ICLARM CONFERENCE PROCEEDINGS 4

Integrated Agriculture-Aquaculture Farming Systems

Edited by
Roger S.V. Pullin and Ziad H. Shehadeh

ICLARM INTERNATIONAL CENTER FOR LIVING AQUATIC RESOURCES MANAGEMENT

SOUTHEAST ASIAN REGIONAL CENTER FOR GRADUATE STUDY AND RESEARCH IN AGRICULTURE

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Published jointly by the International Center for Living Aquatic Resources Management, MCC P.O. Box 1501, Makati, Metro Manila, and the Southeast Asian Regional Center for Graduate Study and Research in Agriculture, College, Los Baños, Laguna, Philippines.

Printed in Manila, Philippines

Pullin, R.S.V. and Z.H. Shehadeh, Editors. 1980. Integrated agriculture-aquaculture farming systems. ICLARM Conference Proceedings 4, 258 p. International Center for Living Aquatic Resources Management, Manila and the Southeast Asian Center for Graduate Study and Research in Agriculture, College, Los Baños, Laguna, Philippines.

ISSN 0115-4389

Preface

Integrated livestock-fish, fowl-fish and rice-fish farming and crop rotation in fishponds have been practiced for centuries in Asia.

The integration of aquaculture with livestock and crop farming offers greater efficiency in resource utilization, reduces risk by diversifying crops and provides additional food and income.

However, reliable quantitative production and management guidelines are yet to be generated, recorded and disseminated to serve as a baseline for development programs.

Recognizing this deficiency, the International Center for Living Aquatic Resources Management (ICLARM) began an integrated animal-fish farming research project in 1978, in cooperation with the Freshwater Aquaculture Center of Central Luzon State University, Nueva Ecija, Philippines.

This conference, held in Manila, Philippines, 6 to 9 August 1979, was called in association with that project, to increase awareness of the effectiveness of integrated agriculture-aquaculture farming systems in increasing production and income from small-scale enterprises; encourage governments and assistance agencies to initiate research and development programs to document and test these systems, and stimulate continuing cooperation in this field.

The immediate objectives of the conference were: to provide an overview of integrated agriculture-aquaculture farming systems as currently practiced in a number of Southeast Asian countries; to review available experience and technology; to discuss the social and economic aspects of these systems and identify research and development requirements. It was financially supported by the Rockefeller Foundation and co-sponsored by ICLARM and the Southeast Asian Regional Center for Graduate Study and Research in Agriculture (SEARCA).

Two symposia on integrated farming and the use of livestock wastes have been organized since the present conference: The Philippine Council for Agriculture and Resources Research (PCARR) symposium/workshop, entitled Agribusiness Systems for Integrated Crop-Livestock-Fish Farming, held in Los Baños, Laguna, Philippines, 19 to 25 November 1979, and an International Symposium on Biogas, Microalgae and Livestock Wastes in Taipei, Taiwan, 15 to 17 September 1980, organized by the Council for Agricultural Planning and Development.

As a follow-up to the conference, ICLARM has produced a bibliography on rice-fish culture, with a view to establishing a document retrieval service on this subject. Further bibliographies are planned on other aspects of integrated farming. ICLARM will also continue to seek financial support to expand its research initiative with Central Luzon State University into a regional research network.

We would like to thank our co-sponsors and participants at the conference for their valuable contributions towards progress in integrated agriculture-aquaculture farming methodology.

R. S. V. PULLIN
Z. H. SHEHADEH
September 1980

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REVIEWS AND BACKGROUND PAPERS: AQUACULTURE IN RICE FIELDS AND IRRIGATION SYSTEMS

Review of Rice-Fish Culture in Southeast Asia

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Abstract

The methods of fish culture in Southeast Asian rice fields are reviewed with comparisons between the captural system (in which stocking is by simple introduction in irrigation water and inputs and preparation are minimal) and the cultural systems (in which fields are prepared for fish and deliberate stocking is practiced). There are two main types of cultural system, concurrent and rotational culture of rice and fish. The numerous fish species cultured in rice fields and their effects on the rice are evaluated. The constraints to rice-fish culture, particularly pesticide use, are discussed and assessment is made of the prospects for future development.

Introduction

Rice is the dominant cereal crop in Asia. It is the staple food of over 1.4 billion people in the world, mostly in Asia where 90% of all rice is grown and eaten. Rice is the main dietary source of carbohydrates for the people of Southeast Asia; it contributes half or more than half of their available calorie supply. For most rural farmers, this single crop is virtually their sole livelihood. It occupies between half and two-thirds of the total arable land available in the principal rice-producing countries. It also contributes up to 20% of their entire gross domestic product.

Rice itself is not a complete food; a rice diet must be supplemented with animal proteins. In Southeast Asia, the most important and cheapest source of animal protein, traditionally, is fish. The annual fish consumption per capita is from 20 to 25 kg in Malaysia and Thailand. In the Philippines and Vietnam, it is a little under 30 kg.

The practice of collecting wild, naturally occurring fish for food from rice fields is probably as old as rice cultivation itself. It has been suggested by Tamura (1961) that fish culture in rice fields was introduced into Southeast Asia from India about 1,500 yr ago. Rice-fish culture in Indonesia started somewhere in the middle of the 19th century (Ardiwinata 1957). Its early development in Indonesia was associated with religious schools and later government agencies.

The oldest written record of rice-fish culture in Japan dates from 1844 although it is believed that it has been practiced long before that (Tamura 1961). The problems of food supplies during the Second World War gave an impetus for extensive fish culture in rice fields. In 1909 only 401.8 t of fish was produced from rice-fish culture whereas in 1943 a yield of 4,437.7 t was harvested (Nambiar 1970). As soon as sea fish became available, farmers lost interest in raising fish and the production fell to less than one ton (Hickling 1962). Another reason for the decline in rice-fish culture has been the introduction of various insecticides which are harmful to fish.

While the total area of irrigated rice fields in Southeast Asia is estimated to be about 21 million ha, only 0.65% or 136,000 ha are used for culturing fish (Coche 1967). The potential for development is still very great and rice-fish culture is one of the best and most rational means of using agricultural land.

Rice-fish culture plays an important role in the rural economy of Southeast Asia. This is because fish culture lends itself well to small labor-intensive farming operations; it can be used in conjunction with rice cultivation to increase productivity. In the central region of Thailand, Pongsuwana (1963) observed that the income derived from fish culture was equal to or even higher than that from rice production itself. In Java, experienced tenant farmers cede the entire rice crop to landowners in exchange for the right to culture fish in the rice fields. Thus fish production plays a very important role in the economy of rice farmers, especially those who do not own land. In Malaysia, it was estimated that over 60% of rice farmers were tenant farmers. Similarly in Indonesia, only 42% of farmers own land themselves and the rest are tenant farmers (Ardiwinata 1957). Of the farms in Java, 42% are smaller than 0.5 ha, 45% between 0.5 and 2.67 ha, and 12% larger than 2.67 ha. The rent for land is very high, landowners collect about 50%-100% of the yield of rice. Under such severe leasing terms, farmers depend heavily on fish culture.

Methods of Fish Culture in Rice Fields

The techniques used for rice-fish culture differ considerably from country to country. Even within one country, for example Indonesia, the techniques in each region may be different (Ardiwinata 1957). In general the different types of exploitation of rice field fisheries may be classified as follows:

1. Captural system. In this system there is no stocking of the rice fields with fish. Wild fish populate and reproduce in the flooded rice fields and are harvested at the end of the rice growing season. Captural systems occupy a far greater area than cultural systems and are important in all the rice growing areas of Southeast Asia.
2. Cultural system. In this system the rice field is deliberately stocked with fish as in a fish pond. Even within this system it is necessary to differentiate between simultaneous and alternate production when referring to the harvest of rice and fish. Hence the cultural system may be further differentiated into:
   a. Concurrent culture–where the fish is reared concurrently with the growing of the rice crop.
   b. Rotation–where the fish is cultured as a single annual crop of rice, as in the "Palawidja method" practiced in Indonesia. Fish can also be cultured as an intermediate crop between the rice harvest and the next replanting, as in the "Panjelang method" in Indonesia.

THE CAPTURAL SYSTEM

In the captural system there is very little input towards the culture of fish. The fields are not especially prepared for the retention of fish, except for the digging of sumps, about 40 to 50 m^2 in area and 2 m deep, in the lowest region of a group of fields.

The current practice in Peninsular Malaysia is to harvest the wild fish stocks which make their way into rice fields when flooded. This captural system has been very successful due to the introduction of *Trichogaster pectoralis* from Thailand into the rice-growing areas (Soong 1951); it has established itself as the main fish crop. In addition to *T. pectoralis,* three other species, *Clarias macrocephalus, Ophicephalus striatus* and *Anabas testudineus,* are also caught.

THE CULTURAL SYSTEM–CONCURRENT CULTURE

The concurrent production of rice and fish has a number of advantages. The presence of fish increases rice production and also helps to control weeds, molluscs and harmful insects. There must, however, be adequate water, both in flow as well as depth. Not all varieties of rice can tolerate deeper water and the required dikes, draining ditches, and capturing sumps take up between 5 and 10% of the field. This loss in space is compensated for by increased rice yields, as well as by added income from the fish.

In addition to the requirement for a higher water level, concurrent rice-fish culture limits the use of modern agricultural techniques, especially chemical fertilizers, insecticides and herbicides. In a number of areas it is slowly being discarded in favor of the rotation methods.

The actual production varies from country to country. In Indonesia, the following method is used. Initially the rice field is prepared by digging peripheral trenches 50 cm wide and 30 cm deep, building bunds 25 cm high and placing bamboo pipes and screens at the inlet and the outlet (Figure 1).

The first stocking of common carp (*Cyprinus carpio*) takes place five days after the rice has been transplanted, at a rate of about 60,000 1-cm fry/ha. During the first weeding, 3 wk after replanting, the field is drained and the fish takes refuge in the trenches. At the second weeding, 5 wk after replanting, the fry (3 to 5 cm) are harvested and sold.

After the second weeding, the rice field is used to raise a second crop of fish for food. The second stocking is made with 8 to 10-cm fingerlings at the rate of 1,000 to 2,000/ha. One and a half months later, the rice fields are slowly drained and fish of 14 to 16 cm weighing between 50 to 70 g are harvested. The yield varies between 75 and 100 kg/ha.

In Western Java, *Sarotherodon mossambicus* is cultured simultaneously with rice. The fields are pre-

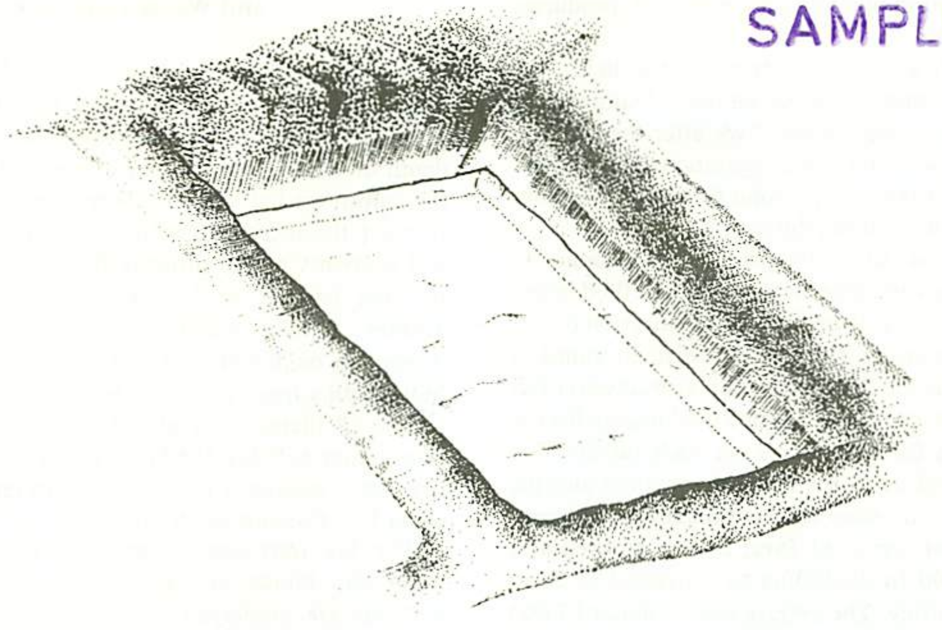


Figure 1. Field preparation for rice-fish culture in Indonesia showing the peripheral trench.

pared as for common carp. A week after the transplanting of rice, the first stocking is made with 1,000 to 10,000 1 to 3-cm fry, together with a few hundred adults/ha. Six weeks later, the largest fish are harvested for consumption and the remainder returned for another six weeks.

In contrast to this very short fish production cycle, the Japanese farmers culture their common carp for 2 to 3 yr. In Japan the fields are prepared by constructing bunds of 40 to 45 cm high around each field. These bunds are about 30 cm wide and are reinforced by various means, such as embedding straw along the inside walls. A sump of a few square meters and about 60 cm depth is dug near the water inlet. A few channels of 30 cm width extend from the sump to the opposite end of the field (Figure 2). Water is supplied to the upper part of the field through a simple inlet. The outlet is placed diagonally opposite. Both the inlet and outlet are encircled by bamboo screens to prevent the passage of fish. The water depth is kept between 6 to 18 cm during the growing season.

The fields are normally stocked with common carp about 7 to 10 d after transplantation of the rice. The stocking rate depends on the size of the fish and the environmental conditions. The usual practice is to stock 3,000 to 6,000 fry/ha. Supplemental food which usually includes silkworm pupae is given to the fish on a daily basis.

The fish are harvested about a week before the harvest of rice. If yearlings are harvested, they are stocked in over-wintering ponds until the next spring, when they are restocked for a second year to produce fish of marketable size. Some fish are reared for a third year until they reach a weight of more than 350 g.

THE CULTURAL SYSTEM–ROTATION OF RICE AND FISH

Rotation permits better care for both rice and fish. It allows the use of machinery, insecticides and herbicides for rice production. It also allows greater water depth for fish production.

Under the Palawidja method of Indonesia, a single annual crop of fish is cultured after the single rice crop. While rice is being cultivated, the farmer can direct all his energy towards the improvement of the rice plants. One or two weeks after rice has been harvested, the field is prepared for the culture of fish. Bunds of 50 cm height are built around each field and ditches of 50 cm width and 30 cm depth are constructed around the field. Simple bamboo pipes and screens are placed at the inlet and outlet to prevent the passage of fish and debris.

Common carp is the main fish grown; other species are of minor importance. The aim of this type of fish culture is two-fold: to raise fry of 3 to 5 or 5 to 8 cm long, and to grow food fish. The fields are stocked with 1-cm fry at 60,000 to 100,000/ha and grown for 3 wk to produce 3 to 5-cm fry. Alternatively, to produce 5 to 8-cm fry, 2 to 3-cm fry are stocked at 20,000/ha and grown for 3 to 4 wk. When the aim is to produce food, as is often the case towards the fish culture season, 5 to 8-cm fry from the previous period are stocked at 6,000/ha. The period of culture is about 40 d, producing fish of about 100 g.

While the fish are being cultured in the fields, the dikes, inlet and outlet are inspected daily. During heavy rains the inlet is closed. About 2 wk after the stocking of fry, paddy shoots and other vegetation are removed. This is repeated if there is a second fish crop. Predatory birds are scared away during the day.

Another method, which in many ways is similar to that above, is the Panjelang method. This method is also practiced in Indonesia; it involves the cultivation of fish between two rice crops. The method originally aimed to produce food fish for the farmers but, as freshwater fish culture expanded, the fields became used mainly for the production of fry for which there is a ready market. The fields are prepared as in the Palawidja method and the stocking rates and fry sizes are also similar in most areas. In the East Garut region of Java, fry are stocked at a density of 20,000 to 30,000/ha to provide 3 to 5-cm fry after 30 d culture. The average yield is about 15,000 5-cm to 8-cm fry, i.e., about 54 kg/ha. Part of the fry produced after the first month are restocked at 4,000 to 5,000/ha and grown to food fish size.

Physical Modifications of Rice Fields and Water Demands

Certain physical modifications must be made to rice fields for fish culture. First, the height of the bunds surrounding the field must be raised to give an adequate depth of water. This must be at least 10 cm for part of the culture period and an inflow is required at intervals to meet the increasing requirements for space, oxygen and nutrients of the growing fish. The depth of water required depends on the size and type of fish cultured. Javanese farmers maintain depths from 4 to 20 cm, depending on the size of fish being cultured, while in India depths from 10 to 60 cm are maintained. For the culture of tilapias, a depth of 7.5 cm of water is sufficient (Hora & Pillay 1962). In China, the water level in rice fields reaches a maximum of 15 cm (China Freshwater Fish Committee 1973).

For the retention of water in rice fields, strong, watertight bunds are also essential. Various simple methods are employed to achieve this. Old existing bunds can either be ploughed and levelled to make way for the construction of new bunds, or they can be repaired. The construction of a new bund is quite

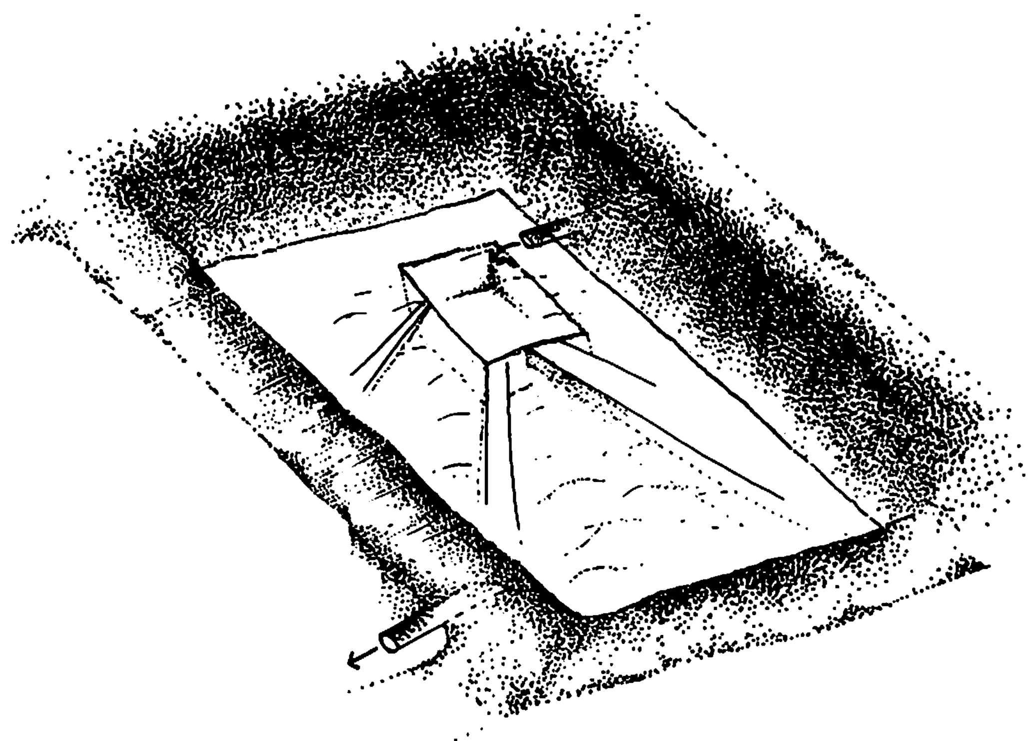


Figure 2. Field preparation for rice-fish culture in Japan showing the inlet, outlet, sump and connecting channels.

simple. Once the old bund has been levelled, a shallow trench measuring 50 cm in width is dug in the ground where the new bund is to be built and filled with new, moist earth that is neither too hard nor too soft and free from grass and weeds. More earth is heaped over this foundation and rammed until the bund is well consolidated and reaches a height of about 35 cm above the field. When this dries, the bund will settle at a height of about 25 cm (Hora & Pillay 1962).

To repair old bunds and to make them impervious, farmers of the Indo-Pacific region, as well as Chinese farmers, just hammer in the sides of the bunds after first removing some earth from the inner side. Such bunds are watertight, and also prevent predators like rats from boring holes (Hora & Pillay 1962). Strengthening of the bunds also prevents soil erosion. In Japan the inner walls of bunds are reinforced by using straw (Kuronuma 1955).

To provide a retreat for fish during periods of temperature extremes or when insecticides and fertilizers are being applied, fish drains or channels are dug, usually on the inner sides of the bunds. The number of channels depends on the size of the field. If a field is large, the channels are peripheral or crosswise. In a narrow rectangular field, however, two or more channels may be dug along the middle of the field. If a field is less than 0.5 ha, a channel around half the perimeter or along two sides of a square field is sufficient. The width of the channel is usually 50 cm and the depth about 30 cm. The best time to excavate the channels is just after rice harvesting (Hora & Pillay 1962). In China channels about 30 cm wide are made by just ploughing the inner bank of the field slightly deeper. Then during transplanting, these channels are deepened so that they are 25 to 30 cm in depth (China Freshwater Fish Committee, 1973).

A sump, approximately 1 m^2 in area, is dug at points where the channels meet (Hora & Pillay 1962). This provides a retreat for fish and aids harvesting. In Japan a sump, called a "kettle," is dug behind the water inlet (Kuronuma 1955). In terraced areas, e.g., Szechuan Province in China, sumps are usually dug on the banks of the fields that do not receive direct sunlight. Occasionally grass and rice straw are placed over the sumps to shield the fish from extreme conditions.

The water inlet and outlet also require some modification before fish can be introduced. They are usually diagonally opposite each other so as to enable the water to cover the whole field evenly. Screening devices at the water inlets and outlets are necessary to prevent the loss of fish and the entry of undesirable species (Figures 3 and 4). In order to deal with floodwater during heavy rains, a spillway should be installed at a suitable height in the field. This should also be screened. Some Chinese farmers use barbed wire, wire netting, bamboo or branches with thorns as screening devices over the mouth of the inlet or outlet pipe, and valves to regulate water flow (China Freshwater Fish Committee, 1973). Japanese farmers use pieces of stones cemented with clay to cover the outlet that is dug through the bund and a wooden gutter to regulate the inflow (Kuronuma 1955).

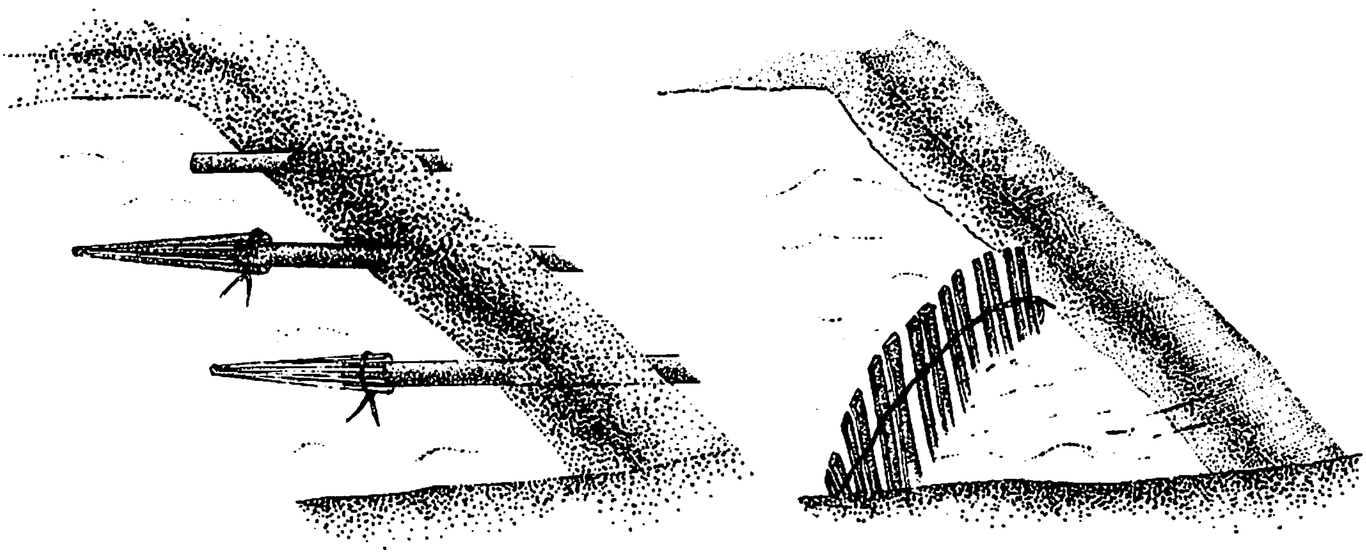
Species of Fish Used in Rice-Fish Culture

Table 1 gives the species of fish used for concurrent or rotational rice-fish culture. Some of these are also cultured in ponds and storage reservoirs. Suitability for rice field culture requires tolerance of shallow water (average depth about 15 cm), high and variable temperatures (up to 34°C with a 10°C range), high turbidities and low oxygen. Fish differ in their toleration to high temperature. The swamp fish species, *Ophicephalus striatus, Clarias batrachus* and *Trichogaster* spp., are able to withstand higher temperatures than riverine fish. Asian varieties of common carp can tolerate up to 34°C provided that the oxygen content of the water is sufficient. The optimum temperature for common carp culture, however, is around 22°C to 28°C.

Light penetration is reduced by high turbidity of water and, hence, photosynthesis is slowed down. In general, tropical species can tolerate wide ranges of turbidity but prolonged exposure to turbid conditions and extremes of turbidities, as in the paddy fields, favors the growth of olfactory feeders, such as *Clarias* spp., over visual feeders.

Oxygen availability is, however, the major factor limiting fish growth and survival (Soong 1951). In tropical inland waters, the dissolved oxygen content is normally about 70% saturation and adequate for fish. Organic pollution, however, may drop this to dangerously low levels. The minimum level of toleration of dissolved oxygen varies with size and species. Certain fish, among them the anabantids and clarids, possess accessory air-breathing organs and can therefore survive well in waters with very low dissolved oxygen.

The predatory/prey relationship of chosen species for culture should be carefully considered. The snake-head, *Ophicephalus striatus*, is a voracious predator and should not be stocked with its prey species. If a system of polyculture is practiced, the choice of fish should be made such that a balanced ecological system is maintained. Most of the species of fish cultured in rice fields are prolific spawners; this aids stocking whether by deliberate introduction or the passive introduction of eggs and fry from water sources. Stocking with selected "fish nests," fish fry and fingerlings is a deliberate



Figures 3 and 4. Screening devices for inlets and outlets from one field used for rice-fish culture.

introduction. These can be obtained from the farmers' own brood stock, government agencies or from other fish farmers. The size of fry or fingerlings that are used varies with species and location. In certain parts of China "fish nests" of the common carp are introduced into rice fields with suitable conditions for hatching (China Freshwater Fish Committee, 1973). In Indonesia the eggs of *Osphronemus gorami* are introduced into the fields and 8 to 11-cm fingerlings harvested and sold for stocking into other farmyard ponds. Male and female *Helostoma temmincki* are also introduced in the rice fields and, when the fry are produced, the young of common carp or *Osteochilus hasseltii* are added (Ardiwinata 1957).

Fry and fingerlings of the various carp species ranging in size from about 1 cm to 12 cm can be introduced into rice fields (China Freshwater Fish Committee 1973). *Puntius gonionotus* fingerlings measuring 5 to 8 cm and *Osphronemus gorami* fingerlings of 8 to 11 cm are also introduced into rice fields in Indonesia (Ardiwinata 1957). Tilapia fingerlings of 9 to 12 cm are stocked in rice fields in China (Tapiador et al. 1977) and in Japan, common carp fry, yearlings and 2-yr-olds have been stocked (Kuronuma 1955). It would be useful to determine the optimum size of the various species relative to their culture periods and markets: fry, fingerlings and food fish. This would minimize wastage of fish, time and money, and optimize the economic returns.

Not much is known about polyculture in rice fields. Where seed fish are introduced passively with the water, various species cohabit the same field. In Malaysia, for example, *Ophicephalus striatus, Trichogaster pectoralis, Trichogaster trichopterus, Clarias batrachus, Anabas testudineus,* and *Puntius gonionotus* are raised. With deliberate stocking, the best combination of species is not well known because this is a relatively recent practice in rice-fish culture. In Indonesia, however, Ardiwinata (1957) reported the following combinations of species: *Helostoma temmincki* (35%), *Osteochilus hasseltii* (15%), *Cyprinus carpio* (15%) and *Puntius gonionotus* (35%); or alternatively, *Sarotherodon mossambicus* (50%), *Helostoma temmincki* (20%), *Osteochilus hasseltii* (15%), *Puntius gonionotus* (15%) and *Cyprinus carpio* (10%).

Table 1. List of fish species harvested from rice fields in Asia.

Anabas testudineus
Carassius auratus
Catla catla
Chanos chanos
Cirrhina mrigala
Clarias batrachus
Cyprinus carpio
Helostoma temmincki
Labeo rohita
Lates calcarifer
Mugil corsula
Mugil parsia
Mugil tade
Ophicephalus striatus
Osteocheilus hasseltii
Puntius gonionotus
Sarotherodon mossambicus
Trichogaster pectoralis
Trichogaster trichopterus

Effects of Fish on Rice

The yield of rice is increased by the introduction of fish into the rice fields. Table 2 gives the cost/ha of rice production for three different areas in Peninsular Malaysia. The costs incurred by a landowner differ from those incurred by a tenant farmer because a landowner has to pay for land and irrigation rates whereas a tenant farmer has to pay rent. It is difficult to estimate with any accuracy the true cost of production of rice in Asian countries since it usually employs family labor.

In Malaysia no additional expenditure is incurred by stocking fish in rice fields as the fish are usually introduced passively with the inflow of water. The physical modifications made to the rice field to accommodate fish may however require some extra input of money if hired labor is employed. Information pertaining to the additional cost incurred for culturing fish in rice fields is rather scanty. The data for Indonesian farmers given by Ardiwinata (1957) lack uniformity and should be further reviewed.

In cases where the rice farmer deliberately stocks fish, e.g., in Indonesia, Japan and China, additional costs for fish production must be considered. These may include payment for fish seed (fry or fingerlings) for supplemental food and additional fertilizers.

The relative importance of fish and rice can be assessed from Tables 3 and 4, which show the importance of fish to landowners and tenant farmers of different segments of land in the Krian District of Perak, Malaysia. These comparisons show that farmers growing a single crop derive a large portion of their income from fish: up to 25% of the rice income for owner farmers and as high as 50% of the rice income for tenant farmers. In view of the relatively high rentals for land, there is little doubt that tenant farmers in single cropping areas depend heavily on the income derived from fish (Tan et al. 1973).

The culture of fish in rice fields generally benefits rice culture. The yield of rice has been increased by about 15% in the Indo-Pacific countries by the introduction of fish (Hora & Pillay 1962). Increases up to 14% have been recorded in China (China Freshwater Fish Committee, 1973) and 7% in Russia (Grist 1965). This probably results from better aeration of the water and greater tillering (Hora & Pillay 1962). The excreta of fish, the additional fertilizers used and any remnants of supplemental food also increase the fertility of soil.

In rice culture, weeds can reduce yield by up to 50% (Coche 1967). The introduction of herbivorous fish controls weeds and reduces weeding labor and costs. Among the most useful species are *Puntius gonionotus, Sarotherodon mossambicus, Trichogaster pectoralis* and *Cyprinus carpio.*

Fish also eat harmful organisms, such as insects and insect larvae. In China, the stem borer is said to have

Table 2. Cost of rice cultivation per hectare per season in Malaysian dollars (US$1.00 = M$2.06) (Based on Selvadurai 1972).

Items	High productivity land: WELLESLEY PROVINCE		Average productivity land: SUNGEI MANIK		Low productivity land: KELANTAN	
	Owner Farmers	Tenant Farmers	Owner Farmers	Tenant Farmers	Owner Farmers	Tenant Farmers
A. Expenses						
Hired labor	191.60	221.39	64.81	62.86	52.19	26.03
Seeds and seedlings	7.76	7.41	7.48	6.35	11.49	12.40
Fertilizers, insecticides	52.24	48.29	20.72	14.55	20.13	15.73
Equipment, buffalo hiring	1.19	4.94	0.59	1.63	1.24	19.59
Land and irrigation rates	11.66	–	8.92	–	8.25	–
Rent on padi land	–	152.05[2]	–	106.16[2]	–	151.86[2]
Subtotal	264.45	434.08	102.52	191.55	93.30	225.61
B. Imputed value of family labor	92.65	94.55	152.23	94.30	170.28	166.45
Subtotal (A & B)	357.10	528.63	254.75	285.85	263.58	392.06
C. Interest on borrowed capital at 6%	207.01[1]	22.01[1]	108.65[1]	15.39[1]	295.91	58.54
Total cost (A, B, & C)	564.11	550.64	363.41	301.24	559.49	450.60

[1]6% per annum for only one 6 month season in Wellesley and Sungei Manik Provinces where two crops per year are grown.
[2]Rent for one season only.

Table 3. Comparison of yearly incomes per hectare from rice and fish for owner farmers (US$1.00 = M$2.06) (Based on Tan et al. 1973).

