Poultry and Fish Production - A Framework for Their Integration in Asia

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Abstract
A framework for the integration of poultry and fish production in the tropics and sub-tropics is proposed. Poultry may be integrated with fish culture in several ways and benefits extend to both. Both poultry production and processing wastes have value as nutrient inputs to fish and the water used for fish culture can be used for evaporative cooling of poultry and fertilization of crops. The conceptual basis of controlled eutrophication of fishponds using poultry manure for the production of herbivorous fish is compared to feeding of abattoir wastes to carnivorous fish. A comparison of poultry production systems in terms of their potential for integration with fish culture is made; the modern feedlot is compared and contrasted with traditional systems. The nature of poultry wastes is reviewed with respect to the effect of poultry strain/species, diet, and poultry and waste management. The impacts of the use of bedding materials, frequency of waste collection and contaminants are discussed. The use of poultry feedlot waste alone for fish culture is compared to the use of waste and additional fertilisers or feeds. The relative value of wastes from scavenging poultry alone or together with other inputs is analysed. The political economy of current poultry and fish production are considered in this article. The impacts on public health and the environment are also discussed.

KEY WORDS: aquaculture, fish nutrition, poultry, integrated systems, wastes.

Introduction

Fish raised in semi-intensive, freshwater systems provide the major proportion of farmed, global production (FAO, 1995). A high proportion of this aquaculture occurs in rapidly developing Asian countries, which are also experiencing sharply increased consumption of poultry. Semi-intensive systems are usually based on ponds fertilised with livestock manure and fed with low cost supplementary feeds. This type of integration can increase overall production intensity and economise on land, labour and water requirements for both poultry and fish. For example, one hectare of static water fish ponds can 'process' the wastes of up to 1500 poultry, producing fish in quantities of up to 10 MT/ha without other feeds or fertilisers. Also, since effluents are few, environmental impacts are minimal.

The importance of poultry wastes in aquaculture is relatively recent. In areas of traditional fish culture, ruminant and pig manure have predominated as pond fertilisers in the Indian subcontinent and China respectively. Poultry manure was not used to any extent probably because small flock size and extensive management precluded collection.

Livestock production systems, and opportunities for reuse of wastes and byproducts, are changing. Vertical integration of the poultry industry by agribusiness has been stimulated by the biology and widespread acceptability of poultry, particularly chickens. Global trends in livestock production indicate that poultry, particularly layer and broiler chickens, are increasing faster than any other (FAO, 1989, 1990, 1991, 1993). The intensive nature of modern poultry production and processing tends to concentrate high quality byproducts, and this has stimulated their reuse. A range of poultry byproducts are produced and reused in livestock feeds including feather meal, bloodmeal, poultry litter meal etc. (Muller, 1980), and poultry wastes are also used as fertilisers and soil conditioners. Economic growth is fuelling demand for both poultry and fish in many parts of the Asia Pacific region and a major question is the extent to which their integration should be promoted further here and elsewhere.

Table 1: Matrix of livestock waste qualities and suitability for use in aquaculture (* = high to * = low)**

	Factors increasing relative suitability for aquaculture				
Livestock type	Collect-ability	Accept-ability	Nutrient density	Low opp-ortunity cost	Lack of deleterious compounds
Poultry					
feedlot	***	***	***	*	***
scavenging	*	**	**	**	**
Pigs					
feedlot	***	*	**	**	***
scavenging	*	*	*	**	**
Ruminants					
feedlot	***	**	**	**	**
scavenging	*	**	*	**	*

Poultry production wastes have inherent qualities that make them particularly valuable for fish production compared to other livestock wastes (Table 1). Commercial 'feedlot' production leads to concentration of nutrient-rich waste which can be handled and transported cost-effectively. The small individual size of poultry also allows their confinement and production directly over fish ponds. Poultry manure has been used widely in both fresh and brackish water aquaculture. In the latter, penaeid shrimp, milkfish (*Channos channos*) and tilapia (*Oreochromis* sp.) have been the principle organisms raised. Inland culture systems in which poultry and fish such as the carps, tilapias and catfish are raised in commercial and subsistence systems are the focus of this review.

Poultry manure is now widely used in commercial freshwater aquaculture. In central Thailand, use of livestock wastes is the norm in the production of cheaper herbivorous fish. In other areas, intensification of culture using high quality feeds has reduced the importance of poultry waste to fish production. Predisposing factors to intensification include shortages of land or water and high product prices, but ready availability and competitively priced quality feeds are also critical. Wohlfarth and Schroeder (1979) identified the relative price of feeds and manures as being critical to determining input strategies.

Most published data concern integration of fish culture with modern poultry systems which are typically inappropriate for resource-poor farmers. Village or backyard poultry systems predominate in areas where modern breeds and systems are absent, or co-exist in competition with them. Recent research indicates that integration of such poultry and backyard fish culture can also bring benefits at little extra cost.

