8]. Manipulation of feed composition offers the potential to enhance the quality and market value of the end

Table 1: Main feed parameters assessed on-farm[5]

Parameter	Calculation
Growth	= Gain in body mass/unit time
Food conversion ratio (FCR)	= $\frac{\text{Mass of food consumed (dry)}}{\text{Increase in mass of animal produced (wet)}}$
Protein efficiency ratio (PER)	= $\frac{\text{Increase in the mass of animal produced (wet weight)}}{\text{Mass of protein in feed (dry weight)}}$
Net protein utilisation % (NPU)	= $\frac{\text{Protein gain in fish (g)}}{\text{Protein intake in food (g)}}$ X 100

product by enhancing desirable characteristics[9]. For example, the Southern blue-fin tuna industry in Australia feeds wild-caught fish with pilchards specifically to increase the oil content and value of fish destined for the premium Japanese sashimi market[9]. In this case fat content may be a more appropriate measure of performance than growth.

Evaluating economic performance of feed

To be profitable, feed must give good biological performance at a reasonable price. The cost of feed per unit production will have a large impact on the profit margin and this is a variable that should be frequently assessed since it should be a consideration in management decisions. Cost per unit production can be evaluated by comparing records of feed applied to ponds with observed growth rates. Cost per unit production can be calculated simply as per Table 2.
An estimate of cost per unit production can be generated during the course of the production cycle using observed feed conversion ratios and estimates of biomass or population. Growth rate should be monitored through regular sampling of the population. However, estimating population size can be difficult and 'rule of thumb' estimates of survival are often used based on experience.

Evaluating the cost of feed production

Manufacturing feed on-farm

On-farm manufacture of feed offers the potential to reduce the costs associated with purchasing feed from a commercial supplier. The economic viability of this option will depend on an assessment of the amount of feed consumed and of the cost of local ingredients, labour, necessary equipment and capital infrastructure for feed manufacture[10]. Successful feed manufacture also requires knowledge of the nutrient requirements and feeding habits of the culture species, nutrient composition and bioavailability of ingredients, and of the type of processing required[2,5,11].

A further advantage of on-farm feed manufacture is that it also allows greater control over the nutrient profile and hence performance of the feed. Possible mechanisms for reducing feed costs are discussed below. These mechanisms should be exploited as far as possible during the formulation of on-farm feeds.

Economically optimum protein level

Protein is the most expensive component of feeds[12] and reductions in protein content can lead to savings. De Silva et al.[13] reported that the growth rate in juvenile Tilapia increased as dietary protein content was raised up to an optimum content of around 30-34%. Higher levels of dietary protein lead to a decrease in growth rate showing that excessive levels of dietary protein can be wasteful and have a negative effect on production. The increase in growth rate was also observed to slow approaching the optimum such that there was little increase in growth across a relatively wide range of protein levels in the feed. This suggests that the protein content of feed could therefore be significantly reduced from the biological optimum with only a small trade-off in growth, leading to more economical production. They termed this the 'economically optimum dietary protein level'.

Protein sparing

Unless there is a non-protein source of energy in the diet, some of the protein intake will have to be degraded in order to support the energy demands for tissue synthesis and metabolism[13,14,15]. This will reduce the quantity of protein that is available for growth. Carbohydrates and lipids serve as alternative energy sources, thereby reducing the proportion of dietary protein that must be catabolized in order to meet energy demand[3]. Lipids have greater energy content than carbohydrates and exert a greater protein sparing effect[16]. Carbohydrates are often of limited digestibility to fish but are relatively cheap[3]. Feed formulations should therefore seek to optimise the use of fat and carbohydrate energy sources in order to reduce feed costs.

The effectiveness of the protein sparing effect of carbohydrates and lipid is related to the ratio of protein to energy in the diet. The optimum ratio is species specific and varies with protein source[5]. Variation away from the optimum ratio will result in either the catabolism of protein for energy, or the production of fatty animals[3]. However, both scenarios result in suboptimal feed efficiency[17].

Use of alternative feed ingredients

Fish meal and other animal by-products are the most important and often most expensive components of aquaculture feeds[3]. The use of lower-cost plant and other non-animal proteins in feeds is therefore an attractive approach to reducing production costs[2,18,19]. With improved processing techniques many are now routinely used ingredients in aquaculture feeds. However, there are several factors that limit the incorporation of non-conventional proteins in feeds for aquaculture. These are[19]:

a) low protein content;
b) amino acid imbalance or deficiency; and
c) presence of anti-nutritional factors.

Additionally, most animal and plant meals of terrestrial origin do not satisfy the requirements of fish for (n-3) polyunsaturated fatty acids5. Some alternative protein sources may be unpalatable to the target species[20,21,22].