	Segment	Net income from rice (M$)	Net income from fish (M$)	% Income from fish
Double cropping segment	A	619.13	32.89	5.31
	B	672.24	64.04	9.53
	C	716.68	48.99	6.84
	D	757.43	47.12	6.22
	E	718.85	30.81	4.29
	F	660.28	37.55	5.69
Average for segments	A-F	704.03	42.86	6.09
Single cropping segment	G	389.83	117.35	30.10
	I	380.29	82.48	21.69
	L	288.07	72.60	25.20
Average for segments	G-L	342.27	90.82	26.53

Table 4. Comparison of yearly incomes per hectare from rice and fish for tenant farmers (US$1.00 = M$2.06) (Based on Tan et al. 1973).

	Segment	Net income from rice (M$)	Net income from fish (M$)	% Income from fish
Double cropping segment	A	278.46	32.89	11.81
	B	331.57	64.05	19.32
	C	376.01	48.99	13.03
	D	416.76	47.12	11.31
	E	378.18	30.81	8.15
	F	319.61	37.55	11.75
Average for segments	A-F	363.36	42.86	11.80
Single cropping segment	G	219.49	117.36	53.47
	I	209.96	82.48	39.28
	L	117.74	72.60	61.66
Average for segments	G-L	171.94	90.82	52.82

been controlled by the introduction of fish (China Freshwater Fish Committee, 1973) and infestation of rats and other pests can also be greatly reduced by the higher and more solid bunds erected for rice-fish culture.

Rice field fish can also contribute to the control of waterborne diseases by feeding on aquatic intermediate hosts, such as mosquito larvae (malaria) and freshwater molluscs (bilharzia).

Rice-fish culture also, however, presents certain disadvantages in addition to the extra water depth and contribution requirements mentioned above. Some fish, such as grass carp, may eat rice seedlings and tilapias may uproot them. Also the presence of fish may complicate the process of draining and drying fields following an outbreak of viral stem rot. In some cases, a decrease in rice yield has been reported with rice-fish culture, e.g., up to about 15% in some areas of Indonesia (Ardiwinata 1957) and unspecified decreases for Taiwan. This is because of the areas taken up by the fish channels which remain unplanted. The income obtained from the sale of fish, however, more than compensates for the loss of rice (Hora & Pillay 1962).

Economics in Relation to Rural Development

The primary purpose of irrigated rice fields is to produce rice. This is the main crop and all cultural operations are directed towards increased rice production. At the same time, it is recognized that rice farmers in Southeast Asia derive relatively low income from rice cultivation alone (Dixon 1971; Selvadurai 1972; Mears et al. 1974). In a survey of rice farmers in the Krian district in Malaysia, Tan et al. (1973) estimated that the average owner farmer earns about M$750* per annum compared to M$400 for the average tenant farmer. With such income they would be among the poorest farm communities if solely dependent on rice culture. It is unlikely, however, that the average farmer depends solely on the income from rice. Many farmers have other sources of income and one of the main traditional sources has always been the sale of fish harvested under the captural system. Hickling (1961) estimated that fish provide an additional income, varying from 20 to 33% of the income from rice culture. The average yield of fish from rice fields using the captural system is about 135 kg/ha (Hora and Pillay 1962). The actual production varies greatly from place to place, depending mainly on water conditions. Soong (1951) estimated that in Malaysia, with neutral pH, the yield was between 220 to 450 kg/ha whereas acidic water gave a much lower yield of 11-56 kg/ha. These yields are much higher than those obtained in Java under the captural system, which are only about 3 kg/ha (Ardiwinata 1957).

Under the cultural system, the yield depends to a large extent on the species stocked, the culture period, the fertility of the soil and water, and the degree of supplemental feeding. Some indications of the yields in some Asian countries are provided in Tables 5 and 6.

Ardiwinata (1967) also reported yields from the various methods of rice-fish culture. Under the Palawidja method (alternate culture of rice and fish) the production of food fish was about 600 kg/ha in fertile waters, 300 kg/ha in moderately fertile waters, and only 100 to 200 kg/ha in infertile waters. For common carp fry culture, production was about 100,000 to 200,000 4 to 5-cm fry, together with about 50 to 100 kg of food fish/ha. Under the Panjelang method (culture of fish between two rice crops), the yield was 40 to 60 kg/ha; 40,000 to 60,000 3 to 5-cm fry or 20,000 to 30,000 5 to 8-cm fry, with in each case an additional 20 to 30 kg of food fish/ha. Farmers culturing *Puntius gonionotus* produced about 80,000 to 100,000 2 to 3-cm fry under the same system. Using *Osteochilus hasselti*, about 75,000 to 90,000 2 to 3-cm fry were produced/ha and using *Helostoma temmincki*, about 1 million. Concurrent rice-common carp culture yielded about 50 to 70 kg/ha of food fish. The corresponding yield for *Puntius gonionotus* was 40 to 60 kg/ha and for both fish stocked together, about 60 to 100 kg/ha.

The value of food fish produced in Indonesia in 1955 was estimated by Ardiwinata (1957) to be 75 million rupiahs for the total production of 9.16 million kilograms of fish. The total number of fry raised was estimated at 3,200 million in 1955. It was not possible to estimate their value as the price of fry varied considerably. Whereas data on actual economics are very vague, it has been estimated that the cost of fry is about 30 to 50% of the value of the fish crop, while maintenance expenses accounted for 5 to 20%, leaving a profit margin of 30 to 65% of the value of the fish cropped.

Constraints to Rice-Fish Culture

While there are many benefits to integrating rice and fish culture, there are also problems. These problems are especially critical for concurrent culture, whether under the captural or cultural systems, as indicated in the reduced rice-fish culture in Japan (Table 7) and Malaysia (Tan et al. 1973).

The recent decline in Malaysia indicates the limitations of the captural system, especially in areas with

*US$1.00 = M$2.06.

Table 5. Fish yields from rice-fish culture using the captural system.

Country	Main fish species	Average annum yield	Source
India (West Bengal and Madras)	Miscellaneous estuarine species (*Lates* spp., *Mugil* spp. and *Mystus* spp.)	100-200 kg/ha/an	Pillay 1958
Indonesia	Miscellaneous species	1.5-3.0 kg/ha/an	Huet 1970
Malaysia	*T. pectoralis*	135 kg/ha/6-10 mo	Hora & Pillay 1962
		(Range 10-400 kg/ha/6-10 mo)	Soong 1955

Table 6. Fish yields from rice-fish culture using the cultural system (Data from Coche, 1967).

Country	Main fish species	Type of culture	Average yield
Indonesia	*C. carpio*	F	150 kg/ha/4-6 mo
	C. carpio	RF	75-100 kg/ha/3-4 mo
Japan	*C. carpio*	RF	100-200 kg/ha/yr
	C. carpio	RF*	700-1,100 kg/ha/yr to 1,100-1,800 kg/ha/yr
Thailand	*C. carpio*	F	80-160 kg/ha/3-6 mo
	C. carpio	RF	10-20 kg/ha/3-4 mo
	C. carpio	RF*	210-250 kg/ha/6 mo
Vietnam	*C. carpio*	F/RF	50-130 kg/ha/10 mo

F - rotational culture of fish and rice
RF - concurrent culture of rice and fish
RF* - concurrent culture of rice and fish with supplemental feeding

Table 7. Rice-fish culture in Japan (From Nambiar 1970).

Year	Area of rice-fish culture (ha)	Production (t)
1909	2,225.7	401.8
1913	2,741.8	599.5
1923	3,856.5	1,206.7
1933	5,691.5	1,923.2
1943	13,896.3	4,437.7
1953	7,743.0	995.7
1963	3,388.0	250.0

double cropping. Here the fields are flooded for a much shorter period of 4 mo, as opposed 6 to 8 mo in single cropped areas. This, together with the extensive use of pesticides, has caused a rapid decrease in fish production. It may be necessary for farmers to change to the cultural system to maintain their income from fish.

Many pesticides used on rice, such as endrin, dieldrin, thiodan (Endosulfan), DDT and Gamma-BHC are toxic to fish (Grist 1965). Their increasing use may produce unacceptable fish mortalities. Figure 5 shows the different insecticides used in Krian, Malaysia. Thiodan is the most frequently used, followed by Malathion and Gamma-BHC (Dol granules, BHC). Sevin is also frequently used, whereas Gusathion, Lebaycid, Dieldrin, Endrin, Agrothion and Dursban are less frequently used (for nomenclature see Table 8).

In Indonesia, it has been estimated that about two million kilograms of insecticides are applied annually to more than one million ha (Hardjamulia and Koesoemadinata 1972). Fish mortalities arising from insecticide usage have resulted in significant financial losses (Saanin 1960).

Some insecticides, such as endrin, dieldrin and thiodan, are very toxic to fish and should not be used in rice fields where fish culture is of economic importance. Increasing awareness of the need for fish conservation has resulted in increased research on pesticide toxicity. The toxicity of some insecticides to *Clarias batrachus* is presented in Table 9. Endrin and thiodan (Endosulfan) are extremely toxic, as is Gamma-BHC, with a 96 hour LC_{50} of 0.13 ppm. Careless washing of thiodan containers has been reported to kill fish in irrigation canals (Tan et al. 1973). Hardjamulia and Koesoemadinata (1972) observed 100% mortality within a few hours of thiodan application (usually within 1 hr) and within 3 hr using Endrin. It is known that thiodan breaks down rapidly in biological systems (Schoettger 1966). Garbach et al. (1971) reported that thiodan at normal application rates breaks down to nontoxic levels within 3 to 5 d in rice fields. In contrast Moulton (1973) maintains that toxicity to fish lasted up to 40 d after application of thiodan granules and up to 26 d after application of thiodan E-C-35 foliar.

Insecticides are not only toxic to fish but may also have detrimental effects on the natural enemies of rice pests. Intensive application of some insecticides may bring about an increase in a normally unimportant but potentially damaging species. For instance, Lim and Hoong (1978) reported that the extensive usage of BHC against stemborers (*Conocephalus* spp.) gave rise to an epidemic buildup of *Sesamia inferens* which occupied the same niche and against which BHC had poor control. The recent increase in the green leafhopper *Nephotettix cincticeps* has also been attributed to a reduction of beneficial predator species through indiscriminate insecticide usage (Kawahara et al. 1971; Sasaba and Kiritani 1972). Hence, insecticides do not always reduce

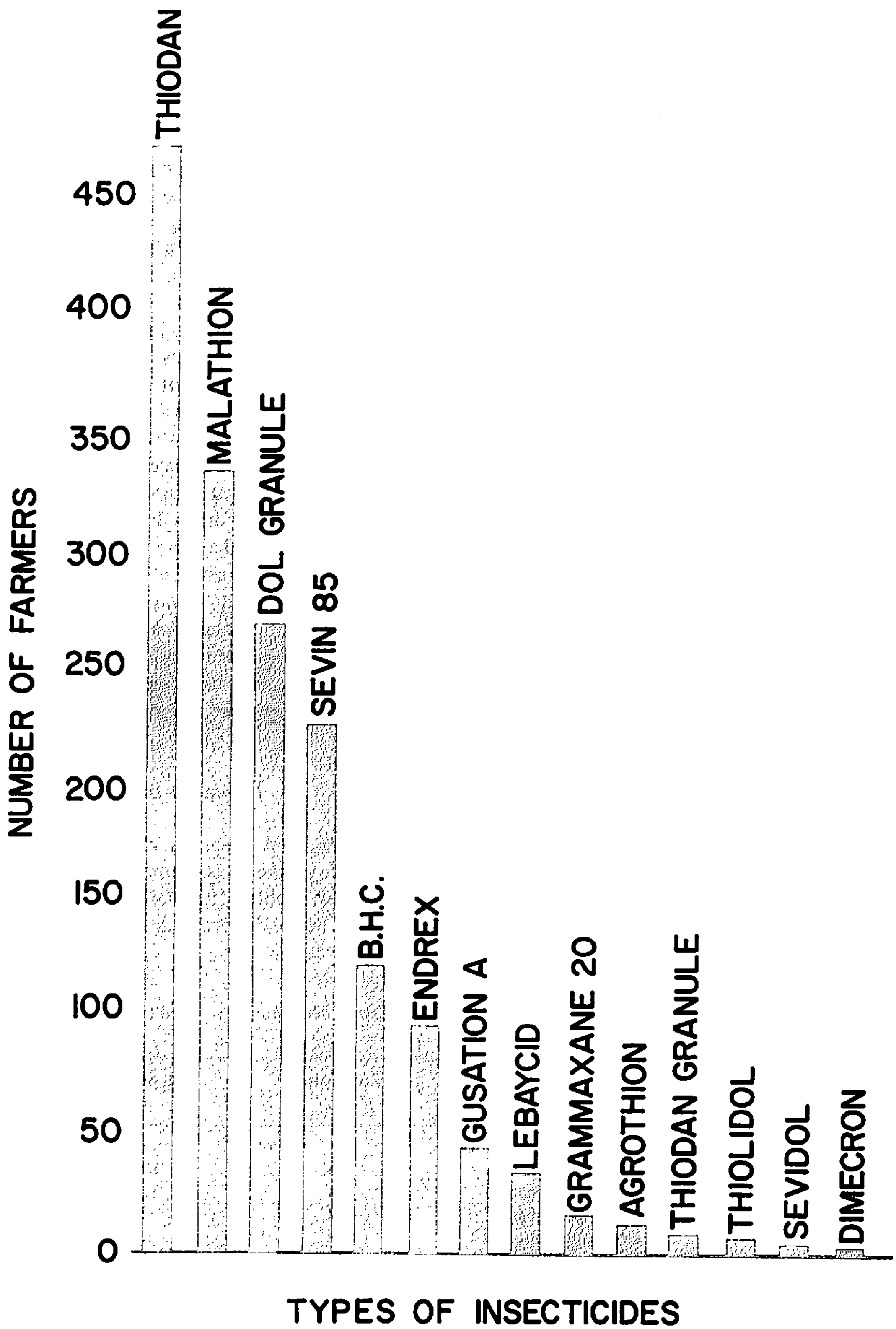


Figure 5. Numbers of farmers using different types of insecticides in Krian, Malaysia, 1973 (see Table 7 for details of nomenclature).

Table 8. Trade names and common names for insecticides used in rice fields (for detailed chemical names see Kenaga and Morgan 1978).

Thiodan - endosulfan
Malathion - malathion
DOL Granule - 6% gamma-benzene hexachloride granules
SEVIN 85 - carbaryl
B.H.C. - gamma-benzene hexachloride
Endrex - endrin
Gusathion - azinphosethyl
Lebaycid - fenthion
Grammaxane 20 - gamma-benzene hexachloride
Agrothion - malathion
Thiodan granule - endosulfan
Thiolidol - mixture of endosulfan and gamma-benzene hexachloride
Sevidol - mixture of carbaryl and gamma-benzene hexachloride
Dimecron - phosphamidon

pests and increase the yield (Lim 1970; Ooi 1975). Lim and Hoong (1978) urge that insecticides be used correctly and only when necessary.

Other constraints to the development of rice-fish culture fields include the insufficient and uncertain supply of fry of desirable species. Alternatively, some fish like tilapias breed so prolifically that overcrowding can occur and adversely affect the yield of both rice and fish. There is also a lack of qualified and experienced technical and extension workers and a limited market for freshwater fish as the population in Southeast Asia has a preference for marine fish with which they are more familiar. Pilferage of the fish is another problem.

Prospects for Future Development

Rice-fish culture, despite the intensive use of pesticide, remains an important means of fish production. With the increasing awareness of the effects of some insecticides both on fish and on the ecological balance between insect pests and predators, there is a great emphasis on the use of less harmful pesticides and biological control methods.

Considering the extensive areas of irrigated rice fields in Asian countries (Table 10), there is a very large scope for expansion. Pillay (1973) observed that if only 30% of the existing 35.6 million ha of irrigated rice fields were used for fish culture, even at a very low rate of production, an annual yield of about 2.2 million tons of fish would result. In Indonesia there are about 4 million ha under the captural system which could be upgraded to join the 90,492 ha under the cultural system. Similarly, there is much potential for the introduction of the cultural system in the other Southeast Asian countries where only the captural system is practiced. This further exploitation of the potential of rice fields will make an important contribution towards the nutritional well being and economic advancement of rice farmers. The prospects for concurrent culture may be restricted because of widespread use of insecticides and rotational culture will become more and more important.

Research Needs

There are many steps which need to be taken to remove some of the constraints to rice-fish culture. The most critical problem is related to insecticide usage. There must be greater research emphasis on the toxicity

Table 9. The toxicity of 10 commonly used insecticides to *Clarias batrachus* in a closed tank system (S. S. Gill and K. H. Khoo, unpublished data).

Insecticide (common name)	Insecticide group	Formulation	96 hour LC_{50}, ppm
Diazinon	Organophosphate	EC	10.0
Chlorpyrifos	Organophosphate	EC	1.0
Fenitrothion	Organophosphate	EC	2.0
Fenthion	Organophosphate	EC	1.8
Malathion	Organophosphate	EC	1.3
Carbofuran	Carbamate	Granular	3.2
Carbaryl	Carbamate	WP	20.0
γ-BHC	Chlorinated hydrocarbon	EC	0.13
Endrin	Chlorinated hydrocarbon	EC	0.00063
Endosulfan (Thiodan)	Chlorinated hydrocarbon	EC	0.0028

EC - Emulsifiable Concentrate
WP - Wettable Powder

Table 10. Estimates of the total area of irrigated rice fields and those with fish culture in some Asian countries.

Country	Total irrigated rice fields (ha)	Area with rice-fish culture (ha)	Source
Cambodia	1,400,000	–	Hora & Pillay 1962
Hong Kong	8,080,000	200	Hora & Pillay 1962
India	5,762,792	1,619	
Indonesia	4,500,00	90,492 + 4,000,000[1]	Ardiwinata 1957
Japan	2,991,100	3,380	Hora & Pillay 1962; Nambiar 1970
Malaysia	332,060	45,500	Hora & Pillay 1962
Philippines	1,400,000	–	Mears et al. 1974
Sri Lanka	350,000	–	Rabanal 1974
Thailand	4,000,000	200,000	Rabanal 1974
Vietnam	4,067,990	1,550	Hora & Pillay 1962

[1]90,492 ha under the cultural system and 4,000,000 ha under the captural system.

of insecticides to fish, as well as to the insect pests. Research should also be directed towards studying the degradation of pesticides in rice fields, as in Gill and Yeoh (1978). Research is also necessary to develop alternative pest control techniques that do not harm fish.

Much more information is required on the optimum fish sizes, stocking rates, species combinations and feeding, including the use of supplemental feeds to increase production. There is also a need to establish hatcheries to supply fry and there is already enough information within the region to develop and expand these.

References

Ardiwinata, R.O. 1957. Fish culture on paddy fields in Indonesia. Proc. Indo-Pacific Fish. Coun. 7(II-III): 119-154.

China Freshwater Fish Committee. 1973. Freshwater fish aquaculture in China. Science Publishers, Peking, China. 598 p. (In Chinese)

Coche, A.G. 1967. Fish culture in rice fields. A worldwide synthesis. Hydrobiologia 30: 11-44.

Dixon, J.A. 1971. Groundnut production in the Kemubu Scheme Area. A report submitted to the Ministry of Agriculture and Fisheries of Malaysia. Mimeo, 21 p.

Garbach, S., R. Harring, W. Knauf and H.J. Werner. 1971. Residue analyses in the water system of East Java (River Brantas, ponds, sea water) after continued large scale application of Thiodan in rice. Bull. Environ. Contamin. Toxicol. 6: 40-47.

Gill, S.S. and C.L. Yeoh. 1978. Degradation of carbaryl in three components of the padifield ecosystem of Malaysia. (Proceedings of a FAO/IAEA Advisory Group and Research Coordination Meeting on Agrochemical Residue-Biota Interaction in Soil and Water.) Mimeo, 27 p.

Grist, D.H. 1965. Rice. Longmans, London.

Hardjamulia, A. and S. Koesoemadinata. 1972. Preliminary experiments on the effects of thiodan and endrin on fish culture in Indonesia. Proc. Indo-Pacific Fish. Coun. 15: 56-64.

Hickling, C.F. 1961. Tropical inland fisheries. Longmans, London.

Hickling, , C.F. 1962. Fish culture. Faber and Faber, London.

Hora, S.L. and T.V.R. Pillay. 1962. Handbook on fish culture in the Indo-Pacific region. Fish Biol. Tech. Pap. 14, FAO Rome. 204 p.

Huet, M. 1970. Textbook of fish culture: Breeding and cultivation of fish. Fishing News Books Ltd. Surrey, England.

Kawahara, S., K. Kiritani and K. Sasaba. 1971. The selective activity of rice pest insecticides against the green rice leafhopper and spiders. Botyu-Kagaku 36: 121-138.

Kenaga, E.E. and R.W. Morgan. 1978. Commercial and experimental organic insecticides (1978 Revision). Entomological Society of America, Maryland, U.S.A. Special Publication, 78-1, 80 p.

Kuronuma, K. 1955. Fish culture on rice field in Japan. Third FAO/ETAT International Inland Fisheries Training Center, Bogor, Indonesia, 31 Oct.-10 Dec. 1955.

Lim, G.S. 1970. Some aspects of the conservation of natural enemies of rice stem borers and the feasibility of harmonizing chemical and biological control of these pests in Malaysia. Mushi, 43: 127-135.

Lim, G.S. and K.L. Heong. 1978. Habitat modifications for regulating pest population of rice in Malaysia. MARDI Report No. 50. 28 p.

Mears, L.A., M.H. Agabin, T.L. Anden and R.C. Marquiz. 1974. Rice economy of the Philippines. University of the Philippines Press, Philippines.

Moulton, T.P. 1973. The effects of various insecticides (especially thiodan and BHC) on fish in the paddy fields of West

Malaysia. Malays. Agric. J. 49: 224-253.
Nambiar, K.P.P. 1970. Carp culture in Japan. A general study of the existing practices. Indo-Pacific Fish. Coun. Occ. pap. 1970/1. FAO, Bangkok, Thailand.
Ooi, A.C.P. 1975. Assessment of damage by rice stem borer in the Tanjong Karang Irrigation Scheme. Proc. Crop Protect. Branch Workshop, Dept. Agric., Malaysia. 16-18 Dec. 1975.
Pillay, T.V. 1958. Land reclamation and fish culture in the deltic areas of West Bengal, India. Prog Fish. Cult. 20:99-103.
Pillay, T.V.R. 1973. The role of aquaculture in fishery development and management. J. Fish. Res. Board Can. 30: 2202-2217.
Pongsuwana, U. 1963. Country statement–Thailand. *In* "Report of Association of Southeast Asian Nations." ASEAN Seminar on Shrimp Culture. 3 p.
Rabanal, H.R. 1974. The potential of aquaculture development in the Indo-Pacific region. South China Sea Fisheries Development and Coordinating Programme, Manila, SCS/74/WP/1. 34 p.
Saanin, H. 1960. Toxicity of insecticides and herbicides to some Indonesian cultivable fish species. Proc. Fourth Pan Indian Ocean Science Congress. Section B, Biological Sciences, 297-303.
Sasaba, T. and K. Kiritani. 1972. Evaluation of mortality factors with special reference to parasitism of the green rice leafhopper, *Nephotettix cincticeps* Uhler (Hemiptera: Deltocephalidae). Appl. Entomol. Zool. 7: 83-93.
Schoettger, R.A. 1966. Toxicology of thiodan in several fish and aquatic invertebrates. U.S. Dept. Interior, Investigations in Fish Control, 35:1-29.
Selvadurai, S. 1972. Padi farming in West Malaysia. Ministry of Agriculture and Fisheries, Malaysia, Bulletin No. 127. 94 p.
Soong, M.K. 1951. The fitness of ecological niches into which fish are introduced at various ages and the survival of the transplanted fish. Proc. Indo-Pacific Fish. Coun. 3: 218-227.
Soong, M.K. 1955. Fish culture in paddy fields in the Federation of Malaya. FAO International Rice Commission 4th Session. Tokyo, Japan, 1954 (mimeo). IPFC 6th Session, IPFC/CSS/CP26. 5 p.
Tamura, T. 1961. Carp cultivation in Japan. *In* G. Borgstrom (ed.) Fish as Food. Academic Press, New York.
Tan, C.E., B.J. Chong, H.K. Sier and T. Moulton. 1973. A report on paddy and paddy field fish production in Krian, Perak. Ministry of Agriculture and Fisheries, Malaysia. Bulletin No. 128.
Tapiador, D.D., N.F. Henderson, M.N. Delmendo and H. Tsutsui. 1977. Freshwater fisheries and aquaculture in China. FAO Fish. Tech. Pap. No. 168, 84 p.

Rice Agronomy in Relation to Rice-Fish Culture

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Abstract

The development of rice-fish culture technology requires a clear understanding of the basic requirements of rice cultivation including land preparation, water requirements, planting methods, fertilizer application and appreciation of N, P and K requirements, pest and disease control, weed control, harvesting methods and land management between crops. All of these are reviewed and discussed with assessments of their implications for fish culture in rice fields.

Introduction

Rice-fish culture consists of stocking rice fields with fish fingerlings of a selected size and species to obtain a fish crop in addition to rice, the main crop. This is practiced in several Southeast Asian countries: the techniques vary depending on climatic and other local conditions. Rice-fish culture was introduced into Southeast Asia from India about 1500 yr ago (Tamura 1961). A broad literature exists on the subject, which can be referred to for detailed descriptions. This discussion is therefore limited to the agronomic requirements of the rice crop and its implications for rice-fish culture. The paper deals exclusively with lowland irrigated rice, and omits discussion of nursery operations since they do not affect rice-fish culture.

In general, the water in rice paddies reaches a level of 5 to 25 cm, and because the paddy bottom is highly fertile, there is high production of plankton. This resource, which is hardly if at all used by the rice crop, can be fully utilized by fish. Acceptable rice yields (3 to 5 t/ha) and fish yields (200 to 300 kg/ha) have been obtained from rice-fish culture (Chen 1954; Coche 1967; Grover 1979; Heinrichs et al. 1977; Arce and dela Cruz 1978). Its success depends, however, on the complementary requirements of both crops.

Rice paddies comprise several different ecological environments, and by raising combinations of fish species with different feeding habits, all the available niches can be exploited. In paddies where complete water control and management is exercised, fish culture can be highly beneficial in eliminating weeds, molluscs and mosquitoes (Vincke 1979) but growing fish in rice paddies without proper planning can also harm the rice crop.

In rice-fish culture, since rice is the main crop, fish culture has to adapt to the conditions and requirements of the rice crop. To grow fish in rice paddies successfully, it is essential to have complete control over the water levels and drainage. In addition, one or more refuges must be made for the fish when the water level is lowered. The fish species chosen must be able to withstand rice paddy conditions, such as shallow water, high water temperature, low dissolved oxygen and high turbidity (Hora and Pillay 1962). Sluggish, fast growing species are preferred.

Rice-fish culture also creates additional costs which must be offset by the revenue from fish production. More water is needed (minimum depth 10 cm) and the water must be regulated to prevent the escape or entry of fish. The water quality must be tolerable for the fish and their food organisms and the paddy dikes need to be stronger and higher than normal to contain the fish and the increased depth of water.

High yielding rice varieties and modern growing techniques require the intensive use of chemical fertilizers and pesticides whose toxic effects on fish may present serious obstacles to rice-fish culture. Therefore, certain agronomic practices must be modified to obtain a better fish crop in paddies. This paper reviews the existing information on rice agronomy in relation to rice-fish culture.

Rice-fish culture has advantages and disadvantages which must be compared and properly understood. The advantages are:

1. The most economical utilization of land is achieved since the same land is used for the production of both rice and fish.

2. Very little extra labor is required to take care of fish, since both rice and fish can be cared for at the same time. Furthermore, this extra labor cost may be compensated for by savings on labor for weeding, since fish tend to reduce the incidence of weeds (Chen 1954).

3. The quantity of supplemental fish feeds, if any are given, will be less than for pond culture.

4. The rice yield is increased due to reduced insect pest pressure and increased organic fertilization (Schuster et al. 1955; Hora and Pillay 1962).

The disadvantages are:

1. The greater water depth required for fish may prove uneconomical when water supply is limited.

2. If fish are introduced too early, they may damage the young rice plants.

3. More fertilizer is required to stimulate primary production than when no fish are stocked (Chen 1954).

4. Certain areas of the paddies are required for trenches and are left unplanted. The reductions in rice yields must be offset by fish production and added income (Chen 1954).

5. Species must be carefully selected to avoid damage to the rice crop (Matthes 1969).

6. The pesticides used for rice protection may prove toxic to fish and/or fish consumers.

In general, only selected rice varieties and fish species which complement each other should be used in rice-fish culture. The fish species commonly grown and/or found in rice paddies are presented in Table 1.

Basic Requirements for Rice Cultivation

LAND PREPARATION

Apart from the essential agronomic practices, such as fertilizer applications, disease and pest control and an adequate water supply, land preparation can also influence yields. Inadequate land preparation may cause serious weed problems and expose plants to harmful substances released by decaying organic matter in the soil. Besides providing a poor medium for growth, these harmful substances may also prove to be toxic to fish. Good land preparation helps in controlling weeds effectively (Stout 1966), mixes organic material with soil, forms a hard layer (plow pan) which reduces water and leaching losses, and finally turns soil into "soft puddle," which facilitates transplanting of rice (Dutt and Bandyopadhyay 1966).

Methods and equipment

Land can be prepared for rice cultivation either by dry land or wet land preparation. In dry land preparation, the fields are thoroughly drained and the land is prepared with the use of heavy harrows, chesels or stubble mulch equipment to stir the soil without inverting or covering the stubble (Johnson 1967). Weeds are thus exposed to the sun and are killed by desiccation. In the humid tropics, however, where the average monthly rainfall at planting time exceeds 150 mm/mo, dry land preparation is not usually practiced. In most tropical Asian countries, wet land preparation is employed. The field is plowed wet and harrowed crosswise and lengthwise until the soil is well puddled.

The land should be tilled at least 15 days before transplanting or direct seeding. In a well prepared paddy, weeds, rice straw and stubble which have been plowed

Table 1. The main fish species commonly grown or found in rice fields.

Common name	Scientific name	Occurrence	Sources
Carps	*Cyprinus carpio* and other species	China, Hungary, Indonesia, Italy, Japan, Madagascar, Pakistan, Spain and some Southeast Asian countries	FAO 1957; Coche 1967; Grover 1979; Arce 1977
Tilapia	*Sarotherodon mossambicus*	Indonesia, Taiwan, Philippines and other Southeast Asian countries and Africa	FAO 1957; Coche 1967; Grover 1979; Vincke 1979; Arce 1977
Mudfish	*Ophicephalus striatus*	Philippines, India, Malaysia Malaysia and Vietnam	Soong 1954; Wyatt 1956; Lemare 1949
Catfish	*Clarias* spp.	Malaysia and other Southeast Asian countries	Gopinath 1955; Soong 1950; Tonolli 1955
Crayfish	*Cambarus clarkii*	Japan	Yoshihiro et al. 1958
Bhekti	*Lates calcarifer*	India	Pillay and Bose 1957
Tengra	*Mystus gulio*	India	Pillay and Bose 1957
Milkfish	*Chanos chanos*	India and Indonesia	Menon 1954; Djaingsastro 1957
Eel	*Anguilla japonica*	Japan and India	Yoshihiro et al. 1958; Anon. 1956
Goldfish	*Carassius auratus*	Japan	Yoshihiro et al. 1958
Grey mullets	*Mugil* spp.	India and some isolated islands in Asia	Pillay and Bose 1957

under are thoroughly decayed and distribution of water is uniform. Application of adequate water is essential to soften the soil. In general, rice fields are irrigated a week before land preparation to facilitate plowing. Immediately after plowing, more water is added to speed up the decomposition of weeds and crop residues that are plowed under. The fields are also kept flooded until transplanting, to minimize the loss of nitrogen released by decomposing organic matter. The last harrowing is done a week after the second harrowing or at least a day before planting to puddle and level the field. There is a gap of 7 to 10 days between the two harrowings to allow the seeds of weeds to germinate and further soften the soil clods.

Traditional tillage practices are still followed by many farmers today. In some countries with advanced technology, however, successive rice crops are grown sequentially with minimal soil disturbance or zero tillage. This is possible because the farmers are able to control weeds with herbicides and insects with insecticides, and harvest the crop from near the soil surface, which leaves very little organic matter to decompose.

Minimal tillage, therefore, gives flexibility to the cropping schedule because farmers can prepare their fields faster. It can also be practiced in soft, marshy lands where conventional tillage is difficult; its reliance on plant protection chemicals may present a serious problem to rice-fish culture.