Waste-fed Aquaculture

A proportion of the nutrient content of feed given to poultry is voided as excretory or faecal waste. These nutrients can be used to support fish culture by their action as fertilisers that stimulate production of natural food organisms, such as phytoplankton, and detritus. A variety of carps and tilapias can grow rapidly on such natural feeds alone.

Stable and high water temperatures and sunlight ensure year-round growth of both fish and their natural feeds. The tropics, in which average water temperatures remain above 25 deg C, are ideal for culturing fish using poultry waste as inputs, although it is also practised in sub-tropical and sub-temperate climates during suitable periods of the year (>20 deg C).

Poultry wastes and byproducts can provide the feed support of aquaculture across a range of intensities. Poultry wastes may act mainly (1) indirectly or (2) directly to support fish production.

Poultry manure can be used fresh, or after processing, to enhance natural food production in sun-lit tropical ponds. Although some nutrition may be derived directly from the waste, natural feed produced on the nutrients released from the wastes is more important. Fish feeding low in the food web - the carps and tilapias benefit most from this type of management since they can utilise plankton, benthic and detrital food organisms effectively.

Several factors affect the level of waste loading and standing stock of fish that can be supported. Greater sensitivity to dissolved oxygen limits carps to standing stocks of <3 MT/ha whereas tilapias may be harvested at standing stocks of over 5 MT/ha. Water quality, particularly the level of dissolved oxygen in the early morning, therefore limit the amount of wastes that can used. Input levels in excess of 75 kg DM/ha/ day typically 'overload' the system over a typical fish culture cycle (4-8 months), causing early morning deficits of oxygen. Balancing the production of wastes from poultry and the requirement of the fishpond is a key aspect of management.

The quality of poultry wastes used in fish culture varies greatly. High levels of spilt feed, for example, increase direct feeding value. Nutrient composition may be a useful guide to value but the availability or release of nutrients to the food web may be more important.

Conventional feed ingredients have been 'replaced' with dried poultry wastes of various types, but low metabolisable energy and digestible protein levels limit their usefulness (Wohlfarth and Schroeder, 1979).

Poultry processing byproducts such as chicken bones, intestines and whole carcasses have greater value as 'direct' feeds and are normally used for higher value fish species raised more intensively. High fish standing stocks can be maintained and yields produced using this type of product and management. Processing wastes can be used fresh, or after further processing, as good quality supplementary, or complete, feeds.

Traditional Aquaculture

A lack of nutrients was a major constraint to traditional aquaculture and this remains true for much of the fish culture practised in the developing World. Yields from carp-based polycultures in China were limited until recently by the paucity of diets for pigs and grass carp (Ctenopharyngodon idella), and their manures, which provided a large portion of the nutrients entering the food web (Ruddle *et al*., 1983; Guo and Bradshaw, 1993). Recycling and reuse of nutrients on-farm has a long tradition born of necessity in the population-dense areas of Asia. However, the high outputs of fish and other products from integrated systems reported from China and elsewhere in recent decades are related to greater inputs from off-farm (Edwards, 1993).

Lack of nutrients and sub-optimal stock management remain major constraints to the production of fish on small-scale farms, as they are for traditional livestock management generally. Greater outputs of fish necessitate more nutrient inputs to be used than are available on typical resource-poor farms. Such inputs may be either direct fish feeds or feeds for livestock that in turn produce waste used in fish culture. Both need to be purchased from off-farm to supplement better reuse of on-farm wastes.

Factors Affecting Use of Poultry Wastes in Fish Culture

The type of poultry production system can greatly influence the amount of fish produced. Poultry systems producing nutrient-rich and collectable wastes are most valuable for fish production. A broad dichotomy exists between 'modern', normally intensive poultry production and 'traditional', extensive systems and this affects potential for integration with fish culture (Little, 1995). Edwards *et al.* (1983) describing the level of integration of poultry with fish in Central Thailand found large differences between small and large producers. Flock sizes of less than 100 birds were unlikely to be cultured with fish but larger flocks (>400) were usually integrated. Modern 'feedlots' raise large flocks and are generally capital intensive, highly dependent on off-farm support and profit-orientated. Generally raised on optimal, processed feeds in 'feedlots', production cycles are rapid and all the high quality waste can be collected for use in fish culture. In contrast, Klausner (1966) observing traditional management in a Northeast Thai village said that 'the owners feel that there is not much point in taking pains and spending money in caring for chickens, when chickens seem quite capable of caring for themselves'.

Many factors appear to constrain close integration of traditional poultry and fish culture. The poor quality supplementary feeds usually given, and the fact that confinement is restricted to overnight, result in less and poorer quality manure being available for use in fish culture. Moreover, farm households may already be using the poultry waste which is collectable for other purposes such as fertilising backyard crops.