Fertilisation, manuring and supplementary feeds

Fertilisation with manure or chemical fertilisers offers a relatively cheap method of enhancing production without the use of feeds. The objective of fertilisation in this context is to enhance the productivity of ponds by increasing the production of phytoplankton and other food organisms for fish[23]. This can significantly improve yields over unfertilised systems and improve apparent feed conversion ratios in semi-intensive systems[24]. Fertilisation can also have beneficial effects in some intensive systems, most notably in prawn culture. Management practices should be evaluated to determine if the farm is fully exploiting natural productivity. Fertilisation regimes should be related to the availability of nitrogen and phosphorus since algal productivity is limited by shortfalls in either of these nutrients[23].

Supplementary feeding of single ingredients to fish and shrimp is often practised in semi-intensive systems but it is often inefficient since a single ingredient is unlikely to supply a balanced intake of nutrients[10]. As a result the feeding of single feedstuffs often results in poor apparent feed conversion ratios[10]. However, even a simple compounded supplementary feed of two or more ingredients can significantly improve nutritional value[25]. The decision to apply fertilisation, supplementary feeds or to move to supplementary feeding or complete dependence on an artificial diet will depend on an assessment of the value of the cultured species, the desired level of production, the cost of supplementation and on the potential economic return.

Evaluating the efficiency of the feeding regime

Feeding practices involve[5]:

- Determining how much should be fed
- Determining how frequently cultured organisms should be fed and what time of day;
- Actual delivery of feed to the cultured organisms.

Efficiency requires that consideration be given to minimising wastage during each of these processes. Monitoring growth, feeding rates and frequencies, temperature and other management practices can help to identify optimum feeding practices. Careful evaluation of this data will allow the feeding regime to be refined over time[3].

Optimum ration size

Growth increases with ration size[26,27]. However, the rate of increase diminishes towards the maximum ration the fish is capable of consuming[3].

The utilisation efficiency and feed conversion ratio also improve up to an optimum point and then decrease towards the maximum ration due to a reduction in absorption efficiency[3,28]. Therefore it is economically beneficial to identify and feed fish at the optimum ration rather than the maximum ration[3].

Ration size is variable and is affected by scaling effects with the growth of the organism and environmental factors, particularly temperature which affects feeding and digestion rates[3]. Ration size also needs to be adjusted to account for mortalities and is dependent on accurate estimate of the size of fish and biomass within the system[5]. This requires that the average mass must be estimated through regular sampling and feeding rates adjusted accordingly.

Feeding frequency

More frequent feeding can enhance the growth rate of fish although the effect varies between species[3]. The growth of tilapia is reported to be enhanced in fish fed six times daily compared to those fed twice daily[29]. However, growth and food utilisation in the grouper Epinephelus tauvina is reported to be best in fish fed once every two days[30]. More frequent feeding in grouper lead to decreased food conversion ratios and decreased survival.

Identifying the optimum feeding frequency may therefore provide considerable economic benefit in terms of increasing growth and the utilisation efficiency of feed. Where appropriate, reducing the frequency of feeding also has the advantage of reducing labour costs[31].

Feeding time

The time of day that feed is delivered can also affect performance since feeding behaviour may be associated with environmental cues such as light levels, tidal amplitude and the movement patterns of prey[5]. Understanding the feeding behaviour of the cultured species can assist in the development of feeds and regimes that reduce the metabolic energy costs in feeding and encourage consumption, which reduces wastage and leaching of nutrients from uneaten feed[22]. For example, superior growth has been reported in the European seabass *Dicentrachus labrax* when feed was delivered during the natural feeding periods of wild fish, compared to feeding by demand or automatically at other periods of the day[32].

Feed distribution

The physical form of the feed material can also affect the efficiency of its consumption. Significant feed loss occurs from small particles and dust in the feed, which are generally not consumed by fish[3]. Feed needs to be presented in a form that is suitable for the feeding habits of the fish. In addition, the water stability of the feed will affect the rate of leaching of essential nutrients[10,11].

Feed can be distributed by hand or by a variety of automatic and demand feeders. Mechanical feed distribution devices offer the opportunity to reduce labour costs associated with hand feeding and to increase the efficiency of feed distribution, depending on the type of system employed[5]. Hand feeding can be labour intensive but it has the advantage of allowing direct observation of feeding rates among surface feeding fish[1]. Use of a floating collar to contain feed can also assist with observation and reduce wastage[10].

Automatic feeders may not account for daily variation in temperature and other factors that may affect consumption. One disadvantage of demand feeders is that dominant individuals may learn to activate the trigger and continue to trigger it even when they are satiated which may increase size variation in the crop[3].