Water Requirements

The water requirements for land preparation vary from area to area depending upon soil factors and antecedent soil moisture conditions. In general, the water requirement for previously dried and cracked Philippine soil is about 10 mm/day (Valera 1977) of which about 7 mm/day is lost through seepage and percolation (Wickham and Singh 1977). This loss could possibly be reduced if soils were kept flooded throughout, even after the rice harvest. Losses from continuously flooded fields are reported to be only about 1 to 2 mm/day (Wickham and Singh 1977). This opens new possibilities for fish culture in rice paddies. The fish culture period could be extended beyond that of the rice, or successive crops of fish could be stocked without yet having rice. The stocked fish could be moved to the trenches (already made for the previous crop) during the land preparation for the next rice crop. This would require increased management of irrigation systems and water delivery to the fields for the periods between the two crops, although the net water requirement per unit time may not be higher than when fields are allowed to dry and crack.

CROP ESTABLISHMENT

Nursery requirements of rice are not discussed here because in most cases seedlings are raised in a separate seedbed which does not interfere with fish culture.

Rice Varieties

High yielding varieties, which have short or medium height and require less growing time (105 to 125 days) than most traditional varieties (160 days), are in current use. Therefore, fish stocked in rice fields must be able to grow to a harvestable size within this period or must be held during rice harvesting until the next crop is planted. These medium height varieties can not, however, be grown in areas which are affected by moderate to deep flooding ($\leqslant$ 50 cm).

Recently, the International Rice Research Institute (1975b) has reported significant efforts to improve deep-water (floating) rice varieties but these are mainly intended for the areas where water depth often exceeds 30 cm; they can be planted in flood-affected areas or in the trenches (made for fish refuges).

Planting methods

Most Southeast Asian farmers establish their crops by transplanting the seedlings from an isolated seedbed, but direct seeding where pregerminated seeds are broadcast on a saturated soil surface is also practiced.

Rice seedlings are planted at a distance of 20 cm between rows and 15 or 20 cm between plants. This allows enough space for fish movement. Even more space for fish movement could be provided by increasing the distance between rows to 25 to 30 cm while keeping the same plant population by reducing the distance between plants and consequently not affecting the yield due to changes in spacing.

Fish fry should be stocked about 10 days after transplantation to avoid any damage to the rice plants but fingerlings should not be stocked until about 3 wk after transplantation. Where seedlings raised by dapog[1] are transplanted or direct seeding is practiced, fish may have to be stocked even later to avoid damage. Seedlings raised by dapog are transplanted earlier than wetbed seedlings (see Figure 1).

FERTILIZER APPLICATION AND MANAGEMENT

Nutrient uptake by the rice plants is a function of climate, soil type, the amount of fertilizer applied, the rice variety used and the method of fertilizer application. Thus, it is difficult to generalize on nutrient requirements and methods which would be acceptable in almost all cases. The results of various studies for all major nutrients are reviewed separately below and the nutrients removed by a rice crop producing 4.75 t/ha yield are presented in Table 2.

In general, for rice-fish culture, more fertilizer is required than for rice alone: 50% to 100% more than normal rice field practice (Chen 1954). This additional fertilizer is required for primary production and associated fish food chains. For comparison, the Philippine Council for Agriculture and Resources Research (PCARR) recommends the application of 2.5 t/ha of organic fertilizer (generally chicken manure), 10 to 20 kg N/ha and 20 to 30 kg P_2O_5/ha for pond culture of tilapias (PCARR 1976).

Nitrogen (N) Requirements

Rice is reported to take up about 40 to 60 kg N/ha by above ground parts only (Watanabe 1977). Watanabe also reported that in Japan, Thailand, the Philippines and Indonesia, about 64, 37 to 52, 76 and 50 kg N/ha, respectively, were absorbed by rice from sources other than mineral fertilizers. The efficiency of fertilizers is only about 50 to 60%, depending upon the amounts

[1] A method common in the Philippines where seedlings are grown without using a soil bed and young seedlings of 7 to 10 d are transplanted.

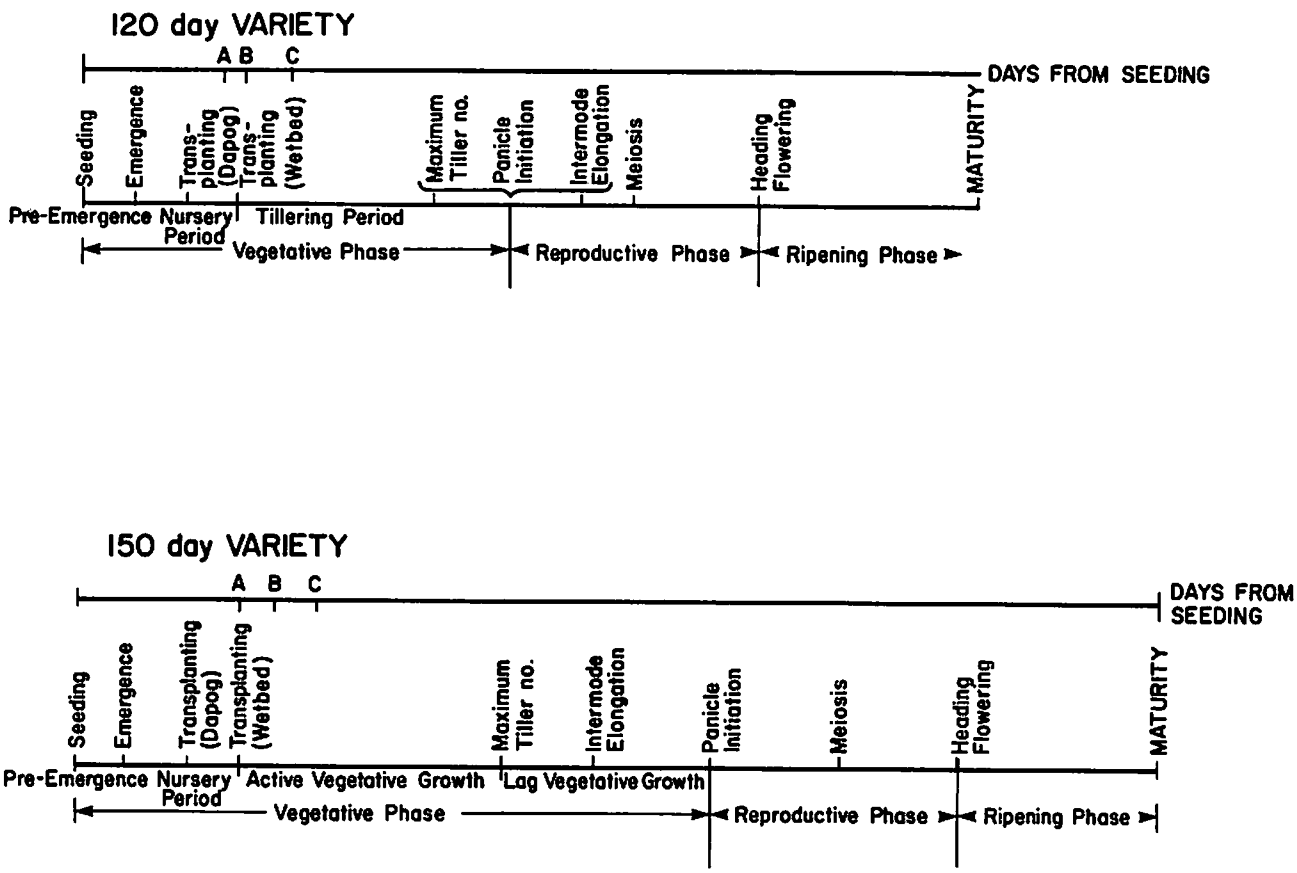

Figure 1. Summary of growth stages for 120- and 150-day rice culture: A, stocking times for fish fry when direct rice seeding is used; B, stocking times for fish fingerlings when direct rice seeding is used or fish fry when transplantation is used; C, stocking times for fish fingerlings when transplantation is used.

Table 2. The major nutrient elements taken up by a rice crop producing 4.75 t/ha of dry grain. (Source: IRRI 1962, adapted from RICE 1967).

Nutrient element	Amount of nutrients in the rice plants at harvest (kg/ha)		Amount of nutrients (kg) taken up by 1 t (1,000 kg) of rice production	
	Total	Panicle	Total	Panicle
Nitrogen	90.0	48.0	18.87	10.00
Phosphorus	20.0	13.0	4.09	2.27
Potassium	219.0	11.0	45.92	2.27
Calcium	34.0	12.0	7.05	2.50
Magnesium	25.0	9.0	5.23	1.82
Iron	12.0	1.6	2.50	0.23
Manganese	12.0	2.3	2.50	0.45
Silica	1780.0	371.0	374.59	77.96

applied and environmental conditions (IRRI 1974; Shiga et al. 1977), but even so the total nitrogen uptake must be markedly higher than the values given above. Shiga et al. (1977) reported about 120 to 128 kg N/ha removal per crop.

For fertilization, about 60 kg N/ha for the wet season crop and about 60 to 90 kg N/ha for the dry season crop (Figure 2) are generally recommended (RICE 1970; De Datta 1977). In Japan, the rates of N application are relatively higher than in most Southeast Asian countries, and sometimes exceed 150 kg N/ha. In most tropical areas, e.g., the Philippines (Briones et al. 1961; Galvez 1963), India (Relwani 1963; Sahu 1963; Choudhury and Raheja 1962; and Basak et al. 1961), Pakistan (Alim and Ullah 1961) and Sri Lanka (Ponnamperuma 1959; Yamada and Kirinda 1959), the recommended dates of fertilizer N for flooded rice have been reported to be 30 to 60 kg N/ha. Fertilizer use in the tropics was previously limited since traditional local varieties tolerate only to low levels of N application.

Methods of application

High losses of N occur when fertilizers are broadcast on the surface (Bouldin and Alimagno 1976). Therefore, several alternative methods, such as deep rootzone placement, soil incorporation, and slow release fertilizers have been suggested. Besides reducing losses, these methods also increase rice yields (IRRI 1975a; 1976;

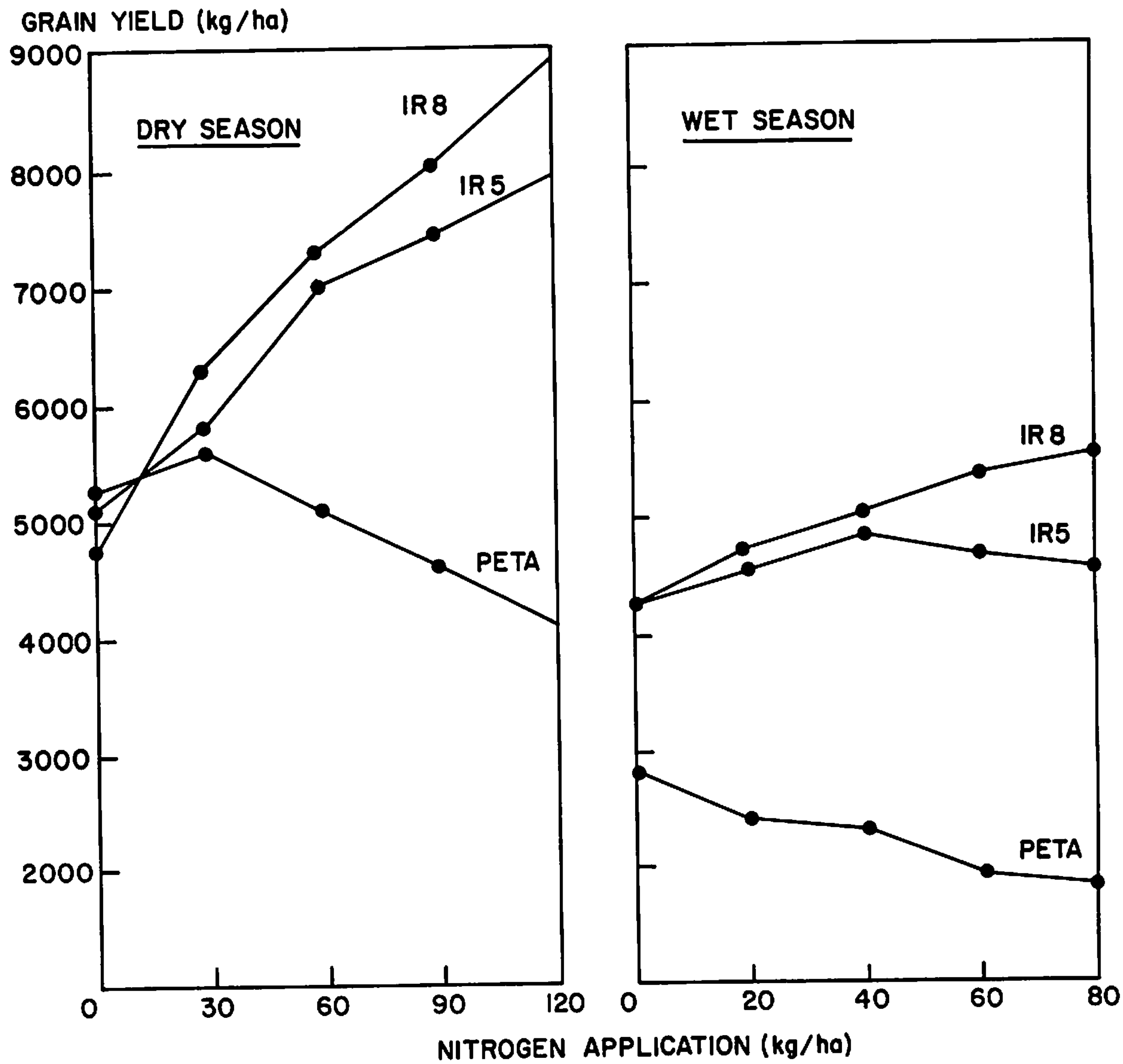

Figure 2. Effect of levels of nitrogen on the grain yield of IR8, IR5 and Peta rice varieties in dry and wet seasons (RICE 1970).

Singh et al. 1978a, 1978b).

Singh et al. (1978a, 1978b) also reported a significant yield increment (0.6 t/ha) when ammonium sulfate was incorporated into the soil than when topdressed on the soil surface at the same rate. They attributed this to higher efficiency and reduced N losses primarily through surface runoff and other mechanisms, such as volatilization. From a series of International Network on Fertilizer Efficiency in Rice (INFER) trials conducted in eight countries, De Datta (1977) reported that grain yields were significantly higher with the placement of urea as mudballs or briquettes (or super granules) than with urea applied in split doses or in bands (Figure 3). A survey of farmers in the Philippines revealed that despite all the benefits of soil incorporation of N fertilizers, almost all farmers still broadcast it on the soil surface in two or three split applications (Singh 1978).

Based on recent studies, it can be concluded that N fertilizer should be thoroughly incorporated into the soil during land preparation and the soil should be kept flooded to maximize rice yields. Subsequent applications should also be at about 5 to 10 cm depth to reduce losses. The methods for deeper placement of the fertilizer can be selected according to the field conditions, and the farmer's preference, or such slow release fertilizers as mudballs, sulfur coated urea or urea briquettes, should be used. If fertilizer has to be broadcast on the surface for later applications, the water should be drained to expose the planted area and the fish confined to the trenches before applying the fertilizer. The field levees and trenches should be high enough (about 30 to 45 cm) to prevent inundation and runoff in case of heavy rainfall immediately after fertilizer application.

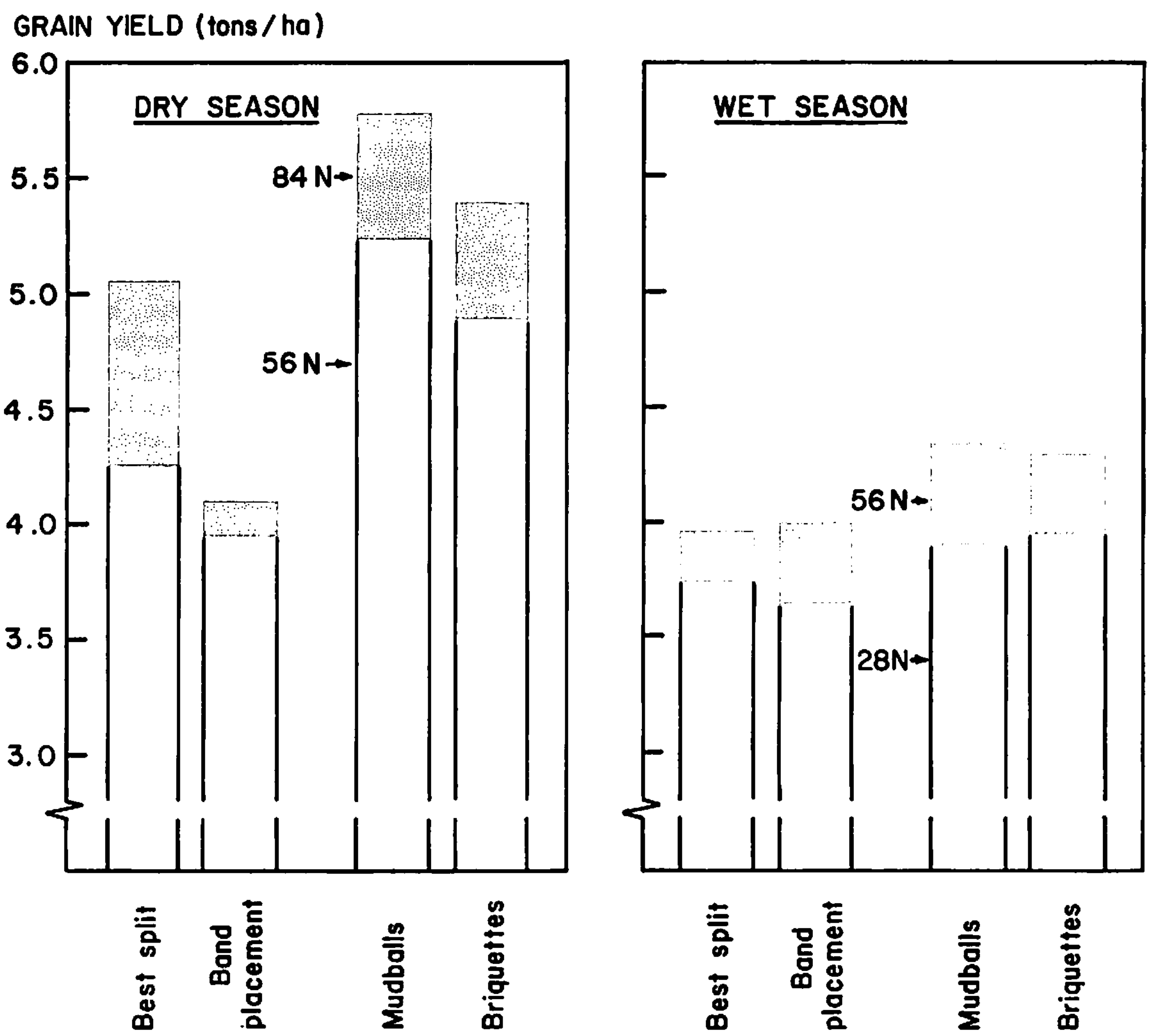

Figure 3. Rice yields following application of nitrogen by various methods: for the dry season results the clear bars refer to 56 kg N/ha and the solid bars indicate the increment gained at 84 kg/ha; the corresponding wet season values are 28 and 56 kg/ha.

Time of application

There are two stages in the growth of transplanted rice at which the efficiency of fertilizer nitrogen appears to be highest. One is soon after transplanting, to encourage maximum tillering, and the second is just before or at panicle initiation, to encourage the maximum number of panicles and of grains per panicle (De Datta 1977). The plants still, however, require nitrogen up to ripening stage (Matsushima 1964).

The number of N applications for rice has probably received more attention than any other aspect of fertilizer use, but the results are confusing. Split applications are recommended for weak-strawed varieties and for coarse texture soils (Evatt 1964) to prevent lodging (IRRI 1967) or to minimize leaching losses. Furthermore, split applications may be desirable from the point of view of the ability of the plant to utilize smaller amounts of N effectively at a particular growth stage.

Based on the studies of De Datta et al. (1974), Singh and Singh (1974) and IRRI (1975b; 1976), it can be concluded that split application of fertilizer N (basal plus at the tillering stage, or 5 to 7 days before panicle initiation) is superior to a single basal application; to a single application at any stage of growth irrespective of season; for both early and intermediate maturing varieties and especially for soils coarse in texture. Split applications of fertilizer N may also be advantageous for sustained production of fish food organisms.

Sources of N

Basically, rice fields in tropical Asia are fertilized with two major sources of N fertilizers: organic and inorganic. Both are also used for fish production. The organic sources include compost, animal manure, rice straw, Azolla and blue green algae, and some green manure crops (Tanaka 1977; Shiga 1976). The widely used inorganic N fertilizers include ammonium-containing or ammonium-producing substances, such as ammonium sulphate, urea, ammonium chloride and anhydrous ammonia (De Datta 1977). All the N fertilizers commonly used by farmers in Southeast Asia may still be used when fish are to be stocked in rice fields since there is no report of their harmful effects in rice-fish culture. Within their own limitations, both the organic and inorganic fertilizers are equally effective in rice production. In general, organic fertilizers are incorporated into the soil several days or weeks before the establishment of the crop and are needed in greater bulk compared to inorganic sources.

Phosphorus (P)

Under normal conditions, paddy rice fails to respond to P fertilization even though upland rice grown on the same soil shows a positive response (RICE 1970; Chang 1976). This may be attributed to the reduction of insoluble ferric phosphate to soluble ferrous phosphate on flooding (Ponnamperuma 1976; 1977a), which increases the availability of P. Adequate P in the soil is essential and if it is limiting, plants do not grow normally and yields are depressed. Furthermore, where P is deficient, hardly any benefit can be derived by adding N and/or potassium (Singh et al. 1975; 1976). P is also one of the major nutrients necessary for the establishment of natural fish food.

More recently, it has been realized that P deficiency is a widespread nutritional disorder of rice on millions of hectares of Ultisols, Oxisols, acid sulphate soils, Andosols, Vertisols and certain Inceptisols. Not only are these soils low in available P but they also fix fertilizer P as a highly insoluble mineral. Furthermore, the increase in availability of P brought about by soil flooding is slight in these soils (Ponnamperuma 1977b). It is suggested that this increase is appreciable only on soils high in organic matter and low in iron.

The P-fixing capacity of a soil is an important factor in recommending adequate levels of P for the desired fertilizer response. Although the mobility of phosphate may be greater in wetland than in dryland soils, the soluble phosphate applied to wetland soil is still largely fixed (Chang 1976). Studies indicate that P-fixation in wetland rice soil is rapid for acid and neutral soils and considerably slower in slightly alkaline soils (De Datta et al. 1966). The relative amount of phosphate fixed by aluminum, iron or calcium depends on their available reactive surface areas in the solid phase and their concentrations in the soil solution.

Requirements

Different amounts of P are recommended for different soils depending on their P-fixing capacity and content. About 30 to 60 kg P_2O_5/ha is generally recommended for lowland rice (RICE 1970) and this may be increased by about 50% for soils which are highly P-deficient and for rice-fish culture.

Methods of Application

The uptake of fertilizer P by rice is low. Because P is relatively immobile, proper placement in the rootzone is suggested. Placement at minimum incorporation depth is usually most effective on upland crops and also appears suitable for paddy rice (RICE 1967). Moreover, recent tests with radio isotopes showed no advantage of deep placement of P (De Datta 1977).

In general, P fertilizer is applied before transplanting either by broadcasting on the soil surface or by broadcasting and soil incorporation. Both methods give comparable yields.

Time of Application

P should be applied early enough to ensure the development of a good root system, because during the early stages of growth, the P available from the soil may be inadequate. Also, the rice plants take up the bulk of their P requirements during the early stages of growth. A later application can be made, provided it is not later than the time of active tillering (Figure 4). P applied during the tillering stage is mostly utilized for grain production. In general, most P applications should be made as a basal application (De Datta 1970; Patrick and Mikkelsen 1971). Split applications have not proved valuable because there is a great mobility of P from old leaves to young ones, the availability of soil P increases with time during submergence, and leaching losses are low (Chang 1976).

Sources of P

Other than in extremely acid or alkaline soils, few significant differences have been found among the effects of various P fertilizers on wetland rice. Superphosphate is widely used in India, Pakistan, the Philippines, Korea and Burma, as is rock phosphate in Sri Lanka, Malaysia, Thailand, Khmer Republic and Vietnam (Mukherjie 1962). On the acid soils of South and Southeast Asia, rock phosphate and bonemeal usually are better than superphosphate. Duangpatra and De Datta (1969) reported that on Buenavista clay soil (pH 6.0, organic matter 0.8 to 1.3%, cation exchange capacity (CEC) 20 to 30 meq/100 g soil), urea-ammonium phosphate with various N:P ratios was as effective as superphosphate for wetland rice, whereas Florida ground rock phosphate was poor. Ammonium

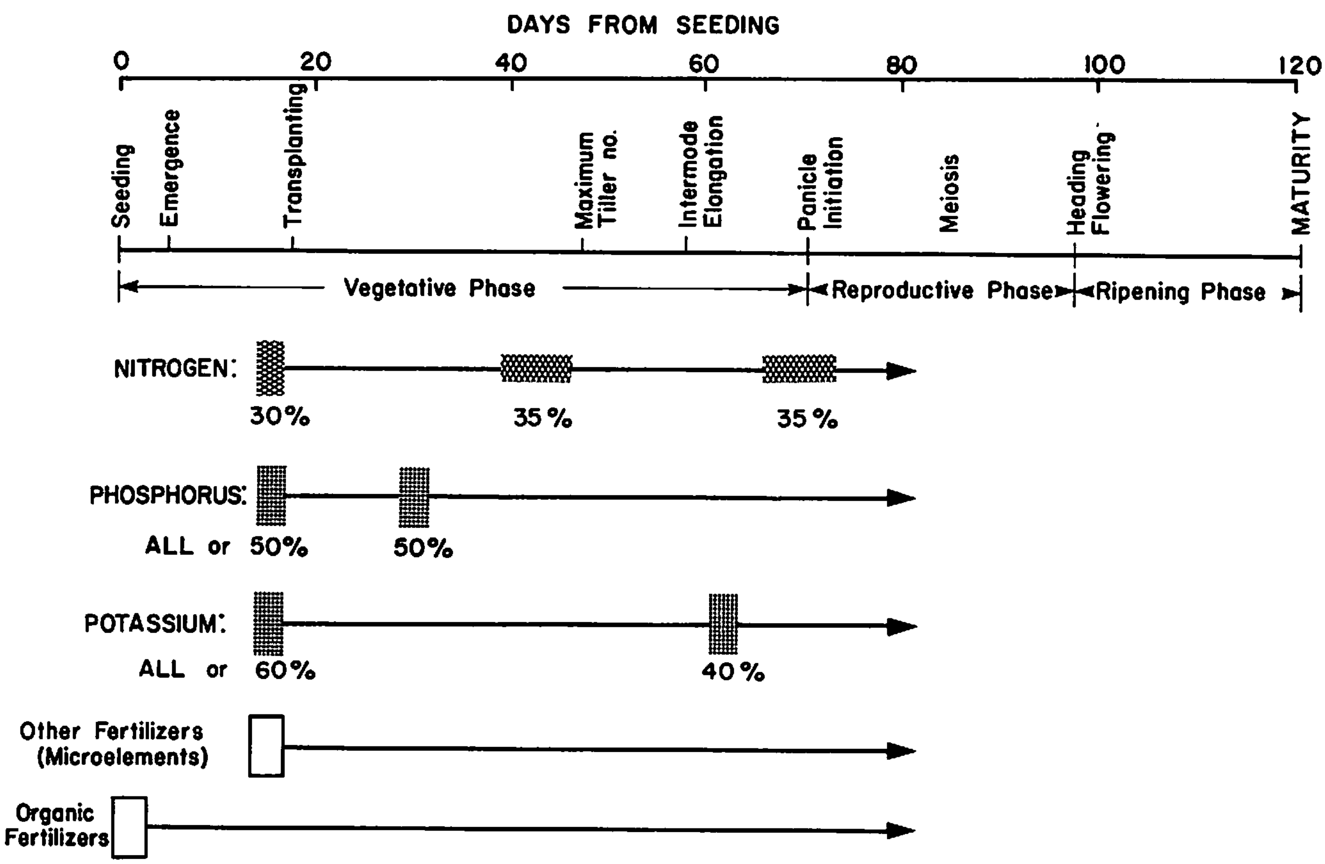

Figure 4. A fertilizer management scheme for transplanted lowland rice.

phosphate should, however, be used with caution where lodging[2] is expected, since it supplies both N and P.

Potassium (K)

The requirement of the rice plant for K is much greater than for either N or P. About 80 to 90% of the absorbed K is found in the straw and hulls. If these residues are returned to the soil, a high proportion of their K can be recirculated. The greatest need for K fertilizers may occur on sandy soils.

Requirements

Except for a few isolated cases in Taiwan, Korea, Sri Lanka and the Khorat region of Thailand, reports show that most soils in Asia do not need K as much as N and P (De Gues 1954). From the low response of rice to K application, it is considered that its K requirement is supplied from plant residues turned under and from K in irrigation water (Desai et al. 1958), or from weathering of primary minerals in young soils (Bunoan et al. 1970). Nevertheless, it is recommended that about 30 to 45 kg of K_2O/ha be applied on deficient soils.

Methods of Application

K can be applied by top-dressing or by mixing it with soil. Generally, it is recommended that K be applied with P at or before planting.

Time of Application

K is generally applied during the final land preparation, although Su's review (1976) concludes that: 1) K absorbed at the maximum tillering stage increases the number of panicles and grains, 2) K absorbed at panicle initiation increases the number of panicles and grains as well as weight of grains and 3) K absorbed after panicle formation mainly helps to increase grain weight. Therefore, K should also be applied in split applications beginning at active tillering (Su 1976). Sometimes, response to split applications of K is related to the optimum N:K ratio. Basal K application should be avoided where N supply from the soil and from basal application is low, the cation exchange capacity of the soil is low and the soil has excessive natural drainage (Von Uexkull 1970).

[2]Collapse of the crop due to poor rooting, adverse weather, etc.

Sources of K

There is not much controversy regarding the sources of potassium for lowland rice. Potassium chloride and complete fertilizer (N P K) are the common sources of K, although potassium sulfate may be equal to or better than potassium chloride in calcareous soils with a high pH (De Datta 1970).

Other Elements

Although other elements, such as calcium, iron, silicon, manganese, zinc, cobalt and molybdenum are important in rice production, supplementation is needed only in certain deficient soils or when deficiency symptoms are seen. Other than N and P, zinc has recently been considered as perhaps the most important nutritional element limiting the grain yield of wetland rice because of the effects of continuous flooding (Ponnamperuma 1977b; Castro 1977). Zinc application to the soil, dipping seedlings in zinc solutions, foliar zinc sprays and other treatments have proven satisfactory (De Datta 1977).

Deficiencies of other elements have also been reported from various countries but are very localized. It is recommended that, in addition to specific treatments, deficiency-resistant rice varieties should be grown because some varieties grow successfully on soils deficient in a particular nutrient element.

Summary of the Implications of Fertilizer Use for Rice-Fish Culture

1. The amounts of N fertilizers applied may have to be increased by about 50% for rice-fish culture. Large amounts and untimely application of N fertilizers in rice fields, however, may lead to high N losses through various mechanisms, especially runoff, and also may depress fish growth due to high ammonia concentrations in water (Colt and Tchobanoglous 1978). Excessive amounts of N fertilizers may also reduce rice yields due to lodging and more severe disease and pest attacks. It is therefore recommended that N fertilizers should be applied in split doses to achieve maximum fertilizer use by the crop.

2. It is always advisable to incorporate N fertilizers into the soil to reduce N losses, especially through runoff, which can reduce the rice yield due to low N

(Singh 1978) and the fish yield due to ammonia toxicity. The possible methods are either to use slow release sources of N, such as mudballs and sulfur coated urea, or to incorporate the fertilizer into the soil by mixing with the last harrowing before planting and by mechanical means (such as rotary weeders) after transplanting (Singh 1978). It should be noted, however, that although rootzone application of N is recommended for higher rice yields, its effects on the growth of fish food organisms are not known.

3. Organic manures are suitable for both rice and fish. They can act as a substrate for the growth of fish food organisms. To avoid any toxic effects, however, they should be applied several weeks before transplanting and the fields should be kept flooded to have complete decomposition.

4. The levees of the trenches and paddy fields should be high enough to prevent flooding and runoff in case of heavy rainfall after fertilization application. Sufficient water should be drawn off to drive the fish into the trenches before applying fertilizers.

5. Application of P is extremely important for rice production and for the growth of fish food organisms. Many studies report that optimum P applications (30 to 50 kg P_2O_5/ha) are more important for algal growth than any other nutrient. Split applications of P may prove better for sustained plankton growth without hampering the yield of rice as long as they are made before tillering, or if made as later applications, are additional to the requirements of the rice crop. The various methods of P applications (surface or soil incorporation) produce similar rice yields, but their effects on plankton production have yet to be determined for rice-fish culture. It is anticipated that surface application should prove better since most plankton grow in the water column.