Recent analysis of current poultry production in small-scale farming households reveals a marginal but important niche.

Poultry Production Waste Characteristics

Poultry manures are nutrient-rich, but there is great variability in their quality at the time of use as fish production inputs. Although between 72-79% of the dietary nitrogen, 61-87% phosphorus and 82-92% of the potassium was present in feedlot egg-laying hens (Taiganides, 1978), the variability in terms of nutrients available (g nutrient/bird/ day) can be much greater. The impacts of the gradual improvements in food conversion efficiencies attained by modern breeds and feeds are probably overridden by other factors, especially diet. Poultry raised on a balanced ration produce a higher quality, more nutrient dense waste than those fed a supplementary feed (Table 2).

Species, size and sex of bird directly affect the quantity of manure produced. The amount of feed spilt during feeding and drinking also varies with these factors together with the nature of the feed and feeding practice. Generally, larger birds produce more waste than small birds; the waste production increases rapidly over the rearing period of modern broilers as a result. Layers produce more calcium and phosphorus-rich excreta than broilers and the waste of replacement birds fed restricted diets high in fibre is correspondingly poorer than laying birds.

In scavenging systems, manure quality is greatly affected by the quality and quantity of supplementary feeds, which in turn affects fish production. Egg-laying ducks fed paddy grain at night produced poorer quality manure than those fed rice bran. The amount of nitrogen and phosphorus in the manure was 50% and 25% respectively of that found in ducks fed relatively nutrient dense village rice bran (Table 2). Restricted feeding of rice bran during night-time confinement to Muscovy ducks (*Cairhina moschata*) scavenging during the day reduced both quantity and quality of collectable wastes. Nitrogen in wastes declined with the level of restricted feed given from 1.28 g N/duck/day, for birds fed ad libitum to 0.55 g N/duck/day for ducks restricted to 50% of *ad libitum* feeding levels. (AFE, 1992)

Table 2. Effect of feeding and management on waste characteristics of poultry.

Poultry	System		Feed		Production		Waste g/animal/day			
	Feed	Scav-eng-ing	Conc-ent-rate	Supp-lemen-tary	Daily LWG	Lay-ing	DM	N	P	Ref
Egg laying duck	Yes	No	Yes	No	1.88	46-58	44.7	1.97	0.49	a
Egg laying chickens	Yes	No	Yes	No	-	-	44	1.3	1.14	b
Broiler chicken	Yes	No	Yes	No	32	-	20	0.7	0.92	c
Egg laying duck	No	Yes	No	Yes	0.38	16.3	59.9	1.16	0.69	d
Egg laying duck	No	Yes	No	Yes	0.42	29.8	24.8	0.52	0.16	e
Muscovy duck	No	Yes	No	Yes	10.4-16	-	40-70	0.65-1.28	0.5-0.8	f

a) Edwards *et al.*, 1983
b) Muller, 1980
c) Hopkins & Cruz, 1982
d) AASP, 1996 (Rice bran)
e) AASP, 1996 (Paddy rice)
f) AASP, 1992

Supplementary feeds of different types drastically affect waste characteristics and their value for fish culture. In a trial in which three different supplementary feeds (village rice bran, ground maize and ground sorghum) were fed to pekin and Muscovy ducks, both waste quantity and quality was affected. The degree of wastage, related to palatability and physical attributes of the feed, was an important factor (see below) but the intake and proximate composition greatly affected the value of waste for fish culture (Niang, 1990). Manure derived from maize-fed ducks was high in nitrogen, sorghum was intermediate and rice bran low, reflecting the composition of the feeds themselves. Total nutrients in the waste tended to be higher than in the feeds, suggesting the scavenged food tended to be of higher feed value than the supplement.

Spilled feed is a loss to the poultry system but a gain to the fish because of it's direct feeding value. The method of food presentation (timing, frequency, location) affects the amount of feed available directly for fish. Feedlot ducks fed complete diets appear to waste less than birds allowed to scavenge during the day and given access to supplementary feed at night. Feed processing can reduce spillage; up to 15 % of granulated feeds may be lost compared to 10% if the same duck feed is pelletised (Barash *et al.*,1982). Feeding behaviour and the nature of different feeds may increase the amounts of feed available directly for fish. Waste feed left in the waterer comprised more than 25% of the collectable dry matter from scavenging Muscovy ducks fed a supplement of village rice bran (AASP, 1996).

Poultry species, strain and environment affect the normal conditions of poultry management in tropical environments and these interact to determine the final characteristics of wastes available for fish culture. The density of birds in a given system and their method of confinement -in small cages or batteries (such as for chicken layers) or in pens with bedding material (litter) affects the management of both the poultry and their waste. Confinement directly over fish ponds is used for both broiler and layer chickens but pens that give access to ponds stocked with fish for drinking and/or bathing are generally used only for ducks and geese.