The appropriateness of any particular feed delivery system must be evaluated according to the relative costs of labour versus technology and on the design of the culture system[3].

Enhancing productivity through manipulation of the culture environment

It is highly desirable to provide cultured fish with conditions that are within their favoured range for optimum growth and production. Failure to provide optimal environmental conditions can result in stress, which ultimately results in an increased basal metabolic rate and poor growth rates[5]. Providing a favourable environment therefore promotes efficient utilisation of feed.

The major stress factors that occur under culture conditions are caused by: changes in pH[33]; chronic exposure to low oxygen concentrations[34,35] and temperature, ammonia, aggressive intra-specific behaviour and handling[36]. Accordingly, the entire production system should be systematically examined to identify and alleviate stressful factors, with reference to the specific requirements of the cultured species[6].

Conclusion

From a nutritional perspective the essential elements of the culture system are the performance of the feed, of the feeding strategies that are employed and of the culture environment. Feed performance should be considered in terms of biological and economic efficiency. The performance of feeds and management practices can be estimated on-farm through use of feed conversion efficiency ratios. Systematic sampling and maintenance of accurate records are essential to farm management and allow the effects of variations in feeding techniques to be evaluated. Manufacture of feeds on farm offers greater control over diet and the potential for cost savings through manipulating nutritional profile and through the use of cheaper alternative ingredients. Maintenance of an optimal culture environment can also enhance productivity.