WATER MANAGEMENT

Water is regarded as the most important single factor in rice production, and water management, both irrigation and drainage, requires continuous attention. Rice yields are generally higher in the dry season than in the wet season, and irrigation to allow a dry season crop in previously nonirrigated areas may more than double their total annual production. It may be the most effective way to increase rice production in many cases.

Water Requirements

The water requirements for tropical rice production have been measured in a number of places, but the results vary widely depending on environmental, management and soil conditions. The water requirements for a rice crop from transplanting to harvesting have not been precisely defined because of variations in 1) the antecedent moisture in the soil, 2) soil type and fertility, 3) length of the growth period, 4) methods of cultivation, 5) topography and 6) variety. Furthermore, rice requires different amounts of water at different growth stages.

Studies at IRRI (1970) during the dry season showed that when cumulative water reaching the crop was from 750 to 1,000 mm, there was no significant change in yield, but when it was below 550 mm, essentially no yield was obtained (Figure 5). System studies in Taiwan during the wet season revealed a sharp yield reduction below 600 mm. In general, the water requirements for rice are relatively critical below soil saturation levels but are relatively non-critical with standing water depths of 100 to 150 mm. At greater depths lower yields can be expected. Fish in rice paddies need deeper water depths, especially in trenches, but this does not affect the rice crop because the trenches are generally left unplanted.

The water requirements for lowland rice comprise evapotranspiration (ET) plus seepage and percolation (S and Pe): collectively termed the field water requirement.

Minimum water requirements are generally estimated at about 1,000 mm per crop, although ET alone accounts for 600 to 700 mm depending on the growth period, season and other factors (IRRI 1963). In most of the tropics, the ET requirement during the wet season is approximately 4 to 5 mm/day. During the dry season, 5 to 7 mm/day may be required for large irrigated areas (De Datta et al. 1970). For small irrigated areas, the ET

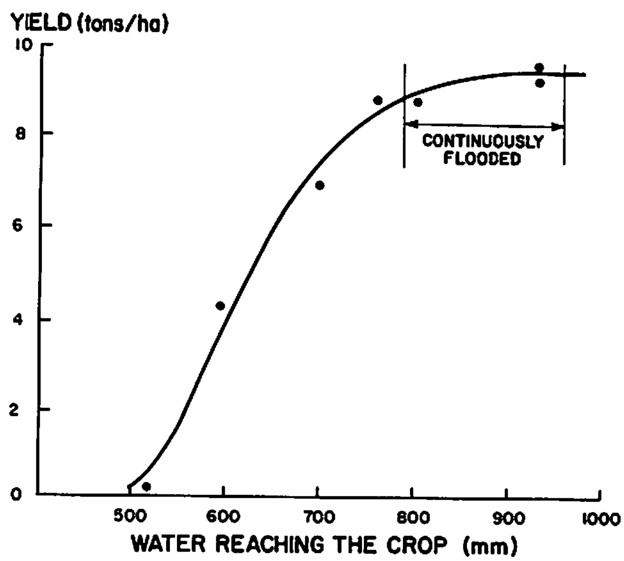

Figure 5. The yield of rice (variety IR-18) as a function of applied water during the dry season, 1969, IRRI, Los Baños, Laguna. Philippines. (R. Reyes, unpublished data, IRRI).

requirement may be even larger because of dry winds blowing from unirrigated areas.

Where fish are to be stocked in rice paddies, the water requirement may increase by two or threefold because deeper water depths of at least 10 cm are required and the trenches must also be filled with water.

S and Pe losses are a function of soil type, topography and management factors (Wickham and Singh 1977). For heavy soils, or where the water table is close to the soil surface, percolation losses are low (approximately 1 mm/day or less) but they may be very high (about 10 mm/day or more) for lighter soils or when the water table is deep (De Datta et al. 1970; Wickham and Singh 1977). If percolation losses are very high, it is difficult to maintain the soil in saturated or flooded conditions. Under such conditions, both rice and fish culture should be avoided.

Mean S and Pe rates for Philippine field areas are about 2 mm/day in the wet season and 4 mm/day in the dry season (Wickham and Singh 1977). The dry season value reflects deeper depths to the water table, increased drought stress and the higher perimeter: area ratios of dry season planted areas. S and Pe rates are site specific, however, with negative values found for areas with positive hydrostatic (artesian) pressure, and more than 25 mm/day for sites with unfavorable characteristics.

Methods of Water Application

For rice-fish culture, the standing water depth should be the maximum tolerated by the rice. A minimum of 5 to 7 cm of water is considered necessary for rice. Water change or leakage should be avoided as much as possible as it entails loss of fertility and fish food organisms. For rice, water depths starting at 3 to 5 cm can be increased with crop growth (Figure 6).

There are two methods of applying required water to the rice crop: continuous submergence and intermittent irrigation. The advantages and disadvantages of each must be weighed for each site.

For continuous submergence, the paddy field is kept flooded from transplanting time to about 2 wk before harvest. The water depth may vary depending upon the water availability and management practice; at least 10 to 15 cm is desirable for fish culture. This method requires less supervision, controls weeds more effectively and is well suited to rice-fish culture.

With intermittent irrigation, the paddy field is alternately flooded and drained and the soil surface allowed to dry prior to the next water application. The advantages of this method are 1) aeration of the soil, thereby avoiding the formation of toxins detrimental to the plants, 2) savings on irrigation water and 3) minimizing drainage problems. This method is not generally suitable for rice-fish culture, however, as fish require a standing water depth throughout the growth period.

Time of Application

Water is required at all stages of rice growth from land preparation to maturity and, therefore, the time of application cannot be defined. In general the best rice yields are produced when the soil is maintained under flooded or saturated conditions. Under limited water

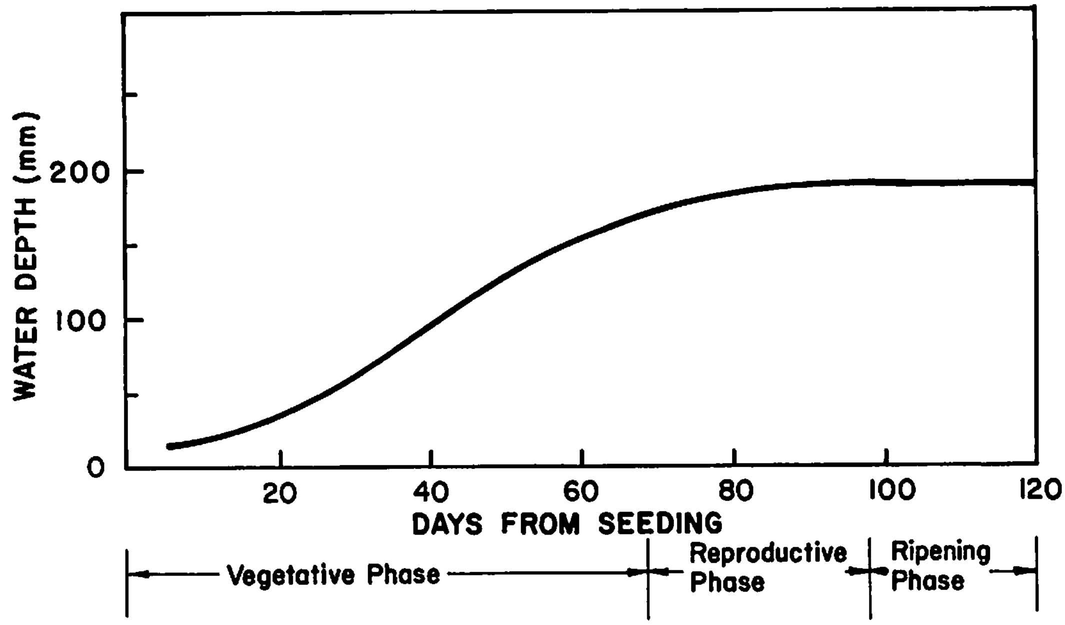

Figure 6. The variations in water depth for the vegetative, reproductive and ripening phases of rice.

supply, especially during the dry season, irrigation must be scheduled to use water most effectively. Any stress from water shortage occurring at the panicle initiation stage results in drastic decreases in yield and water availability is therefore imperative at this stage.

Implications for Rice-Fish Culture

1. Rice can be grown successfully in saturated soils with no standing water, but continuous standing water is essential for rice-fish culture. Ideally the fish should be at water depths two or threefold higher than for rice alone, i.e., 15 to 20 cm in the field and about 50 to 60 cm in the trenches. This additional water requirement has many implications for water management. It may result in a water shortage for the successive crop. This suggests that fish should be grown in the wet season only when the water supply is abundant or in areas where the water supply is assured even during the dry season.

2. Areas with high soil percolation may be unsuitable for rice-fish culture because of their very high water requirements.

3. Continuous flooding with a minimum standing water depth of 10 cm is required for rice-fish culture. Intermittent irrigation can only be practiced if trenches are provided and kept full of water for fish refuges during dry periods.

INSECT PEST CONTROL

Rice yields are depressed by insect pests (IRRI 1976). The losses may be slight or as high as total crop failure. The losses depend on the severity of the attack and stage of rice growth. Pathak (1970) summarized the results of 24 experiments in 6 croppings and reported about 80% yield reduction with no protection.

The use of insecticides to control pests can affect rice-fish culture, since insecticides can be toxic to fish (Yoshihiro et al. 1958; Hardjamulia and Kosoemadinata 1971). The toxicity and persistence of various insecticides are presented in Table 3.

Types of Insecticides

Systemic and contact chemicals are the two types of insecticides most widely used in rice production. In some cases, systemic insecticides may prove better than contact insecticides. Insecticides in common use are listed in RICE (1967, 1970). The use of some insecticides is prohibited by law because of their long persistence and health hazards. Such legal restrictions and their effectiveness vary markedly among the Southeast Asian rice-growing countries. The recommended insecticide dose varies with the stage of growth, severity of attack, method of application and the pest species. In addition to the effects of pest infestation, the high cost and inefficient utilization of insecticides have reduced the profitability of rice growing.

Methods of Application

Foliar sprays and broadcast applications of granules are the most common methods of application. Foliar

Table 3. The toxicity to fish and laboratory rats and the persistence of various insecticides used in rice fields (adapted from the Ministry of Agriculture and Fisheries, Malaysia, 1973).

Insecticide	LD_{50} to fish (ppb)	LD_{50} to white rats (ppm)	Persistence in the environment	Persistence in biological tissues
Thiodan	0.3-8.1 5-8 (24 hr)	100	Rapidly degraded, rapid but variable rate of disappearance	Degraded and excreted
8-BHC	22 to 53 (48 hr) 77 to 790 (96 hr)	125	Variable; degradable with rapid to slow disappearance	Persistent
Endrin	0.5 to 0.3 (48 hr) 0.6 (96 hr)	17.8	Persistent	Persistent non-accumulated
Sevin	2,000 to 2,500 (48 hr) 5,500 (96 hr)	-	Rapidly degraded	Non-persistent
DDT	5.0 (48 hr) 16.0 (96 hr)	113	Persistent	Persistent
Malathion	79 to 86 (48 hr)	1,375	Rapidly degraded	Non-persistent

sprays have been less than satisfactory because of the thick rice canopy, which is not easily penetrated; environmental effects, especially rain affecting residual activity, and the difficulty of controlling internal pests, such as whorl maggot and stem borers (Heinrichs et al. 1977). Furthermore, foliar sprays provide protection only for a short period for about 10 to 15 days. Granular insecticides have increased the duration of effectiveness to 20 to 30 days (Pathak 1968) but insecticides applied to paddy water are still subject to rapid degradation and loss during heavy rains or drainage (IRRI 1978).

To increase the residual period and decrease the required number of applications, the concept of capsule application in the rootzone was developed. This gave a higher efficiency with 220 times more insecticide in leaf blades at 20 days and four times more insecticide at as much as 80 days after treatment, compared to broadcast application (Aquino and Pathak 1976). Carbofuran is a typical systemic insecticide for rootzone application. Rootzone application, using gelatine capsules, has given effective control of a number of pests (Van Halteren et al. 1974; Anon. 1974; Choi et al. 1975), but capsule production has been considered too costly and the manual placement into the rootzone too laborious for general acceptance.

In 1974, IRRI developed some mechanical devices (a liquid injector, granular applicator and slurry injector) to apply insecticides to the rootzone. The results were highly encouraging but the weight and bulk of the machines made them difficult to pull through the mud and reduced their acceptance by farmers.

In 1977, Heinrichs et al. tested a lighter, two-row liquid and band applicator and four-row liquid injector skid assemblies for rootzone application. The results indicated that one application with an injector shortly after transplanting gave pest control superior to a single broadcast application, to one root coat treatment, and to four foliar sprays. The yield for the rootzone treated rice was three times that of the broadcast treated. The application of insecticides by liquid band applicator successfully controlled whorl maggot, green leaf hopper, white backed plant hopper, yellow stem borer, leaf folder and brown plant hopper. The results were comparable to those obtained from carbofuran rootzone application in gelatin capsules. The application of carbofuran with the liquid band injector gave excellent control of most pests and more efficient insecticide use than the conventional application methods. The acceptance of the liquid band injector by farmers has yet to be determined. Further results indicate that carbofuran applied in the field and incorporated using mechanical weeders suffered less runoff losses (IRRI 1978).

Time of Application

Generally, insecticides are applied when the pests are seen in the fields, but prophylaxis with, for example, carbofuran is also recommended.

Pest Control Measures

It is not possible to discuss here the control of all the numerous insect pests of rice. Pathak (1970) gives a detailed review. Control measures can be summarized as follows:

1. Use selective pesticides against each insect.
2. Burn the dried stubble from the previous crop after harvest.
3. Use pest-resistant rice varieties.
4. Destroy intermediate and alternate hosts.
5. Practice clean weed-free culture.
6. Catch the insects by traps, if possible.

Implications for Rice-Fish Culture

The application of insecticides is a major obstacle to fish culture in rice fields. Based on the studies mentioned above, the following conclusions can be drawn:

1. Insecticides applied to a rice field can be toxic to fish (Table 3). Therefore, insecticide applications should be avoided as much as possible.
2. It is advisable to use pest-resistant rice varieties in order to reduce insecticide applications (Table 4) and to obtain good fish yields safe for human consumption.
3. Runoff losses of surface-applied or sprayed insecticides and their accumulation in fish trenches could restrict rice-fish culture (Heinrichs et al. 1977).
4. Insecticides should be applied at rootzone depth or incorporated into the soil (Heinrichs et al. 1977).
5. Ideally, fish should be removed from the field at least for 10 days if insecticides are to be sprayed or broadcast. Alternatively, the fish can be confined to the trenches by lowering the water level, but no runoff of water should be allowed into trenches for at least a week after reflooding the field. This could possibly be done by increasing the height of the trench dikes.

DISEASES OF RICE AND THEIR CONTROL

The common diseases of rice are grouped according to the pathogens involved: fungi and bacteria (Ou and Nuque 1970), viruses (Ling 1970) and nematodes

(Davide 1970). There are also the physiological diseases which are associated with nutritional disorders (Yoshida 1970). The yield losses caused by diseases vary from minimal to total crop failure. Disease control measures include the following: 1) use of resistant varieties (Table 4) and chemical control measures, 2) use of fertilizers in nutrient-deficient or poor soils, 3) avoidance of excessive application of N fertilizer to susceptible varieties, especially in wet season, and of burning straw and stubble from the previous crop (if diseased) or when another crop is to follow in the same area (these are essentially preventive measures) and 4) proper irrigation and drainage management to limit the waterborne spread of infection (Ou and Nuque 1970).

Implications for Rice-Fish Culture

Little information is available on the use of chemicals for rice disease control and their effect on fish but applications should be minimized because of the possibility of toxicity to fish.

WEED CONTROL

Weeds are a contributing cause of low rice yields. They reduce yields directly by competing with rice plants for nutrients, sunlight, and space. They reduce yields indirectly by serving as alternate hosts for diseases and pests. Yield reductions from 17 to 60% have been observed (Vega and Paller 1970). Grasses, sedges and broad leaved weeds are the most common weeds in lowland rice fields.

Control Measures

Although flooding controls the growth of some weeds effectively in lowland fields, certain additional control measures are recommended as follows:

1. Thorough land preparation.
2. Flooding the paddy at an effective water depth.
3. The use of rotary weeders.
4. Hand weeding.
5. The use of chemical herbicides.

Time of Control

In an experiment, fields were kept free of weeds for 10, 20, 30, 40, 50 and 60 days after transplanting (DAT) and then weeding was discontinued (Vega and Paller 1970). The result showed that effective weed control at 20 to 30 DAT is essential for good yields. The same authors studied the effects of competition between rice and weeds and reported that rice varieties differ markedly in their response to competition because of differences in their growth patterns. They reported that IR8 can tolerate weeds between 20 and 30 DAT without adverse effect on grain yield, while C4-63 can tolerate weeds between 30 and 40 DAT. Weeds should still be controlled as early as possible, however, to increase tillering and production.

Implications for Rice-Fish Culture

1. The methods listed above for weed control, including hand weeding and the use of rotary weeders, give almost full control and have no adverse effects on fish.

Table 4. Pest, disease and adverse soil resistance ratings of IRRI rice varieties in the Philippines: R, resistant; VR, very resistant; MR, moderately resistant; MS, moderately susceptible; S, susceptible.

	Insect pests			Diseases				Soil problems				
Variety	Green leaf hopper	Brown plant hopper (biotype one)	Stem borer	Blast	Bacterial blight	Grassy stunt	Tungro	Alkali injury	Salt injury	Zinc deficiency	Phosphorus deficiency	Source
IR8	MR	S	S	S	R	S	MS	S	MR	S	MR	IRRI 1975c
IR5	S	S	S	S	R	S	S	S	MR	R	MR	"
IR20	MR	R	S	R	R	S	MR	S	MR	R	R	"
IR22	S	R	S	S	S	S	S	S	S	S	MR	"
IR24	S	S	S	MR	R	S	S	MR	MR	S	MR	"
IR26	MR	R	MS	R	R	R	MR	MR	MR	S	R	"
IR28	R	R	R	R	R	R	MR	MR	MR	R	R	"
IR29	R	R	R	R	R	R	MR	S	MR	S	R	"
IR30	MS	R	R	R	R	R	MR	MR	MR	R	MR	"
IR32	MR	R	R	R	R	R	MR	S	–	–	–	"
IR34	R	R	R	R	R	R	MR	S	S	R	R	"
IR36	MR	VR	MR	MR	MR to R	R	VR	–	–	–	–	BPI 1978
IR38	MR	VR	MR	MR	MR to R	R	MR	–	–	–	–	"
IR40	R	VR	MR	MR	MR to R	R	MR	–	–	–	–	"
IR42	MR	VR	MR	R	MR to R	R	MR	–	–	–	–	"

Calumpang paddy soils. Philipp. Agric. 45:279-288.
Bunoan, J.C. Jr., T. Eugenio, L.M. Villegas, R. Feuer and S.K. De Datta. 1970. Response of rice to fertilization. p. 18-19. *In* The Philippine Recommends for Rice 1970. PCARR, Los Baños, Laguna, Philippines.
Bureau of Plant Industry (BPI). 1978. Plant Protection News 12(2):12-13.
Castro, R.U. 1977. Zinc deficiency in rice: a review of research at the International Rice Research Institute. IRRI Res. Pap. Ser. 9, 18 p.
Chang, S.C. 1976. Phosphorus in submerged soils and phosphorus nutrition and fertilization of rice. p. 93-116. *In* The fertility of paddy soils and fertilizer applications for rice. Taipei, Taiwan, Food and Fertilizer Technology Center for the Asian and Pacific Region, Dec. 1976. Includes discussion.
Chen, T.P. 1954. The culture of tilapia in rice paddies in Taiwan. Jt. Comm. Rural Reconstr. China Fish Ser. 2. 29 p.
Choi, S.Y., M.H. Heu, K.Y. Chung, Y.S. Kang and H.K. Kim. 1975. Rootzone application of insecticides in gelatin capsules for the control of rice insect pests. Korean J. Plant Protect. 14:147-153. (In Korean with English summary).
Chowdhury, S.L. and P.C. Rahaja. 1962. Effects of nitrogen levels, placement of nitrogen, ridging and spacing on yield of paddy. Indian J. Agron. 6:216-226.
Coche, A.G. 1967. Fish culture in rice fields: a world-wide synthesis. Hydrobiologia 30:1-44.
Colt, J. and G. Tchobanoglous. 1978. Chronic exposure of channel catfish *Ictalurus punctatus*, to ammonia: effects on growth and survival. Aquaculture 15:353-372.
Davide, R. 1970. Common diseases of rice. Part III. Diseases caused by nematodes. p. 235-236. *In* Rice Production Manual. 3d ed. Compiled by University of the Philippines. College of Agriculture, in cooperation with the International Rice Research Institute. College, Laguna, Philippines.
De Datta, S.K. 1970. Fertilizers and soil amendments for tropical rice. p. 106-146. *In* Rice Production Manual. 3d. ed. Compiled by University of the Philippines, College of Agriculture, in cooperation with the International Rice Research Institute. College, Laguna, Philippines.
De Datta, S.K. 1977. Fertilizer management for efficient use in wetland rice soils. Paper presented at the IRRI Symposium on Soils & Rice, Los Baños, Laguna, Philippines, September 20-23, 1977. 35 p.
De Datta, S.K., G. Levine and A. Williams. 1970. Water management practices and irrigation requirements for rice. Part I. Water management practices for rice production. p. 89-95. *In* Rice Production Manual. 3d. ed. Compiled by University of the Philippines, College of Agriculture, in cooperation with the International Rice Research Institute. College, Laguna, Philippines.
De Datta, S.K., J.C. Moomaw, V.V. Racho and G.V. Simsiman. 1966. Phosphorus supplying capacity of lowland rice soils. Proc. Soil Sci. Soc. Amer. 30:613-617.
De Datta, S.K., F.A. Saladaga, W.N. Obcemea and T. Yoshida. 1974. Increasing efficiency of fertilizer nitrogen in flooded tropical rice, p. 265-268. *In* Proc. FAI-FAO Seminar on Optimizing Agricultural Production under Limited Availability of Fertilizers. New Delhi.
De Geus, J.G. 1954. Means of increasing rice production. Geneva: Centre D'Etude De L'Azote. 143 p.
Desai, A.D., T.S. Rao and L.R. Hirekerur. 1958. Need for potash manuring of rice. J. Indian Soc. Soil Sci. 6:17-19.
Djaingsastro, A. 1958. Paddy-cum-milkfish culture: a creation from the lowlands of the Solo River. Proc. Indo-Pacific Fish. Coun. 7(II & III): 163-166.
Duangpatra, R. and S.K. De Datta. 1969. Urea-ammonium phosphates and other phosphorus sources for flooded tropical rice. Int. Rice Comm. Newsl. 18:1-17.
Dutt, N.K. and M.N. Bandyopadhyay. 1966. Improving rainfed rice in India. World Crops 18:18-26.
Evatt, N.S. 1964. The timing of nitrogenous fertilizers application on rice, p. 243-253. *In* Proc. Symp. on the Mineral Nutrition of the Rice Plant. John Hopkins Press, Baltimore, Maryland.
Food and Agriculture Organization of the United Nations. Biology Branch. Fisheries Division. 1957. Fish culture in rice fields–a preliminary review and annotated bibliography. Proc. Indo-Pacific Fish. Coun. 7(II & III): 193-206.
Galvez, N.L. 1963. The response of rice to fertilization under flooded and non-flooded water regions. Int. Rice Comm. Newsl. 12:135-139.
Gopinath, K. 1956. Prawn culture in the rice fields of Travancore–Cochin, India. Proc. Indo-Pacific Fish. Coun. 6(II & III): 419-424.
Grover, J.H. 1979. Rice-fish culture and the green revolution. p. 223-224. *In* T.V.R. Pillay and W.A. Dill (eds.) Advances in aquaculture. Fishing News Books Ltd., Farnham, Surrey, England.
Hardjamulia, A. and S. Kosoemadinata. 1971. Preliminary experiments on the effect of Thiodan and Endrin on fish culture in Indonesia. Inland Fisheries Research Institute, Bogor, Indonesia.
Heinrichs, E.A., G.B. Aquino, J.A. McMennamy, J. Arboleda, N.N. Navasero and R. Arce. 1977. Increasing insecticide efficiency in lowland rice. AMA (Agric. Mech. Asia) 8:41-47.
Hora, S.L. and T.V.R. Pillay. 1962. Handbook of fish culture in the Indo-Pacific region. FAO Fish Biol. Tech. Pap. 14. FAO, Rome, 204 p.
IRRI. 1963. Annual Report for 1963. International Rice Research Institute, Los Baños, Laguna, Philippines. 199 p.
IRRI. 1967. Annual Report for 1966. International Rice Research Institute, Los Baños, Laguna, Philippines. 308 p.
IRRI. 1974. Annual Report for 1973. International Rice Research Institute, Los Baños, Laguna, Philippines. 266 p.
IRRI. 1975a. Annual Report for 1974. International Rice Research Institute, Los Baños, Laguna, Philippines. 384 p.
IRRI. 1975b. Improved rice varieties needed for world's deep water regions. International Rice Research Institute. IRRI Reporter 75:1-4.
IRRI. 1975c. Research highlights for 1975. International Rice Research Institute, Los Baños, Laguna, Philippines. 107 p.
IRRI. 1976. Annual Report for 1975. International Rice Research Institute, Los Baños, Laguna, Philippines. 479 p.
IRRI. 1978. Annual Report for 1977. International Rice Research Institute, Los Baños, Laguna, Philippines. 548 p.
Johnson, L. 1967. Land preparation. IRRI Saturday Seminar Papers (7):1-4. Mimeo. IRRI, Los Baños, Laguna, Philippines.
Le Mare, D.V. 1949. Fisheries Department Annual Report. Federation of Malaya and Singapore.
Ling, K.C. 1970. Common diseases of rice. Part II. Virus diseases of rice, p. 228-235. *In* Rice Production Manual. 3d. ed. Compiled by University of the Philippines. College of Agriculture, in cooperation with the International Rice Research Institute. College, Laguna, Philippines.
Matsushima, S. 1964. Nitrogen requirements at different stages of growth. The mineral nutrition of the rice plant, p. 219-237. *In* Proceedings of the Symposium on the Mineral Nutrition of the Rice Plant, International Rice Research Institute, Los Baños, Laguna, Philippines. February 1964. John Hopkins Press, Baltimore, Maryland.
Matthes, H. 1969. The problem of rice-eating fish in the Central Niger Delta. Committee for Inland Fisheries of Africa. FAO, Rome. 26 p.
Menon, M.K. 1955. On the paddy-field prawn fishery of Travancore–Cochin and an experiment in prawn culture. Proc.

Indo-Pacific Fish. Coun. 5(II & III): 131-135.

Mukherjee, H.N. 1962. Problems of soils of the paddy field. Trans. Int. Soc. Soil Sci. New Zealand, Commission IV and V: 599-616.

Ou, S.H. and F.L. Nuque. 1970. Common diseases of rice. Part I. Fungus and bacterial diseases of rice, p. 217-227. *In* Rice production manual. 3d. ed. Compiled by the University of the Philippines, College of Agriculture, in cooperation with the International Rice Research Institute. College, Laguna, Philippines.

Pathak, M.D. 1968. Application of insecticides to paddy water for more effective rice pest control. Int. Pest Contr. 10:12-17.

Pathak, M.D. 1970. Insect pests of rice and their control, p. 171-203. *In* Rice production manual. 3d. ed. Compiled by University of the Philippines, College of Agriculture, in cooperation with the International Rice Research Institute. College, Laguna, Philippines.

Patrick, W.H. Jr. and D.S. Mikkelsen. 1971. Plant nutrient behavior in flooded soil, p. 187-215. *In* Fertilizer technology and use. 2d. ed. Soil Sci. Soc. Amer. Madison, Wisconsin.

Philippine Council for Agriculture and Resources Research (PCARR). 1976. Culture of tilapia in ponds. Pond preparation, p. 7-10. *In* The Philippine Recommends for Tilapia 1976. PCARR, Los Baños, Laguna, Philippines.

Pillay, T.V.R. and B. Bose. 1958. Observations on the culture of brackishwater fishes in paddy fields in West Bengal (India). Proc. Indo-Pacific Fish. Coun. 7(II & III): 187-192. Session, Bandung, Indonesia, 13-27 May 1957. Sections II and III. FAO, Bangkok.

Ponnamperuma, F.N. 1959. Fertilizer trials in cultivator's fields in Ceylon. Int. Rice Comm. Newsl. 8:1-8.

Ponnamperuma, F.N. 1976. Specific soil chemical characteristics for rice production in Asia. IRRI Res. Pap. Ser. 2. 18 p.

Ponnamperuma, F.N. 1977a. Physicochemical properties of submerged soils in relation to fertility. IRRI Res. Pap. Ser. 5. 33 p.

Ponnamperuma, F.N. 1977b. Screening rice for tolerance to mineral stresses. IRRI Res. Pap. Ser. 6. 21 p.

Relwani, L.L. 1963. Role of blue-green algae on paddy field. Curr. Sci. 32:417-418.

Rice Information Cooperative Effort (RICE). 1967. Rice production manual. Compiled by the University of the Philippines College of Agriculture and the International Rice Research Institute. College, Laguna, Philippines. 362 p.

Rice Information Cooperative Effort (RICE). 1970. Rice production manual. 3d. ed. Compiled by the University of the Philippines College of Agriculture, in cooperation with the International Rice Research Institute. College, Laguna, Philippines. 382 p.

Sahu, B.N. 1963. Simple fertilizer trials on rice in cultivator's fields in Orissa. Rice News Teller 11:22-24.

Schuster, W.H., G.L. Kesterven and G.F. Collins. 1955. La pisciculture et l'exploitation rationelle des pêcheries intérieures dans l'economie rurale. Etude sur la pêche. FAO, Rome 37:67 p.

Shiga, H. 1976. The role of soil nitrogen in paddy rice production. Hokuno 43:18-31. (In Japanese).

Shiga, H., W.B. Ventura and T. Yoshida. 1977. Effect of deep placement of ball-type fertilizer at different growth stages on yield and yield components of the rice plant in the Philippines. Plant Soil 47:351-361.

Singh, A. and N.P. Singh. 1974. Time and method of fertilizer application under limited availability, p. 289-312. *In* Proc. FAI-FAO Seminar on Optimizing Agricultural Production under Limited Availability of Fertilizer. New Delhi.

Singh, V.P. 1978. Nitrogen movement in water draining from irrigated riceland. Ph. D. Thesis, University of the Philippines at Los Baños, Los Baños, Laguna, Philippines. 243 p.

Singh, V.P., I.T. Corpuz and T.H. Wickham. 1975. Fertilization studies of rice grown on scraped soils, land consolidation area, Talavera, Nueva Ecija, wet season 1974. IRRI Saturday seminar paper 6. 10 p.

Singh, V.P., I.T. Corpuz and T.H. Wickham. 1976. Improving the productivity of scraped soils in Talavera, Nueva Ecija, IRRI Saturday Seminar, September 4, 1976. 24 p. Mimeo.

Singh, V.P., T.H. Wickham and I.T. Corpuz. 1978a. Nitrogen movement in water draining from irrigated riceland. IRRI Newsl. (Philippines) 3:23-24.

Singh, V.P., T.H. Wickham and I.T. Corpuz. 1978b. Nitrogen movement to Laguna Lake through drainage from rice fields. *In* Proc. International Conference on Water Pollution Control in Developing Countries, Asian Institute of Technology. February 21-25, 1978. Bangkok, Thailand.

Soong, M.K. 1950. Fishes of the Malayan padi-fields. III. Kali: catfishes. Malayan Nat. J. 5:88-91.

Soong, M.K. 1954. Fish culture in paddy fields in Federation of Malaya. International Rice Commission (IRC) 4th Session paper. IPFC contributed Publ. IPFC/C55/CP26. 5 p.

Stout, B.A. 1966. Equipment for rice production. FAO Agricultural Development Paper 84:1-169.

Su, N.R. 1976. Potassium fertilization of rice. *In* The fertility of paddy soils and fertilizer applications for rice. p. 117-148. Food Fertilizer Technology Center for the Asia and Pacific Region, Taipei, Taiwan.

Tamura, T. 1961. Carp cultivation in Japan, p. 103-120. *In* G. Borgström (ed.) Fish as food. Academic Press, New York.

Tanaka, A. 1977. Role of organic matter. Paper presented at the IRRI Symposium on Soils & Rice, Los Baños, Laguna, Philippines. Sept. 20-23, 1977. 10 p.

Tonolli, V. 1955. An observation of fish culture in rice fields. Bull. Japan Soc. Sci. Fish. 15:4.

Valera, A. 1977. Field studies on water use and duration for land preparation for lowland rice. M.S. Thesis, University of the Philippines at Los Baños, Los Baños, Laguna, Philippines. 126 p.