Poultry house litter (PHL), which can be broiler, replacement or layer bird waste is produced from poultry raised in houses with bedding materials of various types. The type and management of these materials can affect nutrient content and availability for fish culture. Fermentation can result in losses of nitrogen, volatilised as ammonia, or becoming refractory and unavailable. Some vitamins may increase (vitamin B12) and some antibiotics (e.g. Chlortetracycline) decrease with duration of storage (Muller, 1980).

Table 3. Check list of factors affecting characteristics of poultry waste and its use for aquaculture (modified after Muller, 1980)

- used fresh or collected, stored and transported
- nature of bedding materials (bulk density, particle size, moisture retention capacity, compressibility, penetrability, hygroscopicity, biodegradability)
- type of bird (size, growth rate, efficiency, sex)
- housing (open, closed)
- litter management (regular/irregular removal)
- nature of ingredients in poultry ration (digestibility, nutrient density and composition)
- type of storage (aerobic, anaerobic, exposure to temperature, rain, wind)
- quantity of bedding materials per surface unit (nutrient dilution, microorganism activity)

Action of Wastes in the Pond

The rate of nitrogen and phosphorus release, particularly in the most available forms, (dissolved inorganic nitrogen, DIN; soluble reactive phosphorus, SRP) has been used as an indicator of wastes value for fertilisation of fish ponds. Laboratory leaching experiments indicated that DIN was rapidly released as ammonia-N, levelling off at 6 mg NH4-N/g DM chicken manure after 4-5 days (Knud-Hansen *et al.*, 1991). Storage of duck wastes under aerobic conditions for a period of 4 weeks reduced both total nitrogen in the waste and the amount released subsequently as ammonia (Ullah, 1989).

The type of ingredients fed to poultry can affect the subsequent manure quality and release of nutrients for pond fertilisation. Substitution of a mixture of cassava leaf and root meal for village rice bran in complete diets of broiler Muscovy ducks resulted in a more nitrogen-rich manure but a similar cumulative release of nitrogen (5.5-6.7 mg/g DM). Release of DIN varied between 20-74% of the total in the waste. A greater proportion of phosphorus was released as SRP in all the wastes and the amount was inversely related to the level of cassava in the diet (AIT data).

Manure obtained from scavenging Muscovy ducks fed variable levels of a rice bran supplement (100, 75 and 50% of ad libitum) had different release characteristics. Significantly more DIN was released by ducks fed less supplementary rice bran suggesting that the protein in the natural feeds ingested during scavenging were less refractory than the nitrogen contained in village rice bran. SRP showed the inverse trend, with ducks fed ad libitum producing manure richer in phosphorus, of which more was released in the available form (AIT data).

Manures release other factors apart from nutrients that may have adverse effects on water quality and inevitably, fish production. Shevgoor *et al.*(1994) found that tannins and flavonoids were a major factor in the poor water quality observed in ruminant manure-fed systems. Substitution of cassava leaf for rice bran in complete diets for Muscovy ducks correlated with increased levels of tannin released from manure (AIT data).

The value of manures, including poultry manure, as a source of detritus and the role of detritus in the direct nutrition of fish has been much debated (Schroeder, 1978; Colman and Edwards, 1987). The stimulation of bacterial production, both in the water column and sediments is known to be stimulated by addition of poultry waste (Moriarty, 1987). Animals that filter feed or graze on bacteria attached to detritus directly, or consume the grazers, are therefore likely to benefit directly through this mechanism. Both feed and dissolved oxygen are required to maintain high fish yields and phytoplankton, both alive and as detritus, is the most important source of both in fertilised ponds (Colman and Edwards, 1987, Knud-Hansen *et al*, 1993).

Classification of Poultry-fish Systems

A framework for poultry-fish systems is given in Table 4. Feedlot and scavenging poultry represent two ends of a continuum of systems (Little and Edwards, 1994). The type of producer and characteristics of the production system and waste collection methods are distinct. In both cases however, poultry wastes may be part of a range of inputs used to produce fish. The use of poultry processing wastes is distinct and considered separately, although this strategy is linked closely to feedlot broiler production.

Van der Lingen described the concept of increased carrying capacity and fish yields if more nutritional inputs are complemented with higher stocking densities (Edwards, 1986). Yields from fertilisation alone may be increased with the use of supplementary feeds. Further increases in density and yield rely on improvements in feed quality and quantity so that they become the primary source of nutrition to the fish. Poultry wastes are used across a range of intensities, and for different purposes. Poultry wastes, inorganic fertilisers and feeds are to some extent substitutable. Poultry waste can be used in place of inorganics or feeds, inorganics in place of manures or feeds, and feeds in place of either type of fertiliser. Thus if manures are in short supply, inorganics can be used to optimise nutrient loadings and feeds to further increase yields. Feed may be substituted, to some extent, with fertilisers.