References

1. Wee, L. (1991a). "Extruded feeds - can they help reduce feed costs ? Austasia Aquaculture, Vol. 5, No. 8, pp 31-33.
2. Rumsey, G. (1993). "Fish meal and alternate sources of protein in fish feeds: Update 1993", Fisheries, Vol. 18, No. 7, pp 14-19.
3. De Silva, S.S. and Anderson, T.A. (1995). "Fish Nutrition in Aquaculture". Chapman and Hall, London, 319pp.
4. Kapoor, B.G.; Smit, H. and Verighina, I.A. (1975). "The alimentary canal and digestion in teleosts". Advances in Marine Biology, V 13, pp 109-239.
5. Anon. (1999). "Nutrition and Growth in Aquaculture". Study notes for unit SQQ636, Deakin University, Geelong, Australia.
6. Parker, N. (1987). "Feed conversion indices: controversy or contention ?", The Progressive Fish Culturist, Vol. 49, No. 3, July, pp 161-166.
7. Zeitler, M.; Kirchgessner, M. and Schwarz, F. (1984). "Effects of different protein and energy supplies on carcass composition of carp (Cyprinus carpio L.)", Aquaculture, Vol. 37, pp 303-14.
8. Harrison, K. (1990). "The role of nutrition in maturation, reproduction and embyonic development of decapod crustaceans: a review". Journal of Shellfish Research, Vol. 9, No. 1, pp 1-28.
9. Brown, D; Van Landeghem, K. and Schuele, M. (1997). "Australian Aquaculture: Industry profiles for selected species", ABARE, Canberra, 102pp.
10. New, M. (1987). "Feed and Feeding of Fish and Shrimp", ADCP/REP/26.
11. Ostrowki-Meissner, H. (1988). "Disseminating information on feeds for aquaculture in Australia", Austasia Aquaculture, Vol 2, No. 10, pp 5-6.
12. Sumagaysay, N.; Marquez, F. and Chiu-Chern, Y. (1991). "Evaluation of different supplemental feeds for milkfish (Chanos chanos) reared in brackishwater ponds", Aquaculture, Vol. 93, pp 177-189.
13. De Silva, S.S.; Gunasekera, R.M. and Atapattu, D. (1989). "The dietary protein requirements of young tilapia and an evaluation of the least cost dietary protein levels". Aquaculture, No. 80, pp 271-284.
14. Koch, F. and Wieser, W. (1983). "Partitioning of energy in fish: Can reduction of swimming activity compensate for the cost of production ?". Journal of Experimental Biology, No. 197, pp 141-146.
15. Hawkins, A.J.S. and Bayne, B.L. (1991). "Nutrition of marine mussels: Factors influencing the relative utilisations of protein and energy". Aquaculture, No. 94, pp 177-196.
16. De Silva, S.; Gunasekera, R. and Shim, K. (1991). "Interactions of varying dietary protein and lipid levels in young red tilapia: evidence of protein sparing", Aquaculture, Vol. 95, pp 305-318.
17. Hajra, A.; Ghosh, A. and Mandal, S.K. (1988). "Biochemical studies on the determination of optimum dietary protein to energy ratio for the tiger prawn Penaeus monodon (Fab.), juveniles". Aquaculture No. 71, pp 71-79.
18. Akiyama, D. (1991). "The use of soy products nad other plant protein supplements in aquaculture feeds", ASA Technical Bulletin, American Soybean Association, Vol. AQ27, pp 2-18.
19. Wee, K. (1991b). "Use of non-conventional feedstuff of plant origin as fish feeds - is it practical and economically feasible ?", in De Silva, S. (ed.), Fish Nutrition Research in Asia, Proceedings of the fourth Asian Fish Nutrition Workshop, Manila, Asian Fisheries Society, pp 13-32.
20. Tacon, A.; Stafford, E. and Edwards, C. (1983). "A preliminary investigation of the nutritive value of three terrestrial lumbricid worms for rainbow trout", Aquaculture, Vol. 35, pp 187-199.
21. Crampton, V. (1985). "The application of nutritional findings to the formulation of practical diets", in Cowey, C.; Mackie, A. and Bell, J. (eds), Nutrition and Feeding in Fish, London, Academic Press, pp 447-464.
22. Meyers, S. (1987). "Aquaculture feeds and chemoattractants", Infofish Marketing Digest, No. 1/87, pp 35-37.
23. Knud-Handsen, C. and Batterson, T. (1994). "Effect of fertilisation frequency on the production of Nile tilapia (Oreochromis niloticus)", Aquaculture, Vol. 123, pp 271-280.
24. Hepher, B. (1962). "Ten years of research in fish ponds fertilization in Israel, I. The effect of fertilization on fish yields", Bamidgeh, vol 15, pp 78-92.
25. Santiago, C.; Pantastico, J.; Baldia, S. and Reyes, O. (1989). "Milkfish (Chanos chanos) fingerling production in freshwater ponds with the use of natural and artificial feeds", Aquaculture, Vol. 77, pp 307-318.
26. Cui, Y. and Liu, J. (1990a). "Comparison of energy budget among six teleosts - III. Growth rate and energy budget". Comparative Biochemical Physiology, V 97A, No. 3, pp 381-384.
27. Cui, Y. and Liu, J. (1990b). "Comparison of energy budget among six teleosts - IV. Individual differences in growth and energy budget". Comparative Biochemical Physiology, V 97A, No. 4, pp 551-54.
28. Soofiani, N.M. and Hawkins, A.D. (1982). "Energetic costs at different levels of feeding in juvenile cod, Gadus morhua L.". Journal of Fish Biology, V 21, pp 577-592.
29. Tung, P. and Shiau, S. (1991). "Effects of meal frequency on growth performance of the hybrid tilapia, Oreochromis niloticus X O. aureus, fed different carbohydrate diets", Aquaculture, Vol. 92, pp 343-350.
30. Chua, T. and Teng, S. (1978). "Effects of feeding frequency on the growth of young estuary grouper, Epinephelus tauvina (Forskal), cultured in floating net-cages", Aquaculture, Vol. 14, pp 31-47.
31. Kindschi, G. (1988). "Effect of intermittent feeding on growth of rainbow trout, Salmo gairdneri Richardson", Aquaculture and Fisheries Management, Vol. 19, pp 213-215.
32. Azzaydi, M.; Martinez, F.J.; Zamora, S.; Sanchez-Vazquez, F.J. and Madrid, J.A. (1999). "Effect of meal size modulation on growth performance and feeding rhythms in European sea bass Dicentrarchus labrax", Aquaculture, Vol. 170: 53-266.
33. Swingle, H.S. (1957). "Relationship of pH of pond waters to their suitability for fish culture", Proceedings of the 9th Pacific Science Congress.
34. Andrews, J.W., Murai, T. and Gibbons, G. (1973). "The influence of dissolved oxygen on the growth of channel catfish", Transactions of the American Fisheries Society, vol 102, pp 835-38.
35. Boyd, C.E. (1989). "Night time pond aeration boosts production", Highlights of Agricultural Research, Alabama Agricultural Experiment Station, Auburn University, vol 34, no 2.
36. Anon. (1997). "Fish Health Management". Study Guide SQQ637, Deakin University, Geelong.

What's new on the web

...continued from page 25

Getting help

The Techsoup website also supports a number of web boards and discussion groups where you can ask questions or contact people about problems or issues. A free email newsletter is also available to help you keep up to date with new resources as they become available.

While the applications procedure does look a bit US-centric I have contacted Techsoup and they have confirmed that they accept applications from organizations operating in other parts of the world. So once again, if you're involved in a non-profit organization and could use some help with your IT, you might like to have a look at the resources available through this site.