Van Halteren, P., S. Sama and D. Koesnang. 1974. The application of insecticides to the rootzone of rice plants in 1973 and 1974. Bull. Lembaga Penelit. Pert. Maros 4, 14 p.

Vega, M.R. and E.C. Paller Jr. 1970. Weeds and their control, p. 147-170. *In* Rice production manual. 3d. ed. Compiled by the University of the Philippines, College of Agriculture, in cooperation with the International Rice Research Institute, College, Laguna, Philippines.

Vincke, M.M.J. 1979. Aquaculture en rizieres: situation et rôle futur [Rice paddy aquaculture: its situation and future role], p. 208-223. *In* T.V.R. Pillay and W.A. Dill (eds.) Advances in aquaculture. Fishing News Books Ltd., Farnham, Surrey, England.

Von Uexkull, H.R. 1970. Some notes on the timing of potash fertilization of rice (nitrogen-potash balance in rice nutrition), p. 413-416. *In* Role of fertilization in the intensification of agricultural production. Proc. 9th Congress. Int. Potash Inst. Antibes.

Watanabe, I. 1977. Biological nitrogen fixation in rice soils. Paper presented at the IRRI Symposium on Soils & Rice, Los Baños, Laguna, Sept. 20-25, 1977. 35 p.

Wickham, T.H. and V.P. Singh. 1977. Water movement through wet soils. Paper presented at the IRRI Symposium on Soils & Rice, Los Baños, Laguna, Philippines, Sept. 20-25, 1977. 15 p.

Wyatt, I.J. 1955. Padi stem-borer investigations in Krian, Perak. IRC/BP/55/15. 4 p.

Yamada, N. and S.T.W. Kirinde. 1959. Effect of level and time of application of ammonium sulphate on broadcast paddy.

particularly in developing countries where clinical or subclinical protein-calorie malnutrition is widespread.

Aquaculture is a culturally acceptable, traditionally popular, and economically lucrative practice that could contribute substantially to the protein supply. Just as in some countries of the west, the savannah type of ecology and a unique combination of "plain and grain" have enabled them to pioneer and lead in production of livestock, the unique characteristics of tropical Asia provide perhaps the richest aquacultural potential. The rapid strides currently being made in this part of the world in harnessing water resources for expansion of irrigated agriculture create conditions that can either enhance or diminish this potential. Therefore, the real challenge is to work out adequate compromises and adjustments to evolve appropriate measures for the simultaneous development of both these food production systems. This could be done by taking maximum advantage of year-round availability of irrigation water to develop aquaculture in suitable nonarable lands within the irrigation service areas, in conjunction with adequate measures to insulate the aquaculture sites from contamination by agricultural chemicals. This paper discusses briefly some traditional techniques of aquaculture associated with agriculture and describes approaches to large-scale integration of aquaculture into irrigation systems, as evolved in the lower Mekong development project.

Traditional Aquaculture Practices Associated with Agriculture

Several forms of aquaculture are associated with traditional agriculture in Asia. Important among them are: 1) rice-fish farming, 2) alternating rice and fish crops, 3) homestead fish ponds integrated within an agricultural system, and 4) cages or pens installed in irrigation canals. These forms of aquaculture have played a significant role in augmenting the farmer's meager agricultural income and providing a source of protein in his diet.

Rice-fish culture is practiced all over Asia in some paddy fields where a copious water supply is available. Effective fish culture in paddy fields involves certain modifications to the fields, such as construction of higher dikes, ditches around the periphery and sometimes in the center of the fields, and excavation of ponds at suitable locations within or adjacent to the paddy fields, to serve as refuges for fish. In northeast Thailand, production of fish from rice-fish culture ranges from 0.11 to 0.30 t/ha/yr while paddy field fish culture operations (without rice) yield harvests ranging from 0.30 to 1.71 t/ha/yr. Net incomes per hectare from these sources range from US$17.38 to US$1,268.22 (Table 1), depending on the sophistication of management applied, quality and quantity of supplemental feeds and fertilizers used, and the species cultivated. The fish most commonly used in this type of culture in Thailand are *Trichogaster pectoralis*, *Sarotherodon niloticus*, and *Cyprinus carpio*. Elsewhere in Asia the Indian major carps, *Clarias* spp., the Chinese carps, and prawns comprise the most common cultivated species. Yields as high as 937.5 kg/ha/yr are reported from rice-fish culture fields in China (Tapiador et al. 1977).

In some parts of India, fish and prawn culture is also practiced alternately with agriculture in some paddy fields with plentiful water supply and poorly drained soils. This practice could be adapted to aquaculture in irrigation systems and fish could be raised as an alternate second crop provided the use of pesticides is minimal.

In parts of Asia, including the Mekong basin, irrigation and homestead ponds connected to paddy fields are used for fish culture. In some instances, these ponds are connected to the fields by an open channel which provides free passage for the fish to enter and forage in the fields. When the fields are drained, the fish take

Table 1. Total annual yields and crop values per hectare from combined operations including integrated rice-fish farming and alternate rice and fish culture in paddy fields in Northeast Thailand by province (Thailand Department of Fishery Statistics, Mekong Basinwide Fishery Studies, 1976–at 1973 currency rates).

Province	Yield (t/ha)	Value (US$/ha)	Cost of production (US$/ha)	Net income (US$/ha)
Kalasin	0.19	91.52	11.86	79.66
Khon Kaen	0.25	126.67	5.77	120.90
Maha Sarakham	1.71	1296.26	28.04	1268.22
Nakon Rajsima	0.05	30.49	13.11	17.38
Nong Khai	0.17	130.16	12.89	117.27
Surin	0.17	148.94	6.39	142.55
Ubon Ratchathani	1.43	941.40	98.72	842.68

refuge in the ponds. As reported by Kloke and Patros (1975) in this form of fish culture, the net incomes per unit area realized by the farmer are higher than those from irrigated and nonirrigated farming by factors of 21 and 74 times, respectively.

Rice-fish culture is not a success story everywhere. There are many instances where it has been abandoned due to considerable fish losses mainly through poaching, predation by birds and snakes, flooding, and inadvertent introduction of pesticides from neighboring fields. A Mekong Committee-sponsored socioeconomic survey in Kalasin agricultural farms in Thailand has indicated that the risk of such losses, viewed against the relatively high initial investment required for modifications to the fields and towards the cost of fry and feeds, generally discourages many farmers from venturing into this type of fish culture. Therefore, the area under rice-fish culture has been gradually but perceptibly dwindling almost everywhere.

Rice-fish culture is generally considered as being beneficial to the paddy crop in that, theoretically at least, the fish might curb insect infestation by feeding on them, encourage tillering by their movements, and fertilize the fields with their excreta. While really convincing proof of these benefits is lacking, there is incontrovertible evidence that some varieties of fish could severely damage rice plants. Matthes (1977) has observed from experiments in the central delta of Niger in 1969 that fish such as *Distichodus brevipinnis, D. rostratus, Tilapia zillii* and *Alestes dentex* can cause significant damage to tender rice plants. There are no similar recorded observations for Southeast Asia and therefore a study to identify potentially harmful species and the nature and extent of damage they could inflict should be taken up before any serious attempts are contemplated to develop this type of fish culture in association with nonpesticide dependent, irrigated agriculture.

Culture of fish in floating cages and pens erected in irrigation canals is sometimes practiced in several parts of Asia. Such practices are neither widespread nor properly organized at the present time. Also, while descriptions of floating cage and pen culture practices in larger bodies of water, such as reservoirs, rivers and swamps are available in the literature, no accurate records of these practices in irrigation canals exist.

Irrigation Systems

Irrigation systems are generally associated with such structures as dams and polders. As irrigation systems are laid out primarily for agricultural development, all available arable lands within these systems are usually commandeered for agriculture, so as to derive the maximum possible benefit from the irrigation water. This leaves only nonarable lands of marginal value, such as those with soil qualities unsuitable for agriculture or those that cannot be levelled for irrigated agriculture, for aquaculture development purposes. Criteria for site selection for aquaculture lands are, however, as stringent as those for agriculture (see below). With a few exceptions, soils considered suitable for aquaculture are also usually those that are also suitable for agriculture. Hence, if aquaculture is to be developed within irrigation systems, it will first be necessary to identify the areas suitable for aquaculture but unsuitable or poorly suited for agriculture.

Generally speaking, most soils can be adapted for agricultural use by making appropriate improvements, but the magnitude of the costs involved may limit the use of soils in some areas. The characteristics that render soils poorly suited, or nonarable for rice and upland crops, have been listed (Government of Thailand 1973).

The choice of nonarable lands for aquaculture development is restricted to land with one or a combination of the following characteristics (provided they also conform to the criteria set for aquaculture):

1. Lands with undulating topography, which makes them less suitable for large-scale irrigation development.
2. Soils with structures unsuitable for crops.
3. Saline soils where ECe x 10^6 (electrical conductivity of saturation extract) exceeds 4,000 micromhos.
4. Soils with high or low pH levels unsuitable for crops (provided that the pH values of supernatant water, when flooded, will be in the range 6.0 to 8.5).

Besides lands with the above characteristics, there may also exist large seasonally inundated areas, ponds and other water bodies within irrigation systems which can also be developed for intensive aquaculture taking advantage of the year-round availability of irrigation water, provided that these areas have drainage facilities and can be effectively insulated from contamination by pesticides through agricultural return flows or airborne dusts and sprays.

Integration of Aquaculture and Agriculture–The Mekong Case

The Committee for Coordination of Investigations in the Lower Mekong Basin (Mekong Committee), which is charged with the responsibility of developing water and related resources in the lower Mekong basin, has adopted a policy of utilizing irrigation water for developing aquaculture on a large scale in nonarable but aquaculturally suitable lands in the irrigation service areas of dams constructed under its auspices, to replace the fishery losses resulting from dam construction. This new concept of "irrigated aquaculture" was first examined in detail in 1972, during the feasibility study of the proposed Pa Mong dam on the mainstream Mekong. Detailed surveys were conducted (US Bureau of Reclamation 1972) to locate the extent of nonarable land suitable for aquaculture within the Pa Mong irrigation service area in the Lao People's Democratic Republic (PDR) and Thailand. Estimates arrived at as a result of these surveys are given in Table 2.

Lands are adjudged as being suitable for aquaculture on the basis of the following criteria:

1. Suitable topography, to allow construction with a minimum of earth movement.
2. Fertile soil, free of toxic effects.
3. pH values not less than 6.0 and not more than 8.5.
4. Low seepage rate.
5. Adequate and secure supply of good quality water.
6. Availability of drainage channels and protection against flooding.
7. Freedom from contamination by pollutants.
8. Possibility of reuse of fish farm drainage water for irrigation.
9. Access to roads and to electrical power supply.
10. Integration into regional development works, such as flood protection, drainage and irrigation facilities, etc.
11. Absence of agricultural land within the aquaculture area.

Table 2. Summary of irrigable areas available for agriculture and nonarable land suitable for aquaculture by division and province for the Lao PDR and Thailand.

Division		Irrigable areas for agriculture (ha)	Areas available for aquaculture (ha)
Lao PDR			
Vientiane		10,620	1,350
Nam Lik		30,720	3,900
Vientiane extension		14,720	1,840
Laos Pumping		46,070	5,850
	Subtotal	102,130	12,940
Thailand			
Huai Mong		29,370	3,730
Udorn		185,720	23,630
Kumphawapi		33,380	4,240
Lam Phaniang		144,710	18,380
Huai Pong		210,280	26,700
Khon Kaen		71,330	9,060
Nai Nah		45,450	5,770
	Subtotal	720,240	91,510
	Total	822,370	104,450

Farm Fisheries

The Mekong Committee proposes to develop selected sites as fish farms (farm fisheries as they are styled in this paper within these irrigation service areas, using the Pa Mong project as a pattern. The farm fisheries will be collections of independent units, each approximately 50 ha, operated by fish farmers with technical assistance and support services provided by extension staff of the Pa Mong project. The projected yield is about 6 t/ha/yr. It is therefore estimated that even 5% of the suitable nonarable areas under the Pa Mong project could yield 30,000 t of fish per year which would more than compensate for the anticipated fishery losses of 19,000 t/yr (9,000 t/yr due to losses in the river downstream and 10,000 t/yr due to conversion of existing fisheries and aquaculture areas into agricultural lands) (Mekong Committee 1976).

Planning Considerations

Farm fisheries within the irrigation service areas will be fed from the same main irrigation canals as agricultural lands. Their water will be returned for reuse in the irrigation system, apart from losses through seepage and evaporation. Initial filling, or refilling, of ponds will be done during months of minimum irrigation demand: August to September. In the following 3 to 4 mo, irrigation demands are also usually low and ideal fishpond levels can be maintained with liberal replenishments of water. Full canal capacity will be required for agricultural purposes from January to April when the fish farm requirements will have to be curtailed. Fish culture systems with high water demand will not be possible during this period. Lateral canals will be used exclusively for fishpond water deliveries, to reduce chances of contamination through agricultural return flows and to allow rapid filling when required.

Operation and Maintenance

Farm fisheries appear to be compatible with related agricultural service irrigation operations, as their maximum water deliveries will occur during periods of low demand. The physical support facilities will include fishponds and hatcheries. Water management will be relatively easy as the farm fishery units will consist of one or more series of ponds with separate inlets and outlets. The main demands on the irrigation system will be to ensure that sufficient water is delivered to maintain full ponds for 5 to 6 mo and that further minimal deliveries made during the remaining months compensate fully or partly for evaporation and seepage losses.

Maintenance of the farm fisheries will consist primarily of maintaining the width and elevation of the dikes and controlling their weed populations. This will be facilitated by establishing a good growth on the dikes of desirable grasses and other plants, which could also serve as feed for phytophagous fishes such as grass carp. The narrow roads on top of some dikes and the internal water distribution system will also require some maintenance. Hand labor is planned for all maintenance requirements.

The farm fisheries are considered as commercial operations and it is assumed that fish culture will be the sole, full-time occupation of the farm operators. The farm operations will also be coordinated with hatchery and rearing operations, with technicians and equipment serving both functions. It is anticipated that management, based on commercial-type fish farms, will be moderately intensive and will involve weed control, control of predacious and trash fishes, fertilization to induce the proper plankton level, artificial feeding, pond sanitation, and disease control.

Harvesting operations could start 5 to 6 mo after the initial stocking and continue at suitable intervals all year round. Only one raising per harvesting cycle per year is planned for the farm fisheries where it will be desirable to begin thinning the population during the "dry months" of January to May.

Pilot Farms

To demonstrate the economic and technical feasibility of these farm fisheries and to evolve appropriate systems and levels of fish culture, the Mekong Committee approved the construction of five pilot fish farms: one each in Thailand, the Lao PDR and Kampuchea, and two in the Socialist Republic of Viet Nam. These pilot farms will be operated as demonstration and production farms, with attached aquaculture training and extension centers, and will provide the foci for future aquaculture development. They are being, or will be, constructed amid existing irrigated agriculture development areas so as to conform to the conditions that will be encountered in irrigation service areas. Preconstruction feasibility studies and operational plans have been prepared (SKR International Consultants 1975; Mekong Committee 1977).

Three different production levels, each representing a specific system of raising fish in ponds, are envisaged in the pilot farms: intensive, semi-intensive and extensive. The projected fish yields depend on the water flow directed through the ponds for oxygen supply, the quantity and quality of artificial feeds, and the species combinations. The system chosen for a given area will depend on socioeconomic conditions and the local availability of fish feed components. Imported components will be avoided throughout. Projected yields at different water flows are shown in Table 3. Fish yields will differ not only between systems but also within the same system in different locations. The terms intensive, semi-intensive and extensive are not, therefore, meant to signify specific yield levels but merely the culture systems and management levels applied. The general criteria for selection of species for culture are:

1. Fast growing domesticated species suitable for controlled culture, with known reproductive cycles and amenability to induced breeding.
2. Species with known food habits which are compatible with others in the combination used.
3. Species that meet consumer preference and command a ready market.
4. Fish that can be easily transported to market, preferably live.

The fish used in intensive culture are those that can utilize artificial feeds readily and efficiently. Here production is entirely a function of the quality and quantity of feeds provided, water flow, and stocking density. Semi-intensive and extensive levels, on the other hand, use species that can crop the natural productivity of ponds, such as plankton, detritus and periphyton. In both, manuring of ponds to stimulate growth of plankton for food and supplemental feeding with locally available feeds is envisaged. The main differences between them lie in the density of stocking, quantity of supplemental feed provided, and the water flow for oxygenation and removal of debris.

The level of management is another very important factor in determining production. The production levels planned for the Mekong pilot fish farms operated under guidance from specialists will be higher than those envisaged for the farm fisheries operated and maintained by farmers in the Pa Mong irrigation service areas. Projected yields and species combinations for the pilot farm at Tha Ngone in the Lao PDR, which is currently

Table 3. A broad assessment of the probable annual yields of fish from three production levels with related water flows for fish oxygen supply: Tha Ngone pilot farm, Lao PDR.

Production level	Water flow (m^3/hr/ha)	Probable annual yields (t/ha) range	best estimate
Intensive	150	15 to 16	16
Semi-intensive	10	10 to 15	12
Extensive	6	7 to 10	9

under construction and which typifies the Mekong pilot fish farms, are given in Tables 4 and 5.

Table 4. Projected fish yields from operations at three different production levels for the Tha Ngone pilot farm, Lao PDR.

Production level	Area (ha)	Projected yields (t/ha/yr)	(t/yr)
Intensive	1.0	16	16
Semi-intensive	15.0	12	180
Extensive	28.0	9	252
Total	44.0		448*

*This gives an average yield of 10.18 t/ha/yr.

Table 5. Proposed species combinations for three different production levels for the Tha Ngone pilot farm, Lao PDR.

Production level	Species	Combination (%)
Intensive	Catfish *(Clarias batrachus)*	60-70
	Common carp *(Cyprinus carpio)*	30-40
Semi-intensive and extensive	Common carp *(Cyprinus carpio)*	20-25
	Mrigal *(Cirrhinus mrigala)*	10-15
	Rohu *(Labeo rohita)*	10-15
	Grass carp *(Ctenopharyngodon idella)*	10-15
	Silver carp *(Hypophthalmichthys molitrix)*	20-25
	Bighead *(Aristichthys nobilis)*	10-15
	Catla *(Catla catla)*	5-10

Water Requirements

The water requirements for aquaculture include filling the ponds, compensating for evaporation and seepage losses, and oxygen supply. The main requirement is for filling ponds. For the 60-ha pilot fish farm at Tha Ngone (Lao PDR), the water flow required to obtain the minimum water level of 70 cm in a filling time of 2 d is estimated at 290 m^3/hr. The average evaporation rate in Vientiane plain area (Lao PDR), as measured by class A pan, is 4.8 mm/d, with highest values at 6.4 mm/d. Using the highest evaporation rate and the average infiltration rate of 3 to 4 mm/d at the site selected, the flow required to compensate these is estimated at 250 m^3/hr. The flow for oxygen supply will depend on the quality and quantity of feeds, the oxygen requirements of the fish and the BOD. For Tha Ngone this is estimated at 150 m^3/hr. The annual water requirement for this fish farm is given in Table 6. All this water, apart from what is lost through evaporation and seepage, will be reused for agriculture.

Table 6. Annual water requirements (m^3) for the Tha Ngone pilot farm, Lao PDR.

1. Water for fish oxygen supply 150 m^3/hr x 8,500 hr	1.275×10^6
2. Water for filling auxiliary ponds 6 ha x 12,000 m^3/ha x 2 cycles	0.144×10^6
3. Water for filling production ponds 44 ha x 17,000 m^3/ha x 2 cycles	1.496×10^6
4. Water to cover evaporation and seepage losses 60 ha x 84[1] m^3/ha/day x 365 days	1.840×10^6
Total (A)	4.755×10^6
5. Effective rainfall (B) 60 ha x 10,000[2] m^3/ha	0.600×10^6
Average annual requirement (A-B)	4.155×10^6

[1]The average evaporation and seepage losses is 4.8 + 3.6 = 8.4 mm/d or 84 m^3/ha/d.
[2]The average rainfall is 1.7 m/yr of which about 1 m is estimated to be the useful or effective rainfall.

Table 7. The dimensions for spawning, nursery, growout and auxiliary ponds in the Tha Ngone pilot farm, Lao PDR.

Type of pond	Number of ponds	Depth (m)	Area of each pond (ha)	Total area (ha)
1. Broodstock ponds	5	1.5	0.20	1.0
2. Nursery ponds	20	1.1	0.05	1.0
3. Rearing ponds	19	1.3	0.20	3.8
4. Auxiliary ponds for additional rearing and growout or holding prior to marketing	2	1.7	0.1	0.2
Total	46			6.0

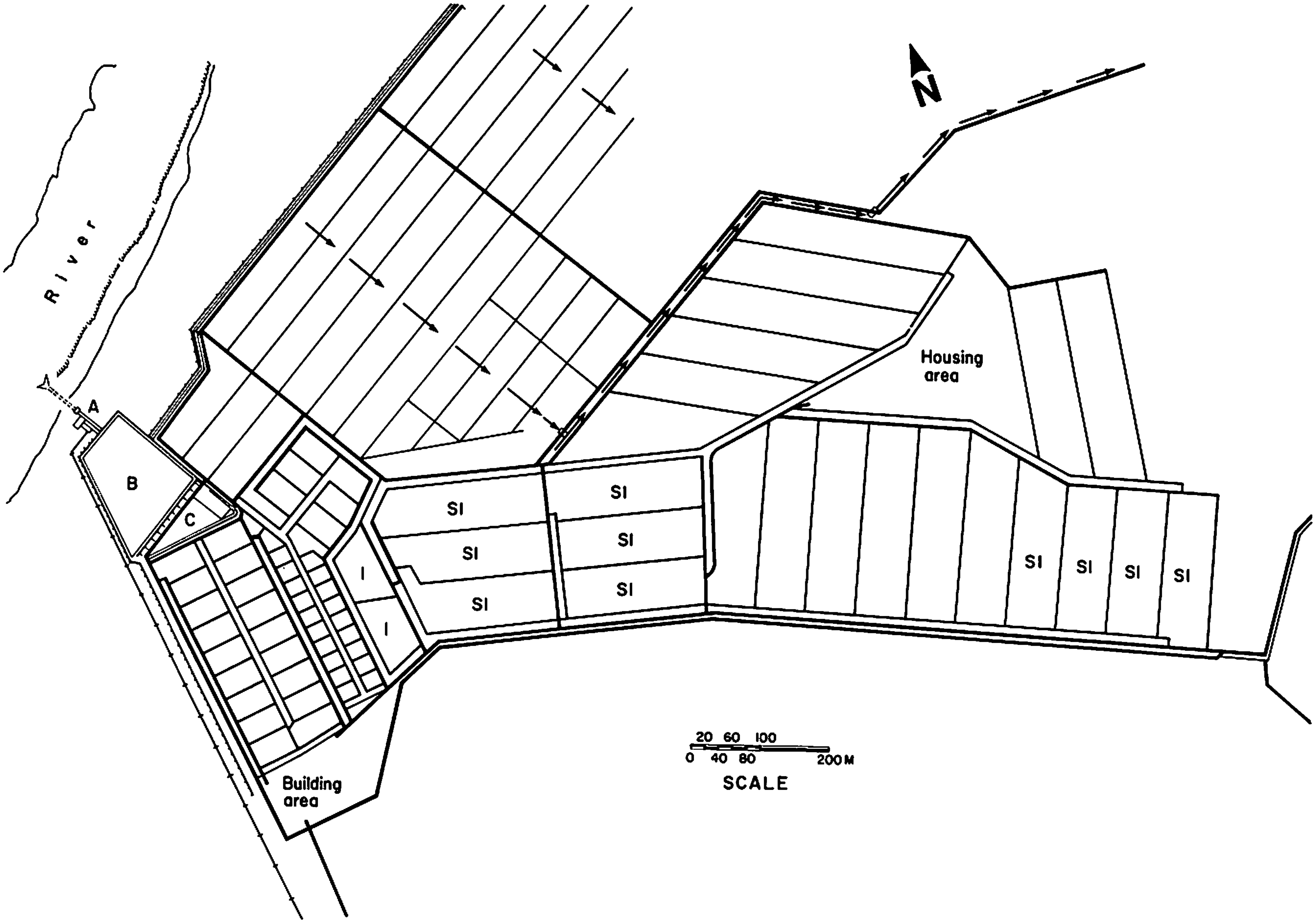

Figure 1. Design of the proposed Tha Ngone pilot fish farm. Smallest ponds are nursery ponds. Above and left are spawners and rearing ponds. I, intensive ponds, SI, semi-intensive. Remainder of ponds are for extensive farming. The fish farm is part of a large agricultural complex. Arrows show flow of irrigation water through fields. A, irrigation pumping system. B, irrigation regulating pond. C, fish farm regulating pond.

Table 8. Summary of the planned facilities, inputs and projected yields for the Tha Ngone pilot farm, Lao PDR.

	Production ponds				Other ponds					Grand
	Intensive	Semi-intensive	Extensive	Total	Nursery	Rearing	Auxiliary	Broodstock	Total	Total
1. Area (ha)	1.0	15.0	28.0	28.0	1.0	3.8	0.2	1.0	6	50
2. Number of ponds	2	10	14	26	20	19	2	5	46	72
3. Pond size (ha)	0.5	1.5	2.0	–	0.05	0.2	0.1	0.2	–	–
4. Water requirement (m^3/hr/ha)[1]	150	10[1]	6[1]	–	–	–	–	–	150	–
5. Fish distribution	Cb[2]:Cc	Cc:M:R:Gc:Sc:Bh:C		–	All 7 species stock individually		Cb	All carps	–	–
6. Ratio of each sp. (%)	67:33	25:10:15:15:20:10:5		–	species ratio same as production ponds				–	–
7. Stocking rate/ha (1 x 10^3)	47	19	14.3	–	1,125	150	448	1.5	–	–
8. Rate of survival (%)	90	90	90	–	50	85	70	90	–	–
9. Total number (1 x 10^3)	47	285	400.4	732.4	1,524 3,000[3]	825	44.8 3,000[3]	1.67	–	–
10. Total number/cycle (1 x 10^3)	23.5	142.5	200.2	366.2	762	412.5	22.4	–	–	–
11. Feeds										
i) ton/ha/annum	30.2	19.5	12.9	–	4.7	3.3	8.8	4.5	–	–
ii) ton/annum	30.2	292.7	361.8	684.7	4.7	13.2	0.4	4.5	22.8	707.5
iii) weeds/ton/annum	–	75	140	215	–	8	–	3	11	226
12. Manure										
i) kg/day/ha	–	70	70	–	50	50	50	70	–	–
ii) ton/annum (300 to 340 d)	–	357	666	1,023	20	64.6	3.4	21	109	1,132
13. Mechanical aeration (water wheels/pond)	1	2	2	50	–	–	–	–	–	50
14. Food conversion ratio	2.0	1.7	1.5	–	–	–	–	–	–	–
15. Production										
i) ton/ha/cycle	8	6	4.5	–	1.07	1.9	1.7	–	–	–
ii) ton/pond/cycle	4	9	9	–	–	–	–	–	–	–
iii) ton/ha/annum	16	12	9	–	2.14	3.8	3.4	–	–	–
iv) total production ton/annum	16	180	252	448	–	–	–	–	–	448

Notes (1) Water from auxiliary ponds flows first through the intensive ponds, then through the semi-intensive ponds and finally through the extensive ponds. Most water can be reused once more for irrigation. The maximum water requirement is 650 m^3/hr. The net annual water requirement is about 1 million m^3 or 110 m^3/hr.

(2) Cb = Catfish

Cc = Common carp M = Mrigal R = Rohu Gc = Grass carp Sc = Silver carp Bh = Bighead

(3) 3 million post-larvae (total for all species), will produce 1.5 million fry (3 g) which will be sold to fish farmers

Total production 448 t: Supply to market: 1.4 t/d–6 d a week

Number of deliveries in a year to Vientiane market–100 (4 to 4.5 t per delivery)

Approximately one pond will be drained every 7 d.

Pond Structure and Design

The design of the Tha Ngone pilot fish farm is shown in Figure 1. Each extensive production level pond has an approximate area of 2 ha: determined as the optimum by a special study. Assuming that the optimum size would lie somewhere between 0.5 and 15 ha, several analyses were made by preparing a typical 50-ha development on varying topographic slopes and comparing these with a straight line declining benefit curve, which assumes 100% benefit from 0.5-ha ponds and 50% benefit from 15-ha ponds. Sizes of nursery and rearing ponds (Table 7) were determined on the basis of experience in other areas.

Operation and maintenance at the Tha Ngone pilot farm will be essentially the same as for the farm fisheries, except that in view of the higher level of management applied, there will be two production cycles per year: July to December and January to May.

Economics

The projected economic characteristics of the pilot farm are given in Table 8 and anticipated economic features of newly established farm fisheries in irrigation service areas in Table 9. These values, which are estimated on the basis of practical experience in well organized fish farms in India, Israel, Thailand and elsewhere, may appear unrealistic to those that are conditioned to think in terms of traditional aquaculture in Asia, but the important factor in projecting possible yields is the planned level of technology and management.

Table 9. Estimated annual costs and returns per hectare for the Tha Ngone pilot farm, Lao PDR.

Item	Amount (US$)	
Expenses:		
Fish fingerlings (10,000)	200	
Feeds (10 t/yr)	2,500	
Herbicides, insecticides, disease and predator control	32	
Labor:		
Unskilled	100	
Technical assistance	100	
Annual non-project maintenance and return costs (machinery, electricity, equipment and facilities	188	
Land tax	50	
Miscellaneous expenditure	63	
Interest on short-term working capital	18	
Loan repayment on initial capital borrowed	18	
Total expenses (A)	3,269	
Returns to enterprise (6 t of fish/ha/yr at US$ 0.79/kg)		4,740
Adjustments for operator and family labor		72
Gross income (B)		4,812
Net income (B − A)	1,543	

Conclusion

Much has been said in favor of small-scale integrated farming/fish culture/livestock raising enterprises and their importance in developing rural economics and the improving lot of poor farmers. This "small-scale" approach is, however, totally inadequate in the context of present food requirements and population growth trends in Asia. An "industrial" and intensive technological approach to agricultural development is essential if the present and future food needs are to be adequately met. This inevitably involves irrigation, monoculture of high yielding crop varieties, the use of fertilizers, pesticides, etc., which are generally incompatible with aquaculture. Therefore, integration of aquaculture and agriculture in the traditional sense of paddy-fish culture cannot have a place in future development plans unless radical innovations and breakthroughs are achieved in, for example, developing insect-resistant plant varieties. The only possible way in which aquaculture and agriculture could coexist is by integration of discrete units of both these food production systems in the same general area, using the same facilities as explained in the approach outlined in this paper.

References

Boonbrahm, H. 1975. Aquaculture in Thailand. Faculty of Fisheries, Kasetsart University, Bangkok, Thailand. (Mimeo) 28 p.

Government of Thailand. 1973. Soil interpretation handbook for Thailand. Land Classification Division, Government of Thailand, Bangkok. 71 p.

Kloke, C.W. and M. Patros. 1975. Aquaculture as an integral part of the agricultural farming system—a case study in the northeast of Thailand. IPFC Occ. Pap. 4: 1-10. FAO, Bangkok.

Matthes, H. 1978. The problem of rice-eating fish in the central Niger delta, Mali, p. 225-252. *In* R.L. Welcomme (ed.) Symposium on river and floodplain fisheries in Africa, Bujumbura, Burundi, 21-23 November 1977, review and experience papers. FAO, Rome.

Mekong Committee. 1976. Fisheries and integrated Mekong river basin development. Committee for Coordination of Investigations of the Lower Mekong Basin, Bangkok, Thailand. 367 p.

Mekong Committee. 1977. Pre-construction review of the fish farm at Tha Ngone in the Lao PDR. Committee for Coordination of Investigations of the Lower Mekong Basin, Bangkok, Thailand. MKG/58. 87 p.

SKR International Consultants. 1974. Feasibility study on pilot fish farm projects in the Mekong basin. Committee for the Coordination of Investigations in the Lower Mekong Basin, Bangkok, Thailand.

Tapiador, D.D., H.F. Henderson, M.N. Delmendo and H. Tsutsui. 1977. Freshwater fisheries and aquaculture in China. A report of the FAO Fisheries (Aquaculture) Mission to China 21 April-12 May 1976. FAO Fish. Tech. Pap. 168. 84 p.

U.S. Bureau of Reclamation. 1972. Pa Mong Phase II–Main report. Committee for the Coordination of Investigations in the Lower Mekong Basin, Bangkok, Thailand. 265 p.

Van Heck, B. 1974. The future of the Mekong delta fishermen--report for the Mekong basinwide fishery study. Committee for the Coordination of Investigations in the Lower Mekong Basin, Bangkok, Thailand. (Mimeo) 49 p.