Table 4 Input and output of poultry-waste-fed-aquaculture

SYSTEM	INPUTS (g/m^2/day)						Ref
	POULTRY WASTE			OTHER			
	DM	N	P	DM	N	P	
FEEDLOT							
Egg-laying ducks	6.71	0.3	0.07	-	-	-	a
Broiler chickens	10.0	0.4	0.46	-	-	-	b
Layer chicken	14.3	0.4	0.3	-	-	-	c
Layer chicken	1.07	0.03	0.018	-	0.47	0.23	d
SCAVENGING							
Muscovy duck	9.7	0.15	0.10	-	-	-	e
Egg-laying duck	3.0	0.23	0.03	-	0.17	-	f
Egg-laying duck	1.24	0.20	0.01	-	0.17	-	g

SYSTEM	Fish	OUTPUT (g/fish/ m^2/day	System	Ref
FEEDLOT				
Egg-laying a ducks	Tilapia	2.82	200m^2 ponds, 6 months	
Broiler chickens	Tilapia, common carp	2.87	400m^2 ponds, 3 months	b
Layer chicken	Tilapia	1.33	1000m^2 ponds, 5 months	c
Layer chicken	Tilapia	2.75	220m^2 ponds, 5 months	d

Table 4 (Continued)

SCAVENGING				
Muscovy duck	Tilapia	1.38	5m^2 tanks, 3 months; duck fed 75% ad libitum	e
Egg-laying duck	Tilapia	1.21	200m^2 ponds, 4 months	f
Egg-laying duck	Tilapia	1.21	200m^2 ponds, 4 months	g

a) Edwards *et al.*, 1983
b) Hopkins & Cruz, 1982
c) Green *et al.*, 1994
d) Knud-Hansen *et al.*, 1991
e) AFE, 1992
f) AASP, 1996 (Rice bran)
g) AASP, 1996 (Paddy rice)

Feedlot Systems

Most of the poultry-fish systems described in the literature use waste from feedlots. Modern breeds of poultry raised on balanced feeds give the most nutrient-rich waste and produce the most fish, but systems are frequently sub-optimal, resulting in inefficient waste or space usage. Poultry manure is used either directly on-site, through the siting of poultry houses over ponds, or after collection, storage and transport to the site of fish culture.

Construction of the poultry house over the pond allows waste to drop directly in, saving labour costs. Also, in the peri-urban, flood-prone land often used, the cost to fill land for poultry housing, and the opportunity cost of land itself, are reduced. Confining poultry next to, or over, water can also improve their productivity under tropical conditions. Evaporative cooling can reduce heat stress in broilers (Theimsiri, 1992) and access to water improves feather quality of ducks, although growth may suffer (Edwards, 1986). Ducks free ranging over ponds in large numbers can damage dykes and cause water quality problems, restriction of the ducks to the water and pen prevents this problem (Edwards *et al.*, 1983). However, evidence from on-station research and farmers suggests that access to complete feeds and some degree of scavenging optimises egg production in Khaki-Campbell ducks (AIT, 1986).

Fish species is a critical factor in determining loading rates of poultry waste since there is a range of sensitivity to dissolved oxygen among the commonly cultured fish species. Air-breathing fish, such as clarias catfish and the silver-striped catfish (Pangasius hypothalmus), can tolerate the highest input levels and, at the high stocking densities normally raised, also require extra feed to sustain growth. These fish species are also probably inefficient at using the phytoplankton-dominated food web. In contrast, the microphagous Nile tilapia is more sensitive to low dissolved oxygen in the early morning but thrives at numbers of poultry between 1000 and 1500 egg-laying ducks/ha without other inputs. Using poultry manure alone, net extrapolated yields of up to 12 MT, or standing stocks of 5-6 MT/ha, appear possible in monocultures of tilapia.

Polycultures of carps are often considered most efficient in waste-fed ponds but greater sensitivity to dissolved oxygen necessitates lower input levels. Hopkins and Cruz (1982) found a poor survival of the more sensitive common carp in a tilapia-dominated polyculture, and Yakupitiyage *et al.* (1991) recorded poor survival of large silver barb (Puntius gonionotus) under similar circumstances. Research using more sensitive Indian Major carps has normally been undertaken at lower loading rates (<100-500 poultry/ha; Jhingran and Sharma, 1978, 1980).

Temperature regime affects the level of wastes that can be used in ponds and this is reflected in the lower stocking densities in eastern Europe (Edwards, 1986). Low temperatures reduce the amount of waste that can be processed by a given area of fish ponds. The fish kills reported in Hong Kong (Sin, 1980) are related to a continued build up of waste during the cool season, causing a subsequent bacterial and plankton boom as temperatures rise. This phenomenon, equivalent to a massive overloading, quickly removes oxygen from the water.

The dynamics of poultry flocks can make management of the waste for fish culture problematic. Direct use of egg-laying poultry for instance, in which the birds are of constant weight and produce fairly constant levels of waste, are easier to manage than broilers in which waste availability is cyclical (Hopkins and Cruz, 1982). The timely availability of replacement stock, veterinary support and market demand may be critical to maintaining both poultry and their waste production.

Higher loadings of waste necessitate water exchange or mechanical aeration to maintain dissolved oxygen. Green *et al.* (1994) significantly improved yields of Nile tilapia at high loading rates of chicken manure (1000 kg DM/ha/week) using mechanical aeration to ensure a high survival rate of fish. Additional aeration at levels of 10% saturation were sufficient to improve yields by 20% over unaerated ponds. Regular exchange of water to reduce phytoplankton biomass can alleviate water quality problems from overloading. In a well designed system, this would be avoided as effluents reflect inefficient nutrient reuse and negative impacts on surrounding environment.

Overloading of poultry waste can also be avoided by housing poultry over concrete or earthen floors, rather than directly over ponds, and regular manual or mechanical addition. This option may reduce construction costs considerably and also enables farmers to sell manure surplus to their requirements.

Supplementation of Feedlot Wastes

Various factors may limit the size of a poultry flock that a farmer can manage and integrate with fish culture, reducing wastes to levels below optimum. Edwards *et al.*(1983) found that problems of marketing duck egg, and high feed costs constrained small-scale farmers from maintaining even 30 ducks over small ponds (200m^2) as feedlots. Farmers with limited numbers of poultry for their pond area need additional nutrient inputs to optimise productivity.

Inorganic fertilisers may be a cheaper form of nitrogen and phosphorus than purchased poultry manure in many situations (Table 5), and highest yields may be achieved with relatively low loadings of poultry manure. The optimal level of poultry manure in ponds fertilised with high levels of inorganic fertilisers (5 kg N/ha/d) was found to be around 75 kg/ha/week for a monoculture of Nile tilapia in Thailand (Knud-Hansen *et al.*,1991). These low levels reflect the subtle balance of dissolved oxygen and food production in a highly eutrophic pond. Green *et al*. (1994) recorded similarly high yields (>20 kg/ha/day) of Nile tilapia using higher levels of chicken manure in combination with inorganic fertilisers. There are indicators however that, compared to tilapia, carps raised at lower nutrient loading rates perform better when fertilised with organic manures in addition to inorganics (AASP, 1996). Also, high levels of inorganics may be constrained by their availability or opportunity cost.

Supplementing the use of poultry manure with cheap and available direct feeding of fish is an alternative strategy. The impact of supplementary feed on yields of fish in ponds fertilised with poultry waste is affected by many factors. The level of natural feed to some extent affects the effectiveness of the supplementary feed; more natural feed allows greater feeding of a high-energy supplement to 'spare' the protein requirements and support the growth of more fish. The optimal levels for feeding supplementary feeds are complicated by the variable levels of waste poultry feed mixed with the manure.

Strategic use of additional feeds such as rice bran can boost yields of a Nile tilapia monoculture receiving egg-laying duck manure by between 10-150% (AIT, 1986), but their use may not be cost effective. One trial clearly demonstrated the 'law of diminishing returns' when a low feeding rate (1% body weight/ day) increased yields profitably by between 28-40%, depending on duck manure level, but a further doubling (2% body weight /day) increased yields further by a mere 4% or reduced them by 16% respectively (Yakupitiyage *et al.* 1991).

This suggests that overall dry matter loadings into ponds receiving both feeds and fertilisers should be considered. The variable response of different fish species within the polyculture also illustrates that supplementary feeding should be strategic. Although manure level and rice bran acted independently to boost overall yields, Nile tilapia responded most to duck density and silver barb only to feeding rate, indicating the role of supplementary feeding in polycultures of fish with different feeding niches.

Table 5. Economic comparison of different fertilizers with respect to available nitrogen (N), phosphorus (P), and carbon (US$ = 25 Baht), (Knud-Hansen, 1993)

Fertilizer	Cost (baht/50g)	Available N (baht/kg)	Available P (baht/kg)	Available C (baht/kg)
Chicken manure	20/a	76/b	194/c	7/d
Urea	240	10	-	24
TSP	450	-	45	-
$NaHCO_3$	1000	-	-	140

a/Wet weight
b/Assumes 40 % dry weight of total N is available (Knud-Hansen *et al.* 1991).
c/Assumes 10 % dry weight of total P is available (Knud-Hansen *et al.* 1993).
d/Assumes 50 % dry weight of organic C oxidizes to DIC.