Pesticides as a Major Constraint to Integrated Agriculture-Aquaculture Farming Systems

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Abstract

Pesticides can be a major constraint to integrated agriculture-aquaculture farming systems. The paper considers the effect of pesticides in rice-fish integrated farming as practiced in many Asian countries, notably in Indonesia. Depending on the nature of the compound used, pesticide use in irrigated rice fields can affect 1) fish culture practices, 2) fish consumers and 3) inland fishery resources through the water system and wetland areas. Standard methods for the evaluation of pesticide toxicity to fish in irrigated rice fields are described from three countries, and a standardized methodology is proposed for further studies in Southeast Asia.

Introduction

Many governments and international assistance agencies have recently realized that increasing the incomes of rural people is a prerequisite to total national economic development and social stability in Asian countries. It is therefore to be expected that rurally-oriented integrated agriculture-aquaculture farming systems will be given more favorable attention in the future, to increase the productivity and income of small-scale enterprises.

The basis for integrated farming already exists in most Asian countries, and has been practiced for centuries. This is especially true for rice-fish farming, which started in the Island of Java in the mid-19th century (Ardiwinata 1957). Methods of fish culture in irrigated rice fields have been described by various authors in other Asian countries (Tung-Pai Chen 1953).

Irrigated rice fields constitute an important inland fishery resource, which could be exploited by rural farmers in various ways, e.g., 1) catching operations, to harvest high value species like frogs, freshwater molluscs, etc., 2) rearing fish as a secondary crop for at least 3 mo a year, 3) rearing fish in between crops, with three fish harvests per 2 yr or five per 3 yr and 4) rearing fish mixed with rice cultivation, which permits two, three or five fish harvests a year (Hofstede and Ardiwinata 1950).

For the last 10 to 15 yr, however, there has been some concern that the development of integrated farming will be hampered by various constraints. This is particularly true in Indonesia, where from year to year, the area of irrigated rice fields utilized for fish culture has gradually declined: for example, from 117,014 ha in 1962 to 72,656 ha in 1975 (Directorate General of Fisheries, 1975). The area decreased markedly from 1968 to 1969, when the government initiated an intensification program of rice culture through a mass guidance project called BIMAS (Bimbingan Masal, i.e., mass guidance), the main element of which was the introduction of fertilizers and pesticides.

Although many factors contributed to this decline, including competition for use of irrigated lands with urban settlements and industries, it appears that the major constraint was the use of pesticides.

It has been known for about 20 yr that extensive application of pesticides may cause detrimental effects to the environment. A high proportion of these chemicals has been recognized as toxic to fish and other aquatic organisms, which means that their indiscriminate use will be deleterious to inland fisheries.

This paper considers use of pesticides as a major constraint to integrated agriculture-aquaculture farming, with special reference to rice-fish farming. It also attempts to provide some guidelines for dealing with this constraint to enable rice-fish farming to continue in Asia.

General Considerations

Pesticides commonly have three main properties which determine their value in pest control: chemical stability, absorption properties and toxicity. Unfortunately, these same properties also result in long-term and widespread contamination of the environment. Because of their high chemical stability, many pesticides are persistent, i.e., they remain in the natural environment at significant levels for long periods. Chlorinated hydrocarbons, for example, are very stable with estimated half-lives of 10 to 15 yr. The level of a chemical in the environment is, however, not only related to its stability but also to its rate of entry (Koeman 1974). Therefore, other compounds like organophosphates may also appear persistent.

The pesticide problem also results from uptake by living organisms. Most pesticides are insoluble in water but are highly soluble in organic solvents, and are also retained in biological tissues when absorbed through gills, lungs, integument and alimentary tracts. This is particularly true for chlorinated hydrocarbons.

The third important consideration is pesticide toxicity. Far from being specific to insects alone, almost all pesticides have a broad spectrum of toxicity including fish and other aquatic animals. For the sake of environmental protection, it is to be hoped that highly selective pesticides will be developed, but this will take some years.

The Effect of Pesticide Application in Rice-Fish Farming

Fish mortalities are commonly seen directly or shortly after pesticide application. Dead fish do not always surface, however, and pesticide toxicity, particularly chronic effects, may pass undetected, together with indirect harmful effects to other biota in the rice fields which are important to the fish.

To predict the hazards to fish from pesticide application, the successive phases which determine the fate of these chemicals in the environment must be understood. According to Koeman (1974), these are: 1) the exposure phase, 2) the kinetic phase and 3) the dynamic phase.

The exposure and kinetic phases are defined, respectively, as the method by which the environment gets exposed to the chemical in the first instance, and its subsequent movement. The dynamic phase includes the final toxic responses of certain organisms. The prediction of pesticide hazards in irrigated rice fields, therefore, requires knowledge of: 1) the pesticide formulation used, 2) the chemical stability, 3) the dosage rate, 4) the frequency of application and 5) the toxicity of pesticide to fish and other aquatic biota.

Pesticide Formulation and Chemical Stability

Pesticides are applied in both liquid or solid forms, as mixtures of active ingredients (a.i.) and auxiliary materials.

The most common formulations are solution in oil or water of wettable powder and emulsion or suspension of emulsifiable concentrates in water. These are all applied by spraying. The other popular form of trade product is granular formulation, which is applied by broadcasting.

The persistence and mobility of pesticides in irrigated rice fields can be influenced markedly by the type of formulation employed. Oily formulation can reduce the chance of appreciable run off and granular formulation allows gradual release into rice field water over a long period which can be disadvantageous to fish culture. It has been observed in Indonesia that granular organophosphates are lethal to fish in rice fields within 4 d after application. Also, experimental trials with granular formulations of two organochlorine insecticides, namely Endrin 2G and Thiodan 5G, produced fish kills in rice fields within 11 d and 18 d, respectively. Further experiments demonstrated that emulsifiable concentrates of these chemicals killed fish within 5 to 10 d (Hardjamulia and Koesoemadinata 1972).

Granular formulation has some advantages over sprays, such as better location, the reduction of drift to adjacent areas, and the avoidance of excessive concentrations at the time of application or shortly afterwards (Koeman 1974).

The danger of run off or leaching of pesticides depends upon their water solubility and the rate of application. High solubility generally implies that a pesticide will be very mobile in irrigated rice fields. This may also give quick dilution to a level non-toxic to fish.

A study on the effect of pesticide run off on fisheries was conducted by Gorbach et al. (1971a; 1971b) on the

Brantas River, East Java, following large-scale application of endosulfan during the BIMAS project in 1969/1970.

Rate and Frequency of Application

The persistence of a pesticide in irrigated rice fields depends on both the rate and application. Most rice pest control practice requires three to four applications during one rice-growing season and the procedure and interval of application can interfere greatly with fish culture.

It is important that the pesticide levels in rice field water remain safe for fish throughout the fish-rearing period. High levels caused by downstream effects or widespread contamination by large-scale pest control operations (e.g., extensive spraying of endosulfan in East Java, in connection with the BIMAS project 1969/1970) are serious possibilities. Large-scale endosulfan applications (450 t in 1969 and 800 t in 1969/1970) over an area of 133,000 ha were followed by fish kills in ponds and rivers, bringing considerable economic losses to farmers. Gorbach et al. (1971a) analyzed residues in water samples from the Brantas River System, fish ponds and the Strait of Madura. They found endosulfan residues of 0.00046 ppm in rivers and canals, 0.0008 ppm in fish ponds and less than 0.0003 ppm in the sea water of Madura Strait. Although it was suggested that a rapid degradation of this pesticide had occurred, the large-scale application had already caused great damage to fish farmers. Moreover, the effect of these persistent residues on fish and other aquatic organisms is unknown.

Another organochlorine insecticide, endrin, had a downstream effect for more than a hundred meters from the application site under experimental conditions (Hardjamulia and Koesoemadinata 1972).

Toxicity to Fish

Investigations of pesticide toxicity to fish in irrigated rice fields should include both chemical analyses in the field and laboratory studies on toxicity. Short-term tests of acute toxicity, which are now routinely conducted in many countries, enable pesticides to be ranked in order of their toxicity to fish and provide estimates of levels likely to present serious hazards to fisheries. The result of such short-term tests is generally expressed as the concentration lethal to 50% of a test population over a set period of time. The term LC_{50} is commonly used, with a test-period time always stated.

The pesticide "safe level" is usually derived by multiplying the 96 hour LC_{50} values by an application factor, which varies depending on the compound (Sprague 1970; 1971). For the less persistent pesticides (organophosphates and carbamates), an application factor of 0.1 to 0.01 is suggested (FAO 1969).

It has been recognized, however, that the sensitivity of fish to pesticide varies with species, size and age. It is also known that pesticide toxicity to fish is also affected by water hardness and pH.

The three main groups of compounds used for rice pest control in general have different toxicities to fish. The carbamates are less toxic than the organochlorines and organophosphates (Macek and McAllister 1970). This has also been demonstrated by Koesoemadinata (1975) using *Cyprinus carpio* (see Table 1).

Many organochlorine pesticides are known to be more toxic to fish than the organophosphates, although the reverse is true for zooplankton and some insect larvae (Holden 1972). It has been recommended by many authors (e.g., Alabaster and Abrams 1965; Hashimoto 1970 and Bathe et al. 1974) that tests should be made not only on the a.i. or on technical quality preparation but also on the field formulation of pesticides, since the auxiliary products used in formulation can alter the toxicity.

Legislation on the Use of Pesticides

In many countries, the use of pesticides is regulated by government legislation to ensure that they are used safely, effectively and efficiently. In most cases, the safety of human consumers and the environment is strongly stressed.

Pesticide manufacturers must submit toxicological data for new compounds to government authorities, before their field application can be officially approved. This includes toxicity tests using warm blooded animals (rats, mice, dogs and, sometimes, birds) and fish.

In Indonesia, pesticide legislation to control the sale, storage and use of pesticides was promulgated through Government Decree Number 7, 1973. It came into force on March 17, 1973. A registration procedure for field application has been set up by the Pesticide Committee, and clearance is granted by the Ministry of Agriculture for 1 or 5 yr, after a pesticide has been considered to be safe to human beings and the environment, and the manufacturer's claims for effectiveness verified (Soenardi 1978).

A special prerequisite with regard to fish toxicity is demanded for pesticides which are to be used in irrigated rice fields. The LC_{10}, LC_{50} and LC_{90} values for 24, 48 and 96 hr are determined for two test species commonly grown in rice fields—*Cyprinus carpio* (common carp) and *Puntius gonionotus* (Java carp)—in the Inland Fisheries Research Institute, employing standardized

Table 1. Toxicity of six organosynthetic insecticides to common carp *(Cyprinus carpio* L.) (Koesoemadinata 1975).

Group	Tradename[1]	Common name	Median lethal concentration (LC_{50})[2] 24 hr	48 hr	96 hr
Organochlorines	Endrine 19.2% EC	endrin	0.0058 (0.0051-0.0066)	0.0049 (0.0044-0.0054)	0.0040 (0.0036-0.0044)
	Thiodan 35% EC	endosulfan	0.024 (0.021-0.027)	0.018 (0.014-0.022)	0.0092 (0.087-0.0098)
Organophosphates	Nogos 50% EC	dichlorvos	3.80 (3.52-4.10)	2.70 (2.41-3.02)	2.30 (2.04-2.59)
	Folithion 50% EC	fenitrothion	6.00 (5.50-6.60)	5.40 (4.70-6.20)	3.40 (2.70-4.20)
Carbamates	Lannate 90% WP	methomyl	10.20 (8.80-11.60)	9.50 (8.26-10.92)	5.80 (4.90-6.80)
	Sevin 85% SP	carbaryl	31.50 (29.20-34.00)	14.00 (12.70-15.40)	8.20 (7.20-9.30)

[1]The a.i. content is indicated by % figures following the trade names. EC: emulsifiable concentrate; SP: soluble power, and WP: wettable powder.

[2]Values are expressed in ppm (parts per million) formulated products, with 95% confidence limits (Litchfield and Wilcoxon 1949).

static/renewal bioassay methods. In the Philippines, the Fertilizer and Pesticide Authority (FPA) is responsible for the control of pesticide use throughout the country, whereas in Malaysia, the Pesticide Act, which provides guidelines on registration, labelling and classification of pesticides, was issued in 1974 by the Pesticide Board, Crop Protection Service, Department of Agriculture.

Standard Methods for the Evaluation of Pesticide Toxicity to Fish, with Reference to Their Use in Irrigated Rice Fields

To enable integrated rice-fish farming to continue, selective pesticides which are non-toxic to fish and do not interfere with fish culture practices should be encouraged. This can best be achieved by legislation supported by appropriate technical recommendations.

The most important properties for such pesticides are: 1) low acute toxicity to those fish species commonly cultured in rice fields, 2) short persistence in rice field water and soil and 3) non-accumulation in fish tissues. Their use would eliminate the possibility of direct fish mortality; chronic toxicity to fish, manifested in low fish yield, and contamination of other areas and health hazards to fish consumers, whether human or animal.

There are at least five countries which have standardized their methodology for pesticide fish toxicity testing for the purpose of screening new compounds: the USA (US Department of the Interior, Fish and Wildlife Service 1974), Great Britain (Ministry of Agriculture, Fisheries and Food 1966), Japan (Nishiuchi 1974) and Switzerland (Bathe et al. 1974).

Pesticide toxicity testing has been carried out in Indonesia by the Inland Fisheries Research Institute since 1973, and guidelines for standardized testing procedure have been issued (Koesoemadinata and Djajadiredja 1976). For screening pesticides, the 48 or 96 hr LC_{50} is usually determined under specified conditions (APHA, AWWA and WPLF 1974; Duodoroff et al. 1951).

The same principles and procedures are used both in flow tests (where the pesticide solution to which the fish are exposed is constantly renewed and static test (in which the fish are exposed to fixed volume of solutions) (Sprague 1969). Static tests are more widely employed and have been adopted as the standard method in many countries, including Switzerland, Poland, Japan and Indonesia.

Understandably, their procedures are not in most cases directed towards evaluation of pesticides for use in irrigated rice fields, but the following standard methods used in Japan, Switzerland and Indonesia are applicable.

JAPAN

Static test facilities are used, consisting of cylindrical or rectangular glass test vessels of at least 10-l capacity, to give a ratio of at least 1 g of fish to 1 l of test medium. The principal species used is the common carp *(Cyprinus carpio)*, average length 5 cm (other species are used for chemicals not applied to rice fields). Daphnia is also used as a test animal.

Five to ten fish are used for each concentration and solutions are made using well water or dechlorinated tap water. The fish are kept in the solutions for 72 hr at 20 to 28°C (± 2°C). The results are expressed as LC_{50} values of 24 and 48 hr a.i. calculated by the straight line graphical method of Duodoroff et al. (1951).

Based on the LC_{50} values for fish and daphnia, pesticides can be ranked into three groups as indicated in Table 2. Rank A pesticides can be used without any special precaution, but rank B can only be used in irrigated rice fields by taking precautions against excessive application. Rank C pesticides are not permitted in irrigated rice fields. Pentachlor phenol, rotenone, endosulfan, endrin, dieldrin and telodrin are considered outside the above classification, and their uses are strictly controlled by Law and Government Orders (Nishiuchi 1974).

Table 2. Ranking of pesticides on the basis of their toxicity to common carp *(Cyprinus carpio)* and daphnia (Nishiuchi 1974).

Rank	Test organism	48-hr LC_{50} (ppm a.i.)
A	carp	> 10
	and	
	daphnia	> 0.5
B	carp	0.5-10
	or	
	daphnia	< 0.5
C	carp	< 0.5

SWITZERLAND

Static test facilities are used, consisting of glass basins of 15 to 20 l capacity, to give a ratio of 1 g of test fish to 1 l of test medium, made using deionized water.

The test fish species are common carp *(Cyprinus carpio)* or other species (mainly rainbow trout, *Salmo gairdneri)*, with an average length of 2 to 10 cm. Various numbers of fish are kept for 96 hr at 20°C ± 2°C. The results are expressed as 48 and 96 hr LC_{50}'s a.i., calculated by the method of Litchfield and Wilcoxon (1949). A classification of pesticides has been proposed, to give an indication of their possible toxicity to fish under field conditions (Table 3).

Table 3. Ranking of pesticides on the basis of their 96-hr LC_{50} to fish (Bathe et al. 1974).

Group	96-hr LC_{50} (ppm a.i.)	Evaluation
I	< 0.5	Highly toxic
II	0.5-5	Toxic
III	5-50	Slightly toxic
IV	> 50	Nontoxic

For crop protection, pesticides are applied at a rate of 0.5 to 10 kg ai/ha. In irrigated rice fields with a water level of 10 cm, this will give concentrations of 0.5 to 10 ppm, and 0.5 ppm was therefore selected as the boundary level for highly toxic pesticides. A less strict boundary of 50 ppm was also considered based on the assumption that such a high concentration is unlikely to occur in rice field water, and also because this concentration is regarded as the uppermost limit of water solubility for most pesticides (Bathe et al. 1974).

INDONESIA

Static test facilities are used, consisting of 20-l rectangular glass fiber test vessels (50 x 30 x 30 cm deep), each equipped with a PVC overflow pipe to facilitate the renewal of test media. The vessels give a ratio of 1 g of fish to 2 l of test medium, made from well water. The test fish species are common carp *(Cyprinus carpio)* and Java carp *(Puntius gonionotus)*, with average lengths of 3 to 5 cm (about 1 to 2 g). Duplicate sets of 10 fish each are used for each concentration and are held for 96 hr at 24 to 25°C (± 2°C). The results are expressed as 48 and 96 hr LC_{10}, LC_{50} and LC_{90}'s formulated product (f.p.), calculated by the method of Litchfield and Wilcoxon (1949). Pesticides have been ranked on the basis of their 48 hr LC_{50}'s (f.p.) (see Table 4).

Halogenated hydrocarbons and pesticides containing heavy metal compounds are considered outside the ranking scheme and their possible use in the fields is not evaluated further regardless of rank. Rank A pesticides are considered worthy of further evaluation, only if there is supplementary field data showing quick degradation. Furthermore, extreme care must be taken with these chemicals to prevent contamination of inland fisheries. Rank B or C pesticides are accepted for use in irrigated rice fields, if their maximum concentrations in rice field water (measured or calculated, assuming a 10-cm depth of water) application are below the 96-hr LC_{10}. Rank D pesticides are considered harmless to fish

Table 4. Ranking of pesticides, on the basis of their 48-hr LC_{50}'s to test fish (formulated product) (Koesoemadinata and Djajadiredja 1976).

Rank	48-hr LC_{50} (ppm formulated product)	Evaluation
A	<1	Extremely toxic
B	1-10	Highly toxic
C	10-100	Moderately toxic
D	>100	Low toxic

under all reasonable applications and can be recommended for use in irrigated rice fields.

There may sometimes be difficulties in following this method of evaluation, and field trials are then suggested to assess hazards to fish culture. The trials consist of field bioassay and fish culture tests to demonstrate any toxic effects of the pesticide in question and the extent of any contamination of adjacent areas.

These procedures have been used since 1973 and are now being revised and improved. They have allowed the evaluation of 127 pesticide formulations so far, including 43 single and 23 mixed a.i.'s.

Discussion

Pesticides can be a major constraint to integrated agriculture-aquaculture farming systems affecting particularly fish culture and wetlands. Their indefinite persistence in irrigated rice fields is a serious possibility.

In Indonesia, pesticides are probably responsible for the gradual decrease of fish and other aquatic animals harvested from rice fields, including sawah eel *(Monopterus albus),* frogs and freshwater molluscs (Koeman et al. 1974; Djajadiredja and Koesoemadinata 1974). There is concern that fish reared in rice fields and exposed to a number of pesticide applications might not be safe for human consumption. Such fish-eating creatures as birds, poultry and reptiles may also be risky for humans to eat (Koeman et al. 1974).

There may be no single answer to this problem, but it seems most practical to consider first the development of selective pesticides. This requires effective and efficient screening procedures. Data are available on pesticide toxicity to fish and other aquatic life in temperate regions, although these have been largely acquired from laboratory studies rather than from field observations (Holden 1972). They cannot generally be applied to tropical ecosystems with different fish species, climatic conditions and other factors affecting pesticide behavior. For example, there are indications that many pesticides may be broken down rapidly in rice fields by the anaerobic mud layer at the high prevailing temperature. Preliminary screening data by itself will not enable an adequate assessment of pesticide application hazards in the tropics (FAO 1975). The establishment of water quality criteria may be more appropriate and this is being considered in Indonesia together with the version of the standard procedures for the evaluation of pesticide toxicity to fish.

The new procedures will comprise laboratory and field studies, including bioassays, chemical analyses and fish culture experiments.

Laboratory bioassays will be used to determine the acute and chronic toxicity of both a.i.'s and f.p.'s to fish. The field studies are to determine the acute toxicity of pesticides to fish in field conditions, the persistence of residues in rice field water and fish, the degree of contamination of adjacent areas, and any other effects fish culture practices.

It is hoped that maximum permitted levels of individual pesticides can be established for inland fisheries and fish species. It is essential for monitoring studies on pesticide use.

Recommendations

Many new pesticides have been developed in the past 20 yr, and their evaluation and toxicity to fish will be the subject of extensive future studies. The author recommends the development of a standard methodology for these studies in the tropics, particularly in Southeast Asia, to provide comparable data and promote collaborative work.

A Southeast Asian data bank for the accumulation and dissemination of the results is also recommended to assist research workers in identifying and procuring selective pesticides for use in specific integrated agriculture-aquaculture farming systems.

References

Alabaster, J.S. and F.S.H. Abrams. 1965. Estimating the toxicity of pesticides to fish. Pest Articles and News Summaries (PANS) C, Vol. 11 No. 2 June 1965. Centre for Overseas Pest Research, London. p. 91-97.

American Public Health Association (APHA), American Water Works Association (AWWA), and Water Pollution Control Federation (WPCF). 1974. Standard methods for the examination of water and waste water. APHA. Washington, D.C.

14th Edition. p. 685-740.
Ardiwinata, R.O. 1957. Fish culture in paddy fields in Indonesia. Proc. Indo-Pacific Fish. Coun. 7 (II-III): 119-154.
Bathe, R., K. Sachsee, L. Ullman, W.D. Hormann, F. Zak and R. Hess. 1974. The evaluation of fish toxicity in the laboratory. Excerpta Medica XVI: 113-124.
Djajadiredja, R. and Santosa Koesoemadinata. 1974. Some aspects of inland water pollution in Indonesia, with special relevance to fisheries. Conference on Ecological Guidelines for Forest, Land and Water Resoruces Development in Indonesia. University of Padjadjaran, Bandung, Indonesia, 1974.
Duodoroff, P., B.G. Anderson, G.E. Burdick, P.S. Galtsoff, W.B. Hart, R. Patrick, E.R. Strong, E.W. Surber and W.M. van Horn. 1971. Bioassay methods for the evaluation of acute toxicity of industrial wastes to fish. Sewage and Industrial Wastes 23(11): 1380-1397.
EIFAC/FAO. 1975. Report on fish toxicity testing procedures. EIFAC Tech. Pap. 24, 26 p. FAO, Rome.
FAO. 1969. Report of the Committee on Water Quality Criteria Federal Water Pollution Control Administration, United States Department of the Interior, Washington D.C. Facsimile of Section III–Fish. Other aquatic life and wild life. FAO Fisheries Technical Paper No. 94: 110 p.
Gorbach, S., R. Haarring, W. Knauf and H.J. Werner. 1971a. Residue analysis in the water system of East Java (River Brantas, ponds, sea water) after continued large scale application of Thiodan in rice. Bull. Environ. Contamin. Toxicol. 6(11): 40-47.
Gorbach, S., R. Haarring, W. Knauf and H.J. Werner. 1971b. Residue analyses and biotests in rice fields of East Java treated with Thiodan. Bull. Environ. Contamin. Toxicol. 6(3): 193-199.
Hardjamulia, A. and Santosa Koesoemadinata. 1972. Preliminary experiments on the effect of Thiodan and Endrin on fish culture in Indonesia. Proc. Indo-Pacific Fish. Coun. 15(11): 56-64.
Hashimoto, Yasushi. 1970. Evaluation of fish-toxicity of agricultural chemicals. Japan Pesticide Information No. 3, 15-18. Japanese Plant Protection Association, Tokyo.
Hofstede, A.E. and R.O. Ardiwinata. 1950. Compiling statistical data on fish culture in irrigated rice fields in West Java. Landbouw XXII: 469-494.
Holden, A.V. 1972. The effects of pesticide on life in freshwater. Proc. R. Soc. Lond. B. 18: 383-394.
Koeman, J.H. 1974. Problems associated with the use of agricultural chemicals. Conference on Ecological Guidelines for Forest, Land and Water Resources Development in Indonesia. University of Padjadjaran, Bandung, Indonesia. 11 p.
Koeman, J.H., J.H. Pennings, R. Rosanto, O. Soemarwoto, P.S. Tjoe, S. Blanche, S. Koesomadinata and R. Djajadiredja. 1974. Metals and chlorinated hydrocarbon pesticides in samples of fish, sawah duck eggs, crustaceans and molluscs, collected in West and Central Java, Indonesia. Ecology and Development No. 2. 14 p.
Koesoemadinata, Santosa. 1975. Toxicity of six organosynthetic insecticides to carp *(Cyprinus carpio)*. Master's Thesis. University of Padjadjaran, Bandung, Indonesia. 58 p. (In Indonesian)
Koesoemadinata, Santosa. 1977. Measures for the protection of aquaculture resources in Indonesia. Inland Fisheries Research Institute (IFRI). Contribution No. 4. Agency for Agricultural Research and Development, Bogor, Indonesia. 7 p.
Koesoemadinata, Santosa and Rustami Djajadiredja. 1976. Some aspects on the regulation of agricultural use of pesticides in Indonesia, with reference to their effects on inland fisheries. IFRI Contribution. No. 3. 14 p.
Litchfield, Jr., J.T. and F. Wilcoxon. 1949. A simplified method of evaluating dose-effect experiments. J. Phar. Exp. Therapeutics 96: 99-113.
Macek, K.J. and W.A. McAllister. 1970. Insecticide susceptibility of some common fish family representatives. Trans. Amer. Fish. Soc. 98(1): 20-27.
Ministry of Agriculture Fisheries and Food. 1966. Pesticide safety precaution scheme. Testing pesticide products for toxicity to fish. Working Document No. 6. Pesticide Branch. London.
Nishiuchi, Y. 1974. Testing methods for the toxicity of agricultural chemicals to aquatic organisms. Japanese Pesticide Information No. 19: 15-19.
Sprague, J.B. 1969. Measurement of pollutant toxicity to fish. Rev. paper I. Bioassay methods for acute toxicity. Water Research 3: 793-821.
Sprague, J.B. 1970. Measurement of pollutant toxicity to fish. Rev. paper II. Utilizing and applying bioassay results. Water research 4: 3-32.
Sprague, J.B. 1971. Measurement of pollutant toxicity to fish. Rev. paper III. Sublethal effect and "safe" concentration. Water Research 5: 245-266.
Soenardi. 1978. Pesticide use in relation to plant protection. Course in Environmental Toxicology III. University of Padjadjaran, Bandung, Indonesia. 14 p.
Tung-Pai Chen. 1953. The culture of tilapia in rice paddies in Taiwan. Jt. Comm. Rural Reconstr. China Fish Ser. 2. 29 p.
United States Department of the Interior Fish and Wildlife Service. Procedure for evaluation of acute toxicity of pesticides to fish and wild life. Pesticides Review Staff. Washington, D.C.

Additional bibliography

Kimura, Sekio and Yoshihiro Matida 1958. Study on the toxicity of agricultural control chemicals in relation to freshwater fishery management. No. 1. General summary of the studies on the toxicity of agricultural insecticides for freshwater fishes by means of the bioassay method (Part 1). Bull. Freshwater Fish. Res. Lab. 7(2): 51-53.
Koesoemadinata, Santosa. 1976a. Acute lethal toxicity of Elsan 60 EC to two Indonesian freshwater fish species in irrigated rice fields. IFRI Research Report No. 8. 8 p.
Koesoemadinata, Santosa 1976b. Toxicity of Padan (cartap hydrochloride) to two local Indonesian fish species in irrigated rice fields. IFRI Research Report No. 9. 8 p.

Carbofuran in Rice-Fish Culture

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Abstract

Carbofuran (2, 3-dihydro-2, 2-dimethyl-7-benzofuranyl N-methylcarbamate) is the active ingredient of the systemic insecticide-nematicide, Furadan (FMC Corporation, Philadelphia, Pa). It can be applied in rice-fish culture as a rootzone (soil incorporation) treatment. This appears to eliminate toxicity effects to the fish. Available data indicate that carbofuran is safe to use in rice-fish culture if properly applied and does not accumulate in the fatty tissues of fish.

Introduction

Rice-fish culture is an ancient practice and has been especially successful with the older, traditional rice varieties. It was common practice to trap wild fish that entered with the irrigation water and harvest these with rice. Some farmers also alternated rice and fish crops in the same field.

With the Green Revolution program and the introduction of high yielding rice varieties requiring an increase in the use of fertilizers and pesticides, however, there was a drastic reduction in fish catches from rice paddies and rice-fish culture temporarily lost popularity.

A renewal of interest came about with the introduction of insect-resistant rice varieties and the discovery that certain pesticides provided adequate protection and were thus safe for fish in the paddy, leaving them free of residues and therefore safe for human consumption. This paper presents information on one such pesticide, carbofuran, and its use in rice-fish culture.

Carbofuran

Carbofuran is a common name for 2, 3-dihydro-2, 2-dimethyl-7-benzofuranyl N-methylcarbamate. It is the active ingredient (a.i.) of a systemic insecticide-nematicide, Furadan (a registered trademark of FMC Corporation, Philadelphia, Pa., U.S.A.).

When applied to the soil, carbofuran is readily absorbed by the roots and translocated to other parts of the plants. During early growth (the critical period in the life cycle of the plant), it protects the root system from soil-inhabiting insects and nematodes, and the stem and aerial portion of the plant from borers and foliar feeding insects.

As the plant grows, it continues to absorb carbofuran from the soil and protection lasts for approximately 60 d after planting, depending upon the dosage and such soil conditions as texture, temperature, moisture and pH. During this period, the root system continues to be protected by the carbofuran remaining in the soil. This systemic action of carbofuran makes it effective against a wide spectrum of insect pests.

Carbofuran, like the organophosphates, is a cholinesterase inhibitor causing toxic symptoms, such as muscular tremors, excessive salivation, perspiration, increased motility of the gastrointestinal tract, and constriction of the pupils (Anon. 1977a). There is, however, a very important distinction between these two classes of cholinesterase inhibitors.

Cholinesterase inhibition by methyl-carbamates, such as carbofuran, is reversible. This means that after reaction with carbamate compounds, essentially all the carbamylated cholinesterase is easily hydrolyzed to free cholinesterase again and recovery occurs within hours without special medical treatment.

With organophosphates, however, only a small fraction of the phosphorylated cholinesterase is hydrolyzed to cholinesterase again and the remaining phosphorylated enzyme is regarded as irreversibly inhibited. Recovery depends upon the production of new cholinesterase which may take weeks. In the meantime, even a relatively small additional exposure to cholinesterase inhibitor gives toxic symptoms.

Another important difference is that with organophosphates symptoms do not occur until approximately 1/3 to 1/5 of the lethal dose has been absorbed by the body. With carbamates, however, symptoms occur when only 1/20 to 1/30 of the lethal dose has been absorbed.

In practical terms, this means that there is a greater margin of safety with carbamates than with organophosphates. A worker gets an early warning from accidental exposure to the insecticide long before absorbing a dangerous amount.

Environmental Effects

The chemical and physical properties of carbofuran are such that it does not accumulate in the soil, water, plants and animals. Moreover it has no adverse effects on non-target organisms when used as recommended.

1. BIO-ACCUMULATION

Carbofuran and all its metabolites are soluble in water and relatively insoluble in non-polar hydrocarbon solvents. Thus they have little potential for bio-accumulation. This was demonstrated by Macek (1972) by continuously exposing bluegill *(Lepomis macrochirus)* fingerlings to radioactive carbofuran at levels of 0.02 to 0.01 ppm for 28 d.

All the fish remained healthy throughout the exposure period and equilibrium levels of approximately 0.4 ppm carbofuran equivalent of radioactivity were attained in the edible portion of the fish after 1 to 3 d at the 0.1 ppm exposure level and 10 to 14 d at the 0.02 ppm exposure level. The carbofuran appeared to be completely converted to water soluble metabolites. When the fish were transferred to clean water, their radioactivity declined to non-detectability within 14 d, indicating rapid and complete loss of residues and no accumulation.

Metcalf and Sangha (1971) also studied the effects of carbofuran in a model ecosystem. The results showed that carbofuran was readily bio-degradable and not concentrated in food chains. In the same ecosystem, the organochlorine pesticides, such as DDT, may be concentrated by a factor of 10,000 to 100,000.