Supplementary feeding of fertilised ponds is only necessary if the carrying capacity is exceeded. Green *et al.* (1994) found no benefits to yields in poultry-manure fertilised ponds also receiving high quality pelleted feed, probably because, at the low fish stocking densities ($2/m^2$) used, growth could be supported by natural feed alone. Yields may also be constrained by other factors such as seasonally low temperature and dissolved oxygen levels. The relatively low yields reported in Hong Kong (1.5-4.7 MT/ha/year; Sin, 1980), despite supplementary feeding of carp polycultures fertilised with duck manure, appear to be related to such water quality factors. Green *et al.* (1994) also reported poorer yields in supplementary-fed, poultry waste-fertilised ponds during cooler periods.

The reduction in feeding costs of more intensive systems by fertilising ponds with poultry manure is another strategy that has attracted attention by farmers and researchers alike. Clearly, the fish species raised need to be suitable for culture in plankton-rich, waste-fed systems. Green *et al.* (1994) found that the tambaqui (*Colossoma macropomum*), in contrast to the Nile tilapia, grew poorly in fertilised systems without supplementary feed.

Liao and Chen (1983) reported that Nile tilapia in Taiwan are raised in duck manure-fed, mechanically aerated ponds and also fed pelleted feed; yields of up to 18 MT/ha are the norm. Hepher and Pruginin's (1981) description of commercial polycultures in Israel indicates that fertilisation is an essential component of their high-yielding, semi-intensive systems.

Feed costs may also be reduced by feeding only in the later stages of the culture period, when the nutritional needs of the fish exceed the level supported by natural feed alone. Green *et al.* (1994) found that, at densities of 1 fish/m^2, tilapia could be raised on poultry waste alone for the first 3 months of an 137 day production without any differences in final yield.

Scavenging Systems

The use of scavenging poultry wastes in aquaculture is rare; few systems have been described in the literature in anything but qualitative terms. The variability of such systems must be expected to be greater than conventional poultry-fish systems; the production function between waste level and fish production, for example, is far more variable. The relationship between number of poultry and fishpond area is less clear cut when the wastes from scavenging birds are used. Waste collection is normally limited to overnight to allow enough time for the poultry to obtain natural foods, but absolute amounts of waste collected may still be high (Table 2). If feeds are given ad libitum and all wastes are used for fish culture (see above), dry matter levels/bird may be higher than those produced in feedlot systems. Overloading of these wastes can have clear negative impacts on water quality and fish yields.

Developing fish culture based solely or partly on the wastes of current poultry production requires an understanding of feed constraints. In north-east Thailand, the main supplementary feeds, village rice bran and unmilled paddy rice, are available only in limited quantities. Feeding restricted amounts of feeds to a larger flock of poultry can result in more poultry and fish from the same amount of rice bran (AASP, 1996).

The quality of the scavenging environment might be expected to affect the requirement for supplementary feed and the final quality of wastes produced. Natural forage is frequently seasonal and crop harvests may produce short-lived abundances of residues (dropped paddy, spilt maize) that will affect waste composition.

The relatively low nutrient density of wastes from scavenging poultry fed supplementary feeds explains the rationale for using them as partial inputs into fish culture. Farmers understand this limitation; in a study of farmer practice in Udorn Thani, farmers tended to use a variety of inputs in addition to poultry manure including plant leaves, ruminant manure and rice bran (AASP, 1996).

The quality and quantity of supplementary feed is the key factor in waste characteristics (see above) and subsequent fish yield. Feeds high in cassava products generally depressed fish yields, possibly due to the levels of tannins and unavailability of nutrients. Rice bran, corn and sorghum-fed ducks produced highly dissimilar wastes and subsequent fish yields based on similar numbers of ducks were very variable (Naing, 1990). Egg-laying ducks allowed to scavenge and fed either supplementary rice bran or paddy rice at night showed that tradeoffs may be involved. Egg yields were higher,(Table 2) but fish yields barely half that from ponds in which ducks were fed rice bran (Table 4; AASP, 1996).

Inorganic fertilisation can have a major impact on yields (up to 100%) of microphagous fish such as Nile tilapia in ponds receiving scavenging poultry wastes. In small ponds, the relative amounts required are also affordable, given the value of the fish produced (Edwards *et al*, 1996).

Poultry Processing Wastes

Boneless chicken meat is now an international commodity that resource-rich developing countries, with vertically integrated poultry industries, compete to produce and market. Low labour and feed costs and good infrastructure are necessary preconditions to develop the business that can produce large amounts of high quality byproducts suitable for intensive fish culture.