2. DEGRADATION IN WATER AND SOIL

Carbofuran is readily hydrolyzed in basic solution. The hydrolysis products are carbon dioxide, methylamine and the corresponding 7-phenol. The 7-phenol is also a major metabolite in both plants and animals, and is the least toxic of the carbofuran metabolites. It is also relatively soluble in water. The rate of hydrolysis depends on temperature. For instance, the rate at 25°C is approximately 2.6 that at 5°C.

Most surface waters have pH ranging from 7.0 to 8.5, in which the half-life of carbofuran is expected to vary from approximately 40 d to less than 2 d at 25°C (Anon. 1977a). In the field, however, the observed half-life is usually shorter than expected, e.g., 1 to 2 d in flooded rice fields (Anon. 1977a).

In the U.S.A. (Anon. 1977a), FMC Corporation conducted an experiment where carbofuran was applied to corn, potato, tobacco and peanuts at three locations for four consecutive years. They observed no increase in crop residues which suggests no increase in soil residues.

3. EFFECTS ON NON-TARGET ORGANISMS

A number of studies have shown that non-target organisms, including fish, bees and other pollinating agents, are not adversely affected by the use of carbofuran as recommended. The in-furrow and band application of carbofuran granules also minimize the hazard to birds.

Simulated studies with birds caged on areas treated with carbofuran granules provided no evidence of toxicity (Anon. 1977a). Carbofuran applied directly to bees is toxic but soil application of granules removes this risk in the field.

Soil-applied granules are translocated mainly into actively transpiring aerial portions of the plant, such as the leaves. Only insignificant amounts, usually non-detectable, are translocated into the fruiting bodies and, thus, bees foraging on blossoms are not harmed.

Studies on the Toxicity of Carbofuran to Fish

1. LABORATORY STUDIES

The toxicity of carbofuran to the various species of fish has been studied in the U.S.A. (U S Environmental Protection Agency 1976). Lowe (1970) also studied the longnose killifish *(Fundulus similis)* and the sheephead minnow *(Cyprinodon variegatus)*. The killifish were unaffected by technical carbofuran up to 0.1 ppm but the sheephead minnow showed signs of distress in 0.1 ppm.

Another study by Schoenig (1967) showed that the rainbow trout *(Salmo gairdneri)*, channel catfish *(Ictalurus punctatus)* and bluegill were about equally sensitive to technical carbofuran: the 96-hr LC_{50} ranged from 0.21 to 0.28 ppm for these three species. Carter and Graves (1973) reported that the 24-hr LC_{50} of technical carbofuran to channel catfish was 2.04 ppm under static conditions: 10 times that reported by Schoenig (1967).

Carter (1971) also revealed that 0.19 ppm carbofuran gave a 50% reduction in cholinesterase activity in channel catfish. The treated fish showed the following sequential symptoms: hypoactivity, lethargy, body paralysis, scoliosis, loss of equilibrium, opercular and mouth paralysis followed by death.

In Japan, the 48-hr LC_{50} of 94.2% carbofuran for carp *(Cyprinus carpio)* was 1.4 ppm and for killifish *(Oryzias latipes)* 1.3 ppm (Anon. 1978; see Table 1). The results indicate that carbofuran is almost 3 times less toxic than the minimum requirement of 0.5 ppm.

A similar type of study in Indonesia (Swata 1973) on the toxicity of carbofuran as Furadan 3G showed that its 96-hr LC_{50} for carp *(Cyprinus carpio)* was 49.5 ppm, equivalent to 1.3 ppm a.i., and its 48-hr LC_{50} was 46.5 ppm, equivalent to 1.4 ppm a.i.

2. FIELD STUDIES

Several field studies have demonstrated that carbofuran is safe to fish when applied correctly, at the right dosage and proper time.

In the Philippines, results of joint field studies conducted at the International Rice Research Institute (Heinrichs et al. 1977) and the Freshwater Aquaculture of Central Luzon State University (Anon. 1977b) showed no mortality among fish placed in paddies 7 d after application by broadcasting or rootzone application. On the other hand, broadcasting carbofuran granules in paddies containing fish resulted in 100% mortality.

Carbofuran Residue Studies

In the Philippines, Seiber and Argente (1976a, 1976b) analyzed residues in fillets of fish reared in the carbofuran treated paddies. They found out that carbofuran is not accumulated in the fatty tissues of the fish, making the fish safe for human consumption. Their limit of detection was 0.05 ppm and all their measured residue values fell under the recommended carbofuran limit in edible produce, which is 0.01 ppm.

In a similar study, Mack (1972) exposed bluegill to radioactive labelled carbofuran for 28 d at levels of 0.02 ppm to 0.01 ppm. The equilibrium levels of approximately 0.4 ppm carbofuran equivalents of radioactivity

Table 1. The toxicity of Furadan and Sodium Pentachorophenol (PCP-Na) to carp *(Cyprinus carpio)* and killifish *(Oryzias latipes)*.

Species	Preparation	No. of Fish	Mean Temperature (°C)	48 hour LC_{50}
Carp (Mean total length, 3.76 cm; mean weight, 131 g)	94.9% technical purity	80	25.2	1.4
–do–	PCP-Na	50	25.2	0.13
Killifish (Mean total length, 2.64 cm; mean weight, 0.16 g)	94.9% technical purity	70	25.1	1.3
–do–	PCP-Na	60	25.1	0.30

were attained in 1 to 3 d at the 0.1 ppm exposure level and in 10 to 14 d at 0.02 ppm.

The carbofuran was completely converted to water soluble metabolites. When the fish were transferred to clean water, their radioactivity declined to non-detectability within 14 d, indicating rapid and complete purging of residues.

The Use of Carbofuran in Rice-Fish Culture

Carbofuran, whether in liquid or granular form, is the only pesticide now recommended in rice-fish culture in the Philippines (Guerrero 1977;Anon. 1979a).It protects the rice crops from insect pests and does not affect fish growth, if properly applied (Anon. 1979b).

There are two methods of application: a) Seedbed application–Broadcast 5 to 10 g Furadan 3G/m^2 of seedbed 5 d after sowing; b) Field application–This may be done either by broadcasting, soil incorporation (rootzone application) or by spray. Broadcast 1 to 3 bags of Furadan 3G (16.7 kg/bag) with basal fertilizer.

It can also be incorporated thoroughly into the soil during last harrowing before direct seeding or transplanting. A comparative study of yields using different methods of applications is given in Table 2.

The rootzone application of carbofuran gave the greatest gross income of US$786 due to the longer period of pest control. According to Seiber (1977), this method of application is also considered the safest because the chemical is down in the mud.

It is important to emphasize that the recommended timing of stocking fingerling tilapias at 5,000/ha and carp at 3,000 to 4,000/ha is 5 to 7 d after broadcasting or rootzone application. For late insect infestation, spraying with a 0.01% solution of Furadan F is recommended, for which the instruction to growers is given as two tablespoons full of Furadan F (formulated product) to 19 l (5 US gal) of water.

Socioeconomic Implications

Most farmers shy away from rice-fish culture simply because most of the pesticides which are considered indispensable in rice crop protection are also toxic to fish. With judicious use of carbofuran, however, they can protect their rice crops and, at the same time, culture fish in the paddy.

Arce (1979) compared the returns from growing rice alone and rice-fish culture, with and without the use of insecticide, showing that net income was highest from rice-fish culture with insecticide application. In the Philippines, the Bureau of Fisheries and Aquatic Resources and the National Irrigation Authority (Anon. 1979b) have recorded yields of about 3.5 to 5 t of rice and 0.5 to 1.0 t of fish/ha from rice-fish culture, and trials with Furadan 3G have given rice yields of 6.5 to 7.0 t and fish yields of 0.2 to 0.3 t/ha (Anon. 1979c).

Conclusion

Rice-fish culture is a unique way of diversifying food production and increasing the income of farmers. However, most insecticides used to protect rice crops (to improve quantity and quality of harvested rice) also killi-fish. Carbofuran is safe for use in rice-fish culture. It does not accumulate in the fatty tissues of fish.

Table 2. Yields from Furadan treated plots of rice (IR34) and fish (*Sarotherodon mossambicus* at 3,000/ha stocked 7 days after insecticide application). Source: trials undertaken by the International Rice Research Institute and Central Luzon State University, 1976 (unpublished data).

Method	Rate of application (kg ai/ha)	No. of applications	Rice yield (kg/ha)	Fish yield (kg/ha)	Fish value (US$)	Value of fish and rice and total sales value	Less insecticide and labor costs
Broadcast	1.0	1	4,319	141	115	703	673
	1.0	4	4,935	0	0	671	552
Rootzone	1.0	1	5,116	166	136	832	786
	2.0	1	5,613	150	123	886	794
Control	–	–	4,113	155	127	691	686

References

Anon. 1977a. Carbofuran data summary. Furadan[R] Insecticide-Nematicide. FMC Corporation, Philadelphia, PA, U.S.A. 92 p.

Anon. 1977b. Insecticide increased fish-rice profits. IRRI Research Highlights for 1976. International Rice Research Institute, Los Baños, Laguna, Philippines. 9 p.

Anon. 1978. Furadan toxicity to fish. Nissan Chemical Industries Ltd. Biological and Chemical Research Laboratory. Japan. (Unpublished MS). 8 p.

Anon. 1979a. "Palay-Isdaan" (Rice-Fish Culture). BFAR Extension Paper Series No. 1. Bureau of Fisheries and Aquatic Resources and National Media Production Center, Manila, Philippines. [Translated from Tagalog to English by Cora Adordionisio]. 8 p.

Anon. 1979b. Rice-fish culture, profitable, Bureau of Fisheries and Aquatic Resources and National Irrigation Authority, Manila, Philippines (Translated from Tagalog to English by Cora Adordionisio). 8 p.

Anon. 1979c. Only one insecticide allows farmer to develop a fish culture program in his rice paddies. Bureau of Agricultural Extension. M.A. Innovator II:I Davao City, Philippines. 20 p.

Arce, R.G. 1979. Present development of rice-fish culture research. Freshwater Aquaculture Center, Central Luzon State University, Philippines. 7 p.

Carter, F.B. 1971. In vivo studies of brain acetyl-cholinesterase inhibition by organophosphate and carbamate insecticides in fish. Diss. Abstr. Int. B. 32(50):2772-2773.

Carter, F.B., Jr. and J.B. Graves. 1973. Measuring effects of insecticides on aquatic animals. Louisiana Agric. 16(2):14-15.

Guerrero, R., III. 1977. The return of the fish we had learned to dislike. Farming Today [Philippines] 3(9):14, 16, 18.

Heinrichs, E.A., G.B. Aquino, J.A. McMennamy, J. Arboleda, N.N. Navasero and R.G. Arce. 1977. Increasing insecticide efficiency in low land rice. International Rice Research Institute, Los Baños, Philippines. 14 p.

Lowe, J.K. 1970. Bio-assay screening test–carbofuran. Gulf Breeze Environment Laboratory, U.S. Environmental Protection Agency. Florida, U.S.A. (unpublished). 15 p.

Macek, K.J. 1972. Accumulation and persistence of carbofuran residues in bluegills. Research Report, Bionomics Inc., Massachusetts, U.S.A. (unpublished) p. 424-436.

Metcalf, R.L. and G.K. Sangha. 1971. Model ecosystem studies with carbofuran. University of Illinois at Urbana, Champaign, Illinois, U.S.A. (unpublished).

Schoenig, G. 1967. Fish and bird toxicology, Furadan[R] 10G: Four day fish toxicity. FMC Corporation, Middleport, New York, U.S.A. (unpublished). 20 p.

Seiber, J. 1977. Is the fish fit to eat? [residue analyses of fish raised in Furadan (pesticide)-treated rice fields in the Philippines]. Part 1. Farming Today [Philippines] 3(3/4):14-18. 1979). p. 14-18.

Seiber, J.N. and A. Argente. 1976a. Carbofuran residues in paddy-reared *Tilapia mossambica* from CLSU. Trial 1. IRRI Research Report, International Rice Research Institute, Los Baños, Laguna, Philippines. 5 p.

Seiber, J.N. and A. Argente. 1976b. Carbofuran residues in paddy-reared *Tilapia mossambica* from CLSU. Trial 2. IRRI Research Report, International Rice Research Institute, Los Baños, Laguna, Philippines. 5 p.

Swata, J.N. 1973. Furadan 3G fish toxicity trials. Research Station Inland Fisheries. Bogor, Indonesia. (research report) 6 p.

U.S. Environmental Protection Agency. 1976. Initial Scientific and Programs criteria and evaluation division. Washington, D.C., U.S.A. 7 p.

REVIEWS AND BACKGROUND PAPERS: ANIMAL-FISH FARMING

A Review of Integrated Livestock-Fowl-Fish Farming Systems

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Abstract

Traditional and current practices in integrated farming are reviewed and show that it is concentrated in Asia. The chemical composition of animal wastes and organic compost produced by Chinese methods are summarized and published information on rates of application to fish ponds is discussed. The design of integrated animal-fish units and the formulation of animal feeds are identified as key factors in farm productivity and profitability. Economic analyses are included from selected examples of pig-fish, chicken-fish and duck-fish farms.

Introduction

TRADITIONAL FARMING IN ASIA

The bulk of agriculture production in Asia is undertaken by farmers whose landholdings are too small and fragmented. The application of modern technology and large-scale production are not feasible solutions to their present problems of low income and low productivity.

For centuries, the small farmers have sustained themselves by practicing various kinds of crop diversification and integrated farming systems. Aside from crop production, most small farmers have such livestock as a few head of cattle or buffalo, one or two pigs and a small flock of ducks or chickens. Where there is adequate water supply, a small fish pond is maintained.

Livestock-fowl-fish farming, combined with crop raising, is a workable pattern of integration as exemplified by the well-known Chinese small-scale farming system. The small farm raises pigs and/or ducks, in addition to crops, rotated in accordance with the seasonal climatic cycle. The animals, particularly ducks and pigs, are sources of animal protein, in addition to the fish. Pigs are fed with aquatic plants combined with kitchen leftovers, and animal manure serves as fertilizer for the crops, vegetables and fish ponds. This is a system where practically nothing is wasted. An ecological balance is maintained and a sufficient variety of products are obtained to meet the farm family's needs in terms of food and cash income.

This practice and a variety of other integrated farming systems continue to be used in many Asian countries: each system developed mainly through long years of experience of individual farmers. Unfortunately, no data are available on their technology; neither is there information on economics and yields. One reason for this is perhaps because the small farmers have always been considered as operating at subsistence level and have not gained the attention of economic development planners in the past.

In recent years, however, as information on the agriculture-aquaculture production techniques used in China has spread, the importance of integrated farming systems has begun to be more and more appreciated. National and international organizations are now beginning to take a fresh look at the traditional farming systems practiced in Asia, to obtain a better and fuller understanding of how these systems have sustained the small farmers and to find ways and means of making them more viable for the social and economic well-being of the small farm and rural communities.

Existing Livestock-Fish Farming Systems

PIG-FISH FARMING

The Chinese consider a pig as a "costless fertilizer factory moving on hooves" (FAO 1977a). The annual manure produced by 20 to 30 pigs is equivalent to 1 t of ammonium sulphate applied to the soil. The pigs are fed largely on kitchen wastes, aquatic plants and crop wastes. The sale of meat, bones and bristles after slaughter more than cover the cost of labor and feed. The pig-raiser obtains an annual yield of about 3 t of pig manure which is free. Pig-fish farming is therefore widely practiced in China, not only for meat needs but also to supply manure to fish ponds. Collective as well as individual pig-rearing is promoted. A target of one pig per person has been set and the total number of pigs raised in the country rose to 233 million from 57.8 million in 1976.

Although the pigs are not reared directly over the pond itself, the wastes are collected, made into compost and applied to the farmland and fish ponds. In some places, liquid manure from the oxidation tanks of bio-gas plants is conveyed to the fish ponds through small ditches running through the pond dikes (FAO 1977b).

A similar system is found in Vietnam, particularly in the cooperative and state farms where meat production, mainly pigs, is undertaken on a large scale. The manure is prepared into compost and applied as fertilizer to vegetable plots and fish ponds. The washings from pigsties are also channeled to the ponds.

In most Asian countries, e.g., Thailand, Malaysia, Singapore, Hong Kong and Indonesia, pigs are either reared over the ponds or at the edges so that the wastes can flow down into the ponds. Feeds consist of leftover food from households or restaurants; water lettuce, *(Pistia stratiotes)* (grown in the ponds) mixed with rice bran; water hyacinth, *Eichornia crassipes* (chopped and cooked with abattoir wastes) and peanut cake, corn meal and soybean meal whenever available and cheap.

Pig-vegetable-fish integration in Malaysia is also a successful operation. Although the fish yield is low, the returns are higher compared to the raising of pigs alone due to the high labor and feed inputs in rearing pigs. The overall system is viable and the vegetables serve as food for the pigs.

Thailand practices integrated poultry-pig-fish farming, particularly in the central plain where the water supply is abundant. Here, a three-tier system is applied where poultry is raised above the pigsty over the fish pond. In the poultry-pig-fish combination, the chicken manure is eaten by the pigs and whatever is left unutilized is washed down to the pond with the pig manure, both as fish food and fertilizer. The total production of a 1.5 rai* area using this combination is 4,000 kg of catfish *(Pangasius pangasius)* 8,000 kg of pigs and 15,330 chicken eggs. Vegetables are also produced. (Kamchai,** pers. comm. 1979).

Fish production in pig-fish farming operations ranges from 2,000 to 5,000 kg/ha/6 mo. The number of animals kept averages 10 pigs/rai (about 60/ha). The fish and pig raising periods are 6 mo, which means that a farmer can produce two crops a year. The fish used are mainly tilapias stocked at the rate of 25,000 to 30,000/ha (Petcharoen and Charoensrisuk 1977).

Pig-fish farming is practiced in North Sulawesi (Christian area) and Bali (Hindu area), but not in the majority of Indonesia, on account of cultural and religious considerations. Djajadiredja and Jangkaru (1978), however, found integrated farming systems, such as sheep-fish, horse-fish, duck-fish, poultry-fish and crop-fish combinations in West Java (see also Djajadiredja, Jangkaru and Junus, this volume). Compared with crop-fish integration, the yield and income derived from livestock-fowl-fish combinations are much higher. Fish production combined with animal production averaged 6.22 t/ha/yr, compared to 1.31 t/ha/yr when combined with crops.

In the Philippines, an initial trial on pig-fish farming has shown encouraging results with tilapia, common carp and snakehead. Wastes from 40 and 60 pigs/ha were used in combination with total fish stocking densities of 10,000 and 20,000/ha (see Cruz and Shehadeh, this volume). Experiments on pig-fish farming have also been undertaken in Illinois, U.S.A. by Buck et al. (1978). Fish kills were encountered in two instances; these were attributed to oxygen depletion and poor water quality. Measures must be taken to guard against fish kills.

DUCK-FISH FARMING

Central Europe has perhaps the most extensive duck-fish farming production activities after centuries of development (Woynarovich 1979; this volume). Duck-fish farming expanded rapidly in Central Europe after World War II when animal protein shortages became severe. Through exchange of experiences, practical fish culturists developed the technique of maintaining brood ducks and mass rearing day-old and 14- to 21-d-old ducklings, which are prerequisities for duck-fish culture on a commercial scale. Experiments conducted in the German Democratic Republic showed an average increase in carp production of 100 kg/ha with 300 ducks/ha kept on the ponds. In Hungary, 300 to 500 ducks/ha give fish yields of 500 to 800 kg/ha in 150 d (Woynarovich 1979; this volume).

In Hong Kong, about 58% of integrated fish farms raise ducks and about 8% raise geese (Sin 1979; this volume). The production of fish in ponds with ducks may be a little lower than those without, but it uses 25% less feed and therefore has lower production costs. The number of ducks ranges from 2,500 to 3,500/ha/yr to yield 5 to 6 t/ha of duck meat and 2,750 to 5,640 kg/ha

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*1 rai = 1,600 m^2.

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of fish (Sin and Cheng 1976).

In Vietnam, raising 1,000 to 2,000 ducks/ha on ponds increased the average fish yield to 5.0 t/ha/yr compared to 1.0 t/ha/yr without ducks.

Duck-fish farming is still at an experimental stage in India. Demonstration trials have yielded 4,323 kg/ha/yr with 100 to 150 ducks/ha (Sharma et al. 1979). Nepal has also introduced duck-fish farming with assistance from the Food and Agriculture Organization of the United Nations (FAO) and the United Nations Development Program (UNDP), and initial production estimates of 1.0 to 1.5 kg/ha/yr are considered feasible (Woynarovich 1979).

The high productivity of Laguna de Bay lake in the Philippines is helped by manure from the commercial duck farms on its shores and by the domestic wastes draining into it. The duck population in this area is more than 700,000, raised in about 4,000 duck farms. This lake produces annually 39,055 t of finfish; 27,552 t of prawns, and 98,683 t of snails: an average of 430 kg/ha (Shimura and Delmendo 1969). Aquaculture in enclosures was introduced in the lake in 1971 and gave yields of 4 t/ha/yr (Delmendo and Gedney 1974), making full use of the high productivity water.

OTHER LIVESTOCK-FISH FARMING

Cattle are too large to be kept over ponds but they can be raised in feedlots within a fish farm area and their manure applied to the ponds. This is practiced in Israel where cattle manure is collected from stalls and stored in tanks near the ponds for later application. Schroeder (1978) reported that using organic manure as the sole nutrient in fish ponds gave 75% of the yields attained by using supplemental grain feeds and 60% of the yields attained by using protein-enriched pellets. Manure applied at the rate of 200 to 1,000 kg/ha/d increased fish yields from less than 500 to more than 4,000 kg/ha, representing fish growth of 20 to 40 kg/ha/d, without supplemental feeding. Intensive use of manure in conventionally-fed fish ponds doubled the fish yields with half the normal supplemental feed requirements.

In the United States, tilapia in manured ponds grew at 16.0/kg/ha/d compared to 25.8 kg/ha/d for ponds fed with commercial pellets. No significant difference was found between fish from the manured and pellet-fed ponds. Although the yields from manured ponds are significantly lower than pellet-fed ponds, their profitability is higher where manure is available at a nominal cost. The cost of tilapia production in pellet-fed ponds was $0.41 kg/compared to a range of $0.02 to $0.21/kg for manured ponds. (Collis and Smitherman 1978).

The above practices show that animal-fish farming can give high fish yields, comparable to intensive fish rearing using supplemental feeds. The organic nutrients in the animal manures fertilize the ponds and stimulate the growth of fish food organisms.

Animal Wastes

THE QUANTITY OF WASTES PRODUCED BY LIVESTOCK AND POULTRY

The amount of wastes excreted daily by an animal is directly proportional to its total live weight. Taiganides (1978) calculated the quantity of wastes produced by different animals (Table 1). The availability of organic nutrients for field crop production depends on the handling, treatment and storage of wastes, but this variability should be minimal for wastes added directly to ponds from animals over or adjacent to the water. In addition to direct addition of feces and urine to fish ponds, any leftover animal feed rations may also be used as nutrient inputs.

China has a long history of intensive use of animal and domestic wastes for agriculture and a total annual organic fertilizer use (mainly from pigs) of about 1,689 million tons: equivalent to 8,320,000 t of nitrogen (N), 5,092,000 t of phosphorus (P) and 9,671,000 tons of potassium (K). Estimates of the annual tonnage of manure production/animal are as follows: cow, 6.0; pig, 3.0; goat or sheep, 0.8 and poultry, 0.025.

CHEMICAL CHARACTERISTICS OF ANIMAL WASTES

Taiganides (1978) reported that animal manures contain the major inorganic nutrient components (N, P, K), in addition to such trace elements as Ca, Cu, Zn, Fe and Mg. The major nutrients come from the feeds fed to animals, of which 72 to 79% N, 61 to 87% P and 82 to 92% K are recovered from the excreta. Urine comprising only about 40% by weight of the total daily waste excretion has higher N and K levels than feces. P is contained mainly in the feces except for pigs which have high urine levels.

NPK fertilizer use in aquaculture is well known but the application rates vary with pond soil type and water quality. The quantity and fertilizer quality of animal wastes also vary according to species, size and age, feed and water intake, and environmental factors. Their availability is also influenced by the type of waste management practices used (Taiganides 1978).

N in animal wastes may be in the form of NH_3, NH_4, NO_3 and NO_2, the levels of which vary considerably. Gaseous NH_3 can easily be lost to the atmosphere, and handling can affect other losses of the various forms of N. In solid waste handling, losses of N may vary from 20% in deep pits to 55% in open feedlots, whereas in

Table 1. Farm animal waste output and waste composition: TLW represents total live weight (after Taiganides 1978).

Parameter	Abbreviation	As a % of	Pork pigs	Laying hens	Feedlot beef	Feedlot sheep	Dairy cattle
Total wet wastes (feces and urine)	TWW	TLW/d	5.1	6.6	4.6	3.6	9.4
Total solids	TS	TWW	13.5	25.3	17.2	29.7	9.3
		TLW/d	0.69	1.68	0.70	1.07	0.89
Total organic volatile solids	TVS	TS	82.4	72.8	82.8	84.7	80.3
		TLW/d	0.57	1.22	0.65	0.91	0.72
Biochemical oxygen demand	BOD	TS	31.8	21.4	16.2	8.8	20.4
Chemical to biochemical oxygen demand ratio	COD:BOD	TVS	38.6	29.4	19.6	10.4	25.4
		TLW/d	0.22	0.36	0.13	0.09	0.18
	–	Ratio	3.3	4.3	5.7	12.8	7.2
Total nitrogen	N	TS	5.6	5.9	7.8	4.0	4.0
		TLW/d	0.039	0.099	0.055	0.043	0.036
Phosphorus	P	TS	1.1	2.0	0.5	0.6	0.5
		TLW/d	0.007	0.034	0.035	0.007	0.004
Potassium	K	TS	1.2	1.7	1.5	2.4	1.4
		TLW/d	0.008	0.029	0.011	0.026	0.012

liquid handling, N losses range from 25% for anaerobic systems to 80% under aerobic conditions (Taiganides 1978).

In general, pig and poultry wastes contain higher P levels than cow manure. P is bound to solids in most animal wastes and therefore handling losses are minimal.

Animals fed with high roughage rations will excrete more K than those fed on high concentrate rations. The vegetative plant parts contain higher K levels than grains (Taiganides 1978).

Based on the data in Table 1, 30 pigs (TLW 1,500 kg) will excrete 7,650 kg wastes/day comprising 58.5 kg N, 10.5 kg P and 12.0 kg K. For comparison, 2,500 laying hens (TLW 5,000 kg) will excrete 33,000 kg wastes/day comprising 495 kg N, 170 kg P and 145 kg K.

The number of animals required to supply the appropriate quantity of organic nutrients can be estimated but their initial and final weights should both be taken into consideration.

ANIMAL WASTES IN AQUACULTURE AND FISH YIELDS

Animal wastes applied to fish ponds serve as fertilizer and are also consumed by some fish. Suspended organic matter is used by bacteria while the soluble nutrients are taken up by phytoplankton and larger plants. The possible pathways for animal waste utilization in a fish pond are shown in Figure 1.

METHOD OF APPLICATION

There are different ways of handling animal wastes for aquaculture, depending on existing practices for waste utilization and management.

In China, animal and human excreta are utilized in agriculture and aquaculture. These are prepared in different ways depending on local circumstances. The techniques of homemade manure preparation have been developed through centuries of traditional practice and experience and have now been standardized (FAO 1977a).

The highly integrated nature of Chinese farming facilitates the efficient recycling of animal wastes in agriculture and aquaculture. The farmers keep the optimum number of animals in balance with farm land and fish ponds, to supply the manure required. For fish ponds, 30 to 45 pigs/ha is deemed adequate to supply the organic fertilizer required for the year. The pig wastes are usually applied as compost.

COMPOST PREPARATION AND USE

Composting is a widely known technique and the methods used in China are presented here.

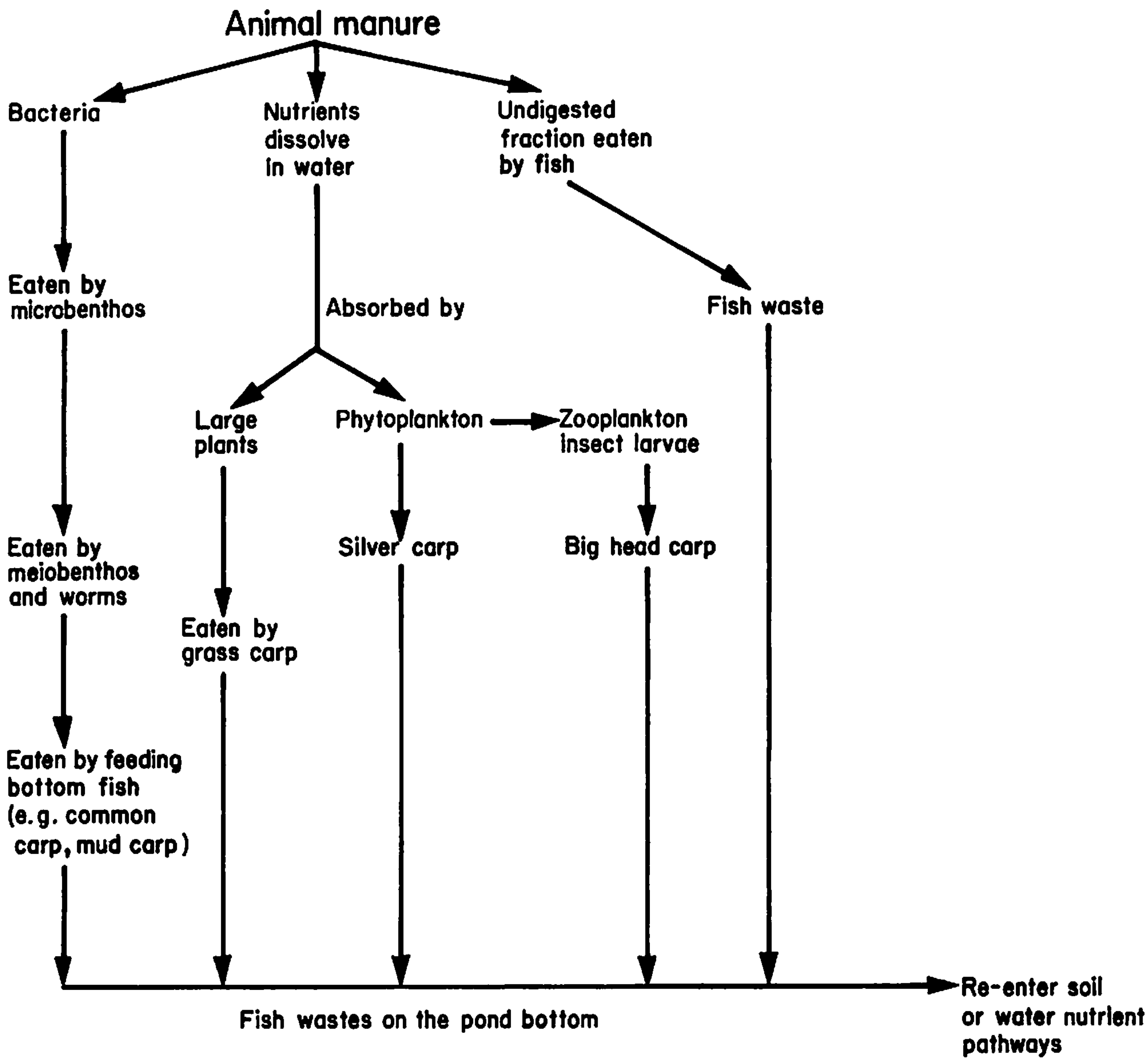

Figure 1. A diagrammatic representation of the breakdown of animal manure in fish ponds and its nutrient pathways in the polyculture of Chinese and common carps.

Animal manure is collected and placed in composting pits located in one corner of the field or farm. The pits are usually circular, measuring 2.5 m bottom diameter, 1.5 m deep and 3.0 m top diameter (Figure 2). Each pit is filled by layering river silt (7.50 t)/rice straw (0.15 t) mixture, pig or cow manure (1.00 t) and aquatic plants or green manure crops (0.75 t) in 15 cm layers. The top is covered with mud and a water column 3 to 4 cm deep is kept at the hollowed surface in order to create anaerobic conditions. This minimizes the N losses. The contents of the pit are turned over after 1, 2 and 2.5 mo after which the compost is ready. In the first turning over, 0.02 t superphosphate is added and thoroughly mixed with the organic material, adding water to ensure moist conditions. Superphosphate is added because the compost is mainly intended for crops. Most collective farms process manure in the same way for both crop lands and fish ponds, varying only the quantity of superphosphate added according to the type of crop or ponds.

Each pit produces about 8 t of compost, adequate to fertilize a 0.1 ha of crop land. The chemical composition of the compost as % wet weight is as follows: N, 0.30; P, 0.20; K, 0.25, and organic matter, 7.8 to 10.3. The carbon:nitrogen (C:N) ratio is 15 to 20:1 (FAO 1977a).