Poultry slaughterhouse wastes are in great demand for feeding hybrid clarias catfish (Clarias macrocephalus x Clarias garipinus) in Thailand.

Heads, viscera and thigh bones are the main byproducts fed fresh after simple on-farm grinding and mixing with a binder. Food conversion ratios of 4-5 (wet:wet basis) are attained under farm conditions (Little *et al*., 1994), similar to levels reported by Prinsloo and Schoonbee (1987) for the use of chicken offal and dead whole chickens fed to Clarias gariepinus.

Benefits - the Political Economy of Poultry-fish Systems

Modern agribusiness control over production and marketing of poultry products is in great contrast to the fish component of integrated farming. Agribusiness companies control the breeds, the feeds and the marketing of broiler chickens in central Thailand and for hen eggs in Northeast Thailand (Engle and Skaldany, 1992). In contrast, the fish stocked are purchased from local entrepreneur breeders (Little *et al*., 1987), fed on poultry and other wastes and marketed directly or through local middlemen and markets. Farmers are willing to contract-grow broiler chickens over their fishponds for minimal return in order to gain the benefits of high cultured fish yields. This has resulted in long term declines in the price of both chicken and freshwater fish over the past decade.

Changes in production and demand for poultry and fish stimulate new opportunities for their integration. Increasing proportions of chicken consumed and exported as boneless products has spurred the use of slaughterhouse wastes as feeds in Thailand, principally for a recently developed hybrid catfish which thrives under such culture conditions (Little *et al*., 1994). These forms of production however are concentrated in the hands of relatively few, richer farmers and entrepreneurs. Urban consumers benefit from lower prices for poultry and freshwater fish but rural small-scale production may be constrained through a lack of feeds and markets.

Environmental and Public Health Aspects

The concentration of nutrients that feedlot agriculture encourages can lead to pollution of surface waters. The controlled eutrophication of static water ponds stocked with herbivorous fish can act as on-site treatment and, providing water exchange is avoided, impacts on surface waters are minimal. Nutrient budgets indicate that, although only 15-20% of input nitrogen and 8-12% of phosphorus are recovered as fish, most of the nutrients accumulate in the sediments (Edwards, 1993). Loss of nutrients with drainage water (<10% of both N and P) and seepage are minimal (Boyd, 1985). Waste-fed aquaculture is therefore more likely to alleviate pollution from livestock production than cause it, although more intensive use of wastes and porous soils could increase nutrient losses to surface and ground water resources.

Public health concerns have been raised about the integration of poultry and fish production on several levels. The risks of direct pathogen transfer to humans in fishponds fertilised with manures, whether consumers, producers or intermediaries, have been most assessed (e.g. AIT, 1986; Buras, 1993). Although faecal bacteria and viruses are present in poultry manures, rapid attenuation of pathogens occurs in most stable, waste-fed ponds (Edwards, 1986, 1993). Clearly, the control of Salmonella and enteric bacteria capable of causing human disease is important and their maintenance in fish culture water below threshold levels that can lead to infection (Buras, 1993). The control of poultry disease, however, leads to the concern that poultry feeds containing prophylactic antimicrobials can encourages the emergence of antibiotic resistant strains of bacteria. The relative risks are likely to be insignificant compared to other causes such as direct human abuse (Dalsgaard, 1993: personal communication) or chemotherapy of fish themselves (Austin, 1993).

There has also been implicit connections made between integrated livestock-fish systems and influenza pandemics (Scholtissek and Naylor, 1988); this disturbing theory has led to widespread comment and discussion of the desirability and impacts of integrated farming (Edwards *et al.*, 1988; Morse,1990; Skladany,1992). The theory maintains that integrated aquaculture encourages the raising of pigs and poultry together to provide manure for fish and that this in turn increases the risks of new forms of influenza developing. Pigs may indeed act as 'mixing vessels' for avian viruses that can transfer to forms more virulent to humans but fishponds have had little role in bringing pigs and poultry together on farms. Indeed, pigs, poultry and fish together are rare on both large and small-scale farms in Asia. Intensified poultry-fish systems are more likely to separate poultry from pigs and other livestock than traditional farms (Edwards, 1991).

The purposeful eutrophication of water, leading to blooms of toxic blue green algae, has also been raised as an issue (Maclean, 1993). The poisoning of mammals drinking water containing toxic strains of Microcystis aeruginosa is established in temperate climates and research has indicated that the Nile tilapia avoids ingesting toxic strains (Beveridge, 1993). Under practical conditions however, such fish grow fastest in ponds dominated by this same species of algae (Colman and Edwards, 1987). Although the possibility of poisoning of fish and mammals from poultry-waste fertilised water exists, their controlled use in fish ponds reduces the likelihood of pollution to other water bodies.

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