Compost is applied to fish ponds in China at levels ranging from 5 to over 10 t/ha, depending on the type of soil, as three applications during the fish culture period (6 to 8 mo), with the first application greater than the last two and applied during pond preparation before

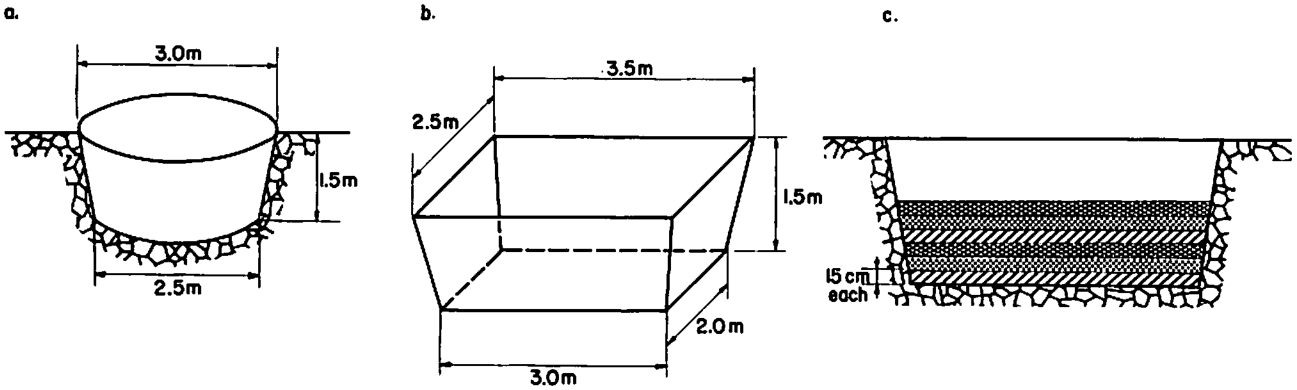

Figure 2. Pits used for composting pig manure with a river silt-rice straw mixture and green manure in the Yueh Chi Commune, Wu County, Jiangsu Province, China: a. and b., two pit designs; c. the layering system used–stripling, silt/straw mixture; double crosshatching, stable manure; single crosshatching, green manure (Source: FAO 1977a).

stocking with fish.

In other countries such as the Philippines, dry chicken manure is added to fish ponds in combination with inorganic fertilizer. The manure is usually brought from distant farms and it entails added costs. The Chinese technique is a classic example of a truly integrated production system where all the manure needed is available. Alternative forms of manure, such as liquid manure and sludge, are considered below.

LIQUID ANIMAL MANURE

Liquid manure is obtained from the anaerobic fermentation of animal manure in bio-gas plants or by mixing fresh manure with water. Animal wastes collected in open tanks or pits and mixed with water can be used as fertilizer in fish ponds, but this requires transport, handling and storage facilities even when the animals are raised within the same farm. The handling of this type of liquid manure is quite difficult.

Liquid manure or effluents from bio-gas digesters are, however, easier to handle as they can be conveyed to delivery points through small canals or pipes. From Chinese experience, the dilution of animal manure for biogas generation may be through any of the following mixtures:

1. 20% urine, 30% human excreta and 50% water.
2. 10% human excreta, 30% animal manure, 10% straw and grass, and 50% water.
3. 20% human excreta, 30% pig manure and urine, and 50% water.
4. 10% each of human and animal excreta, 30% marsh grass, and 50% water.

Crop wastes, grass and other vegetable material are allowed to decompose for at least 10 d before adding them into the digester.

A 10 m^3 capacity bio-gas plant is the standard size for a household in China; it produces about 10 m^3 of sludge and 14 m^3 effluent/yr. The levels of available N, P and K are as follows: sludge–650 ppm N, 40 ppm P, 9,400 ppm K; effluent–500 ppm N, 15 ppm P, 2000 ppm K. The sludge is 35% organic matter (FAO 1977a).

The sludge and effluent are applied to the land with irrigation water or as a top dressing for crops. The effluent is called "fertile water" and is used in fish nurseries as well as growout ponds as feed and fertilizer. The sludge is also used as a base manure.

FRESH, UNTREATED ANIMAL MANURE

The application of fresh, untreated animal wastes to fish ponds is common in Asia, where pigsties and chicken coops are sited over the ponds.

Although this is a widespread practice, the numbers of animals used/unit area of pond surface have not been standardized. Only in China have the rates of application of manures been established.

The application of fresh untreated animal manure to fish ponds has given high fish yields, but excessive amounts can cause fish kills due to oxygen depletion in the water. This problem has lacked adequate investigation because of the lack of quantitative knowledge on the numbers of animals and the quantity of manure appropriate for specific aquaculture operations. The techniques for integrated agriculture-aquaculture have yet to be standardized and at present vary according to individual skills and experience.

Animal wastes delivered to fish ponds undergo decomposition through bacterial action and this process uses dissolved oxygen (DO), creating a biochemical oxygen demand (BOD). This is often the greatest single factor determining the pond water DO. Schroeder and Hepher (1979) reported that such oxygen depletion could be predicted from BOD measurements in manured ponds. The BOD can also be estimated from the % dry matter content of manures.

Manure is applied to ponds at daily rates of more than 1.5 t/ha under Israeli conditions. Table 2 gives the 24-hr BOD at 30°C for various organic fertilizers and feeds used in Israeli ponds. These observations may be a useful guideline for the management of manured ponds in the tropics to avoid dangerously low DO, particularly at night when no photosynthetic activity takes place.

Table 2. The 24-hr Biochemical Oxygen Demand (BOD) for various fish foods and manures used for pond fertilization (after Schroeder 1975).

Material	% Dry matter	BOD g O_2/kg/24 hr at 30°C
Pellets (25% protein, 10% fish meal)	90	140
Milled wheat and sorghum mixture (1:1)	90	96
Wheat grains	91	40
Chicken manure	95	20 to 40
Sorghum grains	88	18
Field dried manure	36	10
Liquid cowshed manure	12.5	7
Liquid calf manure	9	5

LEVELS OF ANIMAL WASTE APPLICATION TO PONDS AS FERTILIZER

The rate of organic manure application in ponds varies with the type of manure, pond conditions and the local climate.

In China, compost applications in ponds range from 5,000 to over 10,000 kg/ha/yr: equivalent to range of 15 to 30 kg N; 45 to 90 kg P_2O_5, and 12.50 to 25.00 kg K_2O/ha/yr. These nutrient levels approximate to the most economic levels applied elsewhere using inorganic fertilizers. For instance, in Taiwan, 40 kg/ha of P_2O_5 is regarded as the most efficient level of superphosphate application and if the natural productivity of the pond is high, about half this amount is needed. Supplying N, P and K from an inorganic fertilizer was found to be more expensive than the use of superphosphate alone; it also failed to give higher yields (Lin and Chen 1967).

In mainland China, the customary use of 30 pigs/ha of pond provides about 58.5 kg N, 10.5 kg P and 12.0 kg K/ha, assuming an individual average live weight of 50 kg and using the factors in Table 1.

Buck et al. (1978) used 60 to 85 pigs/ha, which is equivalent to a fresh manure application of 180 to 255 t/ha/200 d, assuming an average output of 3 t/pig/yr. The pigsties in this case were located over the pond which therefore received all the urine and solid wastes. The nutrient loading of these ponds was higher and, consequently, the fish yields were also higher compared to the average yield in China. The relationship between organic waste loading and yield requires further investigation.

Woynarovich (1979) reported that in Taiwan, duck-fish operations produce an average of 3,500 kg/ha/yr of fish. Polyculture, selective harvesting and stocking, and high density of ducks ranging from 1,000 to 1,500/ha are practiced. The fish yields from similar operations in Hong Kong are higher ranging from 2,750 to 5,640 kg/ha/yr with about 2,000 to 2,400 ducks/ha.

Based on an estimated manure output/duck of 6 kg/40 d or 150 g/d (Woynarovich 1979), the level of duck manure application in Taiwan is 150 to 225 kg/ha/d. In Hong Kong, it is 300 to 360 kg/ha/d.

In addition to the references on manure pond experiments given above, the following contain information relating waste loading to fish yields: Allen and Hepher (1979), FAO (1977b), Moav et al. (1977) and Rappaport and Sarig (1978). The information available shows that ponds receiving from less than 0.5 t to more than 1.0 t/ha/d can give fish yields of from 1,500 kg to more than 8,000 kg/ha/yr, according to local conditions. It should now be possible to design a balanced animal-fish operation, taking into account the feed requirements of the animals, waste output, pond area and fish yields.

Design of Animal-Fish Production Units

There is a wide variety of animal-fowl-fish integrated farming combinations in operation in Asia, but an appropriate integrated farming production unit has yet to be developed which would be practical and viable enough to be adopted by small farmers under different local conditions. The present system practiced in China provides examples to follow, but here land is consolidated into communal farms which allow full integration of aquaculture and agriculture. Most Asian countries have small, fragmented landholdings of individual ownership and the cost of all farm inputs have therefore to be shouldered by an individual farmer. The technological and economic aspects of integrated farming systems should be clearly demonstrated to small farmers, to promote the maximum use of limited resources and inputs.

A small integrated farming system such as that practiced in Singapore–originally described by Ho (1961) and discussed by Bardach et al. (1972)–has a fish pond at the bottom of a sloping farm land. It includes fruit trees, rootcrops, vegetables, chickens and pigs. Natural drainage and agricultural runoff are conserved and utilized in the fish pond. This principle is also beginning to be used in Nepal where much of the land has steep slopes and terrace farming is practiced. Crop rotations are used in the terraces and the lowest plots are used as fish ponds. Ducks are also kept but are not confined to the ponds.

For flat terrain such as the central plain of Thailand, elevated ridges are made for crop raising and the borrow pits between the ridges contain water for fish culture and for irrigation of some crops (e.g., corn and vegetables). The perimeter of the farm is usually planted with bananas, coconuts, papayas or leguminous trees, such as *Leucaena glauca.* In some cases, the farm is divided into two areas separated by a dike: water space for fish culture and a farm plot housing the pigs and the chickens under one roof. The manure from these animals serves as fertilizer for the pond and for crops. Where there is only one small plot and an adequate water supply, the operations may be restricted to animal and fish raising. When two plots are available, these are rotated each year between fish and crop raising. Thus, organic material at the pond bottom becomes used for crop production. This system is illustrated in Figure 3 and Plates 1 and 2.

Although these systems are being practiced, there are no data available to show the effects of size on their production economics. The number of animals, crops produced and the land-use allocation of the farms vary widely and the farm management techniques employed depend on the interest and experience of individual farmers. In most cases, emphasis is on one product only and the rest are not given proper attention. This is mainly due to lack of financial resources for additional inputs and lack of technical know-how on the synergistic relationships of integrated systems.

From the information available on animal waste output and the waste loading levels appropriate for fish ponds, the number of animals to be kept for agriculture-aquaculture integration can be calculated. A demonstration unit of 2,400 m^2 (1.5 rai) has been successful in Thailand, combining 42 pigs (weaners) and 60 hens with growing corn and leafy vegetables and raising 4,000 kg of fish/yr. More data are still needed, however, to determine the smallest production unit which would be viable for the average small farmer, particularly where landholdings are less than 1.0 ha.

Animal Feeds

The high cost of feed is often the major constraint to intensive livestock and fish production. Most farms are therefore under extensive management and small farmers lack the financial resources to intensify their operations.

One approach to reducing the cost of feeds is to

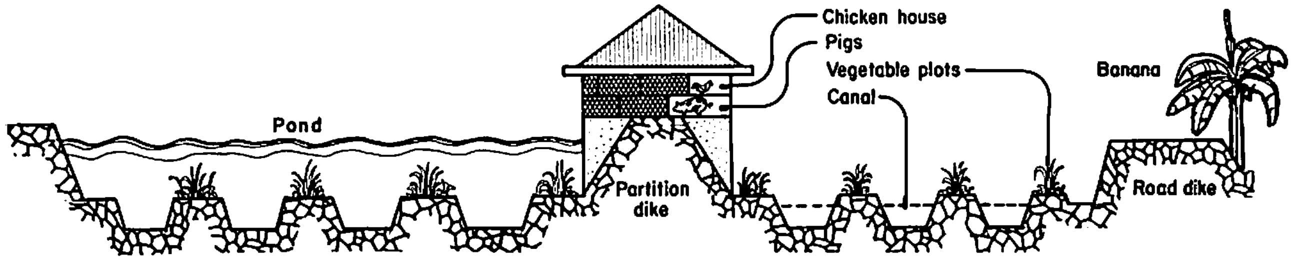

Figure 3. Diagrammatic representation of a small-scale integrated farming system employing rotation between two level plots of land, as practiced in the central plain of Thailand.

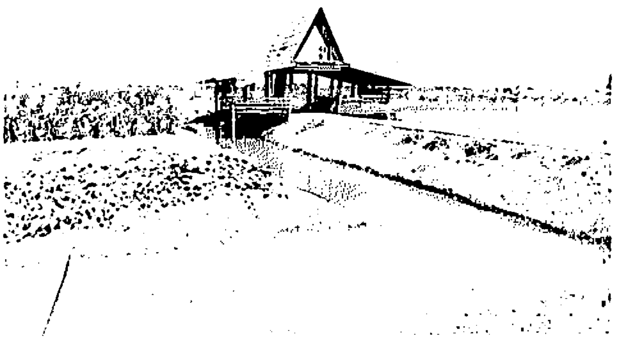

Plate 1. A small-scale integrated farming system employing rotation between two level plots of land, as practiced in the Central Plain of Thailand (see also Figure 3).

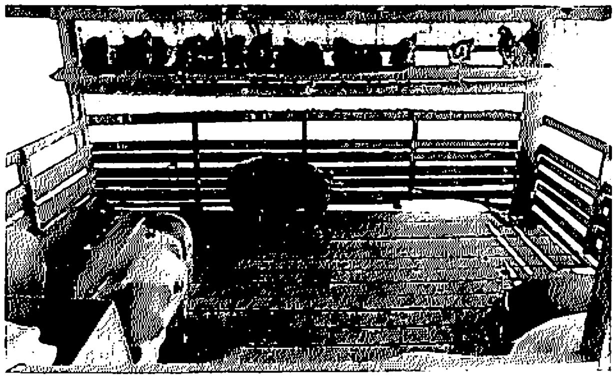

Plate 2. Detail from the system depicted in Plate 2, Figure 3 of the equipment used for keeping chickens above pigs in an animal home projecting over water. The pigs eat chicken droppings and the pig manure fertilizes the water.

produce them within the farm, e.g., feed crops. Pigs can subsist on kitchen wastes mixed with vegetables. Tubers, bananas, coconut meal and grain by-products are also suitable components for pig rations, along with other ingredients rich in carbohydrates, protein and green fodder. Example of feed formulations are shown in Table 3 and of daily feed quantities in Table 4 (COVECO E-104). Green aquatic vegetables, such as water spinach *(Ipomoea aquatica)* mixed with rice bran and kitchen leftovers are commonly used in family scale pig rearing. Bananas, coconut and *Leucaena glauca* are also grown and their fruit and leaves, except for coconut leaves, are used for pig food. Water spinach can be planted along the pond margins or in a shallow portion of the pond but its growth is never allowed to expand to cover the surface area of the pond. It is harvested 30 d after planting and at weekly intervals thereafter by cutting its vertical branches. A hectare of pure *I. aquatica* can give an average yield of 90 t/yr (Eddie and Ho 1969). The nutrient contents of *I. aquatica* and rice bran are given in Table 5.

Rice bran should not exceed 30 to 40% of the total pig feed ration or else soft pork is produced.

In Vietnam, the main materials used for pig food are water spinach and Azolla, which make up about two-thirds of the rations. These are mixed with one-third rice bran and 2 to 3% fish meal. A farm with 6,000 pigs devotes 50 ha to growing water spinach and Azolla.

The green cooking banana *(Musa paradisiaca)* is another good pig food, whether ripe or green, giving a food conversion ratio of 3.55 (Clavijo and Maner 1975). Banana-based pig foods may be supplemented with rice bran, maize or fish meal. Banana leaves can also be fed to pigs. Bananas grow well and fruit all year round (FAO 1977c).

Table 4. Daily feed quantities for pig farming in the tropics: growing mash from 15 to 50 kg and fattening mash thereafter (feed formulations in Table 3). (Source: COVECO E-104).

Pig weight (kg)	Age (wk)	Daily feed quantity (kg)
15	8	0.75
20	10	0.90
25	12	1.10
30	14	1.30
35	15	1.50
40	17	1.70
45	18	1.80
50	19	2.00
55	20	2.10
60	21	2.30
65	22	2.40
70	23	2.50
75	24	2.60
80	25	2.70
85	26	2.80
90	27	2.90
95	28	3.00
100	29	3.00

Table 3. Feed formulations for pig farming in the tropics (after COVECO E-104).

	Starter (%)	Growing mash (%)	Fattening mash (%)	Breeding mash (%)	Lactating mash (%)
Corn	35-60	25-60	25-60	15-40	20-50
Corn grits	–	0-15	0-15	0-20	0-15
Corn gluten feed	–	0-15	0-15	0-15	0-15
Pollard	5-15	10-30	0-35	0-20	0-20
Wheat bran	–	5-20	0-15	10-30	10-25
Rice bran (first quality)	–	0-10	0-25	0-15	0-15
Fish meal	5-10	5-10	–	2-5	5-10
Meat and bone meal	–	0-5	2-7	0-5	0-5
Skim-milk powder	0-20	–	–	–	–
Soybean meal	5-15	2-10	2-5	2-7	5-10
Copra meal	–	0-3	2-7	0-7	0-7
Leucaena glauca leaf meal	0-3	5	5	5	5
Molasses	0-3	5	5	5	5
Sugar	0-10	–	–	–	–
Minerals	1	1.5	1.5	1.5	1.5
Vitamins	As manufacturers' instructions				
Antibiotics	As manufacturers' instructions				
Crude protein	19	16	14.5	14.5	18.5
Starch equivalent (S.E.)	70	68	69	64	66
S.E./crude protein	3.7	4.2	4.6	4.4	3.6
Crude fibre (max.)	4	6	6	8.5	7

Sweet potato tubers can also be grown as a pig feed substitute or supplement. They grow well in warm humid climates, even in poor soil, and withstand drought. They can be harvested every 3 mo. The young leaves and stems are also edible (FAO 1977d).

Water management in small fish ponds should be developed according to local conditions and synchronized with the other farm activities. Ideally, a small farm should be self-sufficient in the material inputs required for animal and fish production. A combined effort is

Table 5. Evaluation of water spinach *(Ipomoea aquatica)*, rice bran and cooking bananas *(Musa paradisiaca)* as pig feedstuffs.

	Major components as a % of dry matter								
Feedstuff	Dry matter %	Crude protein	Crude fiber	Ash	Crude fat	Nitrogen-free extract	Calcium	Phosphorus	Source
Ipomoea aquatica (fresh leaves and stems)	7.5	28.0	12.0	18.7	2.7	38.6	1.2	0.4	Gohl 1975
Rice bran	88.8	10.6	18.9	13.8	10.6	46.1			Gohl 1975
Musa paradisiaca (whole, with peel)	20.0	1.0	1.0	1.0	0.20	16.8			Clavijo and Maner 1975

Table 6. Economics of polyculture and duck-fish systems of selected Hong Kong farms of three size categories: US$1.00 = HK$5.00 (after Sin and Cheng 1976).

	Large farms (over 4 ha) (unit/ha)		Medium farms (1.5 to 4.0 ha) (unit/ha)		Small farms (below 1.5 ha) (unit/ha)	
	with ducks	without ducks	with ducks	without ducks	with ducks	without ducks
Area (ha)	5.32	6.80	2.20	2.80	1.50	1.53
Number of ducks/ha/yr	2,409	–	1,971	–	2,117	–
Duck yield : Quantity (kg)	6,071	–	5,002	–	5,354	–
Value (HK$)	36,720	–	29,508	–	33,777	–
Duck feeds : Quantity (kg)	27,320	–	23,509	–	26,235	–
Cost (HK$)	28,080	–	23,143	–	26,250	–
Feed conversion ratio (duck)	4.5	–	4.7	–	4.9	–
Fish yield : Quantity (kg)	5,640	5,865	3,968	4,050	2,750	3,000
Value (HK$)	41,767	47,783	34,038	34,435	22,697	25,195
Fish feeds : Quantity (kg)	15,038	19,143	10,753	14,175	7,893	9,300
Cost (HK$)	11,278	15,893	7,209	10,208	5,523	7,068
Feed conversion ratio (fish)	2.67	3.26	2.71	3.50	2.87	3.00
Feed cost/kg fish produced (HK$)	2.00	2.71	1.82	2.52	2.01	2.36
Net income : Fish	15,892	18,155	13,461	9,117	5,156	5,644
Duck	2,352	–	1,965	–	2,025	–
Total	18,244	18,155	15,426	9,117	7,181	5,544
Input-output: Ratio of net income/ total costs	0.61	0.61	0.65	0.36	0.29	0.28
Fish operation: Ratio of net income/ running costs	0.69	0.69	0.73	0.39	0.34	0.32

therefore needed by agriculturists and aquaculturists to design balanced systems for integrated agriculture-aquaculture production. For fish production, the quantity of manure loading in ponds could range from 1 to more than 1.5 t/ha/d: higher than the range quoted above. The farmer must, however, prevent fish kills due to oxygen depletion and take such precautions as providing aeration.

Marketing and Economic Aspects

There appears to be no significant difference in the taste and texture of flesh of fish grown in manured ponds and those fed commercial diets. Allen and Hepher (1979) report that fish from ponds receiving well-treated domestic wastes taste as good or even better than fish grown in waste-free ponds. Similarly, Moav et al. (1977) report good flesh color and intramuscular fat levels for fish grown in intensively manured ponds. Examples of the economics of manured pond fish culture are given by Rappaport and Sarig (1978) and Sin and Cheng (1976). There is little detailed information on the economics of pig-fish farming operations in Southeast Asia, but Petcharoen and Charoensrisuk (1977) and Djajadiredja and Jangkaru (1978) give data for a few family farms in Thailand and Indonesia (Tables 7 to 9).

Table 7. Expenditure (excluding depreciation) and income for some integrated pig-fish farms in Thailand: US$1.00 = 20 Baht (after Petcharoen and Charoensrisuk 1977).

Farm size (ha)	0.64	0.96	1.60
Tilapia fingerlings stocked	15,000	25,000	200,000
Number of pigs	45	100	100
Expenditure (Baht)			
Cost of fish seed	1,500	1,250	10,000
Cost of piglets	20,250	50,000	50,000
Feeds and medication	26,311	79,720	144,500
Land rent	–	6,000	–
Total (A)	48,061	136,970	204,500
Gross income (Baht)			
Sale of fish at 6 to 8 Baht/kg	20,000	24,800	30,000
Sale of pigs at 18 to 19 Baht/kg	97,200	203,500	228,000
Total (B)	117,200	228,300	258,000
Net income (B–A)	69,139	91,330	53,500
Ratio of net income to:			
1. gross income	59%	40%	21%
2. operating cost	144%	67%	26%

Table 8. Costs and returns from a 1,000-m^2 chicken-fish farm, holding 100 layer chickens/yr in Tasikmalaya, West Java in 1977: US$1.00 = Rp 627 (after Djajadiredja and Jangkaru 1978).

	Quantity	Cost or value (Rp)	Percent (%)
Capital investment			
Land value	1,000 m^2	1,000,000	
Construction			
Building and equipment	12 m^2	150,000	
Chickens	100	120,000	
Total (A)		1,270,000	
Operating costs			
Fish seed: Common carp and tilapia	250 kg	100,000	19.2
Chicken feed	3,600 kg	216,000	41.5
Labor: Permanent labor	12 man-months	72,000	13.8
Seasonal labor	36 man-days	14,000	2.7
Maintenance and repairs		17,500	3.4
Interest (12%)		32,400	6.2
Taxes		2,000	0.4
Depreciation:			
Chicken house (20%)		30,000	5.8
Chicken layers (30%)		36,000	6.9
Total (B)		520,000	
Income			
Fish	625 kg	250,000	
Eggs	1,200 kg	660,000	
Total (C)		910,000	
Profit (C–B)		390,000	
Rate of return on capital investment ($\frac{C-B}{A}$%)			30.7
Rate of return on operating costs ($\frac{C-B}{B}$%)			74.9

Table 9. Costs and returns from a 1,000-m^2 duck-fish farm in Garut, West Java in 1977: US$1.00 = Rp 627 (after Djajadiredja and Jangkaru 1978).

		Quantity	Cost or value (Rp)	Percent (%)
Capital investment				
Land value		1,000 m^2	1,000,000	
Construction		–	–	
Building and equipment		–	120,000	
Ducks		300	600,000	
	Total (A)		1,720,00	
Operating costs				
Fish seed:	Common carp	140 kg	70,000	4.3
	Nile tilapia	87.5 kg	26,250	1.6
Duck feed		16.9 tons	1,014,000	62.0
Labor :	Permanent labor	12 man-months	144,000	8.8
	Seasonal labor	40 man-days	16,000	1.0
Maintenance and repairs		–	72,000	4.4
Interest (12%)		–	86,400	5.3
Taxes		–	2,000	0.1
Depreciation:				
	Duck house (20%)	–	24,000	1.5
	Duck (30%)	–	180,000	11.0
	Total (B)		1,634,650	
Income				
	Common carp	280 kg	140,000	
	Nile tilapia	350 kg	105,000	
	Eggs (incubated)	33,600	1,176,000	
	Ducklings	1,000	600,000	
	Low quality ducks	40	60,000	
	Total (C)		3,019,000	
Profit (C–B)			1,384,350	
Rate of return on capital investment ($\frac{C-B}{A}$%)				80.5
Rate of return on operating costs ($\frac{C-B}{B}$%)				84.7

Acknowledgments

This writer would like to thank the International Center for Living Aquatic Resources Management for their kind invitation to participate in this Conference.

Gratitude is also conveyed to Dr. H. R. Rabanal, Senior Aquaculture Development Officer, South China Sea Fisheries Development and Coordinating Programme, and Dr. H. Chaudhuri, Deputy Director, SEAFDEC, Institute of Aquaculture, for their comments on the manuscript.

References

Allen, G.H. and B. Hepher. 1979. Recycling of wastes through aquaculture, and constraints to wider application, p. 478-487. *In* T.V.R. Pillay and W.A. Dill (eds.) Advances in aquaculture. Fishing News Books Ltd., Farnham, Surrey, England.

Bardach, J.E., J.H. Ryther and W.O. McLarney, 1972. Aquaculture: The farming and husbandry of freshwater and marine organisms. Wiley Interscience, New York.

Buck, D.H., R.J. Baur and C.R. Rose. 1978. Polyculture of Chinese carps in ponds with swine wastes, p. 144-155. *In* R.O. Smitherman, W.L. Shelton, J.H. Grover (eds.). Symposium on Culture of Exotic Fishes. Fish Culture Section, American Fisheries Society, Auburn, Alabama.

Clavijo, H. and J. Maner. 1975. The use of bananas for swine feed, p. 99-106. *In* Proc. Conf. on Animal Feeds of Tropical and Sub-tropical Origin. Tropical Products Institute, London.

Collis, W.J. and R.O. Smitherman. 1978. Production of tilapia hybrids with cattle manure or a commercial diet, p. 43-54. *In* R.O. Smitherman, W.L. Shelton, J.H. Grover (eds.). Symposium on Culture of Exotic Fishes. Fish Culture Section, American Fisheries Society, Auburn, Alabama.

COVECO E-104. Manual for pig farming in tropical regions. Union of Livestock Marketing Cooperatives, Frieshandal-Leewardeen, P. O. Box 310, Holland.

Delmendo, M.N. and R.H. Gedney. 1974. Fish farming in pens. A new fishery business in Laguna de Bay. Laguna Lake Development Authority, Manila, Philippines. Tech. Pap. 2. 71 p.

Djajadiredja, R. and Z. Jangkaru. 1979. Small-scale fish/crop/livestock/home industry integration. Indonesian Agricultural Research and Development Journal 1(3-4):1-3.

Edie, Harry H. and Bess C. Ho. 1979. *Ipomoea aquatica* as a vegetable crop in Hong Kong. Econ. Bot. 23:32-36.

FAO. 1977a. China: Recycling or organic wastes in agriculture. Report of the FAO Study Tour to the People's Republic of China, 28 April-24 May 1977. FAO Soils Bulletin 40. 107 p.

FAO. 1977b. Freshwater fisheries and aquaculture in China. A Report of the FAO Fisheries (Aquaculture) Mission to China, 21 April-12 May 1976. FAO Fish. Report No. 168.

FAO. 1977c. Bananas. Better Farming Series. FAO Economic and Social Development Series, No. 3/18. 27 p.

FAO. 1977d. Roots and tubers. Better Farming Series. FAO Economics and Social Development Series, No. 3/16. 58 p.

Gohl, B. 1975. Tropical feeds. FAO Feeds Information Centre, Rome, Italy. p. 259-345.

Le Mare, D.W. 1952. Pig-rearing, fish-farming and vegetable growing. Malaysian Agric. J. 35:156-166.

Lin, S.Y. and T.P. Chen. 1967. Increase of production of freshwater fish ponds by the use of inorganic fertilizers. FAO Fish Rep. 44(3):210-225.

Moav, R., G. Wohlfarth, G.L. Schroeder, G. Hulata and H. Barash. 1977. Intensive polyculture of fish in freshwater ponds. I. Substitution of expensive feeds by liquid cow manure. Aquaculture 10:25-43.

Petcharoen, J. and Somsak Charoensrisuk. 1977. Fish-cum-swine raising. (In Thai with English translation). Mimeograph Leaflet No. 1. 4 p. Freshwater Fish Culture Centre, Kasetsart University, Bangkhen, Bangkok, Thailand.

Rappaport, U. and S. Sarig. 1978. The results of manuring on intensive growth fish farming at the Ginosar station ponds. Bamidgeh 30(2):27-36.

Schroeder, G.L. and B. Hepher. 1979. Use of agricultural and urban wastes in fish culture, p. 487-489. *In* T.V.R. Pillay and W.A. Dill (eds.) Advances in aquaculture. Fishing News Books Ltd., Farnham, Surrey, England.

Schroeder, G.L. 1975. Nighttime material balance for oxygen in fish ponds receiving organic wastes. Bamidgeh 27(3):65-74.

Schroeder, G. 1978. Agricultural wastes in fish farming. The Commercial Fish Farmer & Aquaculture News 4(6):33-34. Also published in Water Res. 11:419-420. 1977.

Sharma, B.K., D. Kumar, M.D. Das and S.K. Neazi. 1979. Observations on fish-cum-duck rearing, p. 95. Abstracts. Symposium on Inland Aquaculture, 12-14 Feb. 1979. Barrackpore, West Bengal.

Shimura, T. and M.N. Delmendo. 1969. A listing survey of fishermen and fishing households in Laguna de Bay area. A report to the Philippine Fisheries Commission, Intramuros, Manila. 20 p. (Unpublished).

Sin, A.W. and K.W.J. Cheng. 1976. Management systems of inland fish culture in Hong Kong. Indo-Pacific Fisheries Council, Bangkok, Thailand. IPFC/76/Symp/51. 9 p.

Taiganides, E.P. 1978. Principles and techniques of animal waste management and utilization. FAO Soils Bulletin 36:341-362.

Woynarovich, E. 1979. The feasibility of combining animal husbandry with fish farming, with special reference to duck and pig production, p. 203-208. *In* T.V.R. Pillay and W.A. Dill (eds.) Advances in aquaculture. Fishing News Books Ltd., Farnham, Surrey, England.

Additional Bibliography

Periodical: Animal Production and Health Commission for Asia - Asian Livestock Newsletter. Vol. III, Nos. 5 and 11, May and November 1978, Bangkok, Thailand.

Delmendo, M.N. 1977. Environmental and engineering considerations in the development and management of aquaculture projects in flood plains. Joint (South China Sea Programme/Southeast Asian Fisheries Development Center) Workshop on Aquaculture Engineering (with emphasis on small-scale aquaculture projects), Volume II -Technical Report, SCS/GEN/1977/15 Iloilo City, Philippines. p. 75-83.

Mendola, D. 1976. Aquaculture Energy Primer/Aquaculture. p. 129-141. New Alchemy Institute, Woodshole, Massachussetts.

Fish Farming in Manure-Loaded Ponds

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Abstract

The principles of farming fish in manure-loaded ponds are discussed, including the autotrophic and heterotrophic food webs. The uses of manure as an aquatic fertilizer and as a component of supplemental feed are compared. Different animal manures are considered in relation to their quality for pond fertilization (C:N:P:K ratios, BOD, crude protein, fiber, etc.) and methods and rates of application are described. The recommended manuring rate as dry organic matter is 2 to 4% of the fish biomass/d. Fish yields in manure-loaded ponds are compared from Israeli and other data. Maximum fish yields of 30 kg/ha/d, averaged over a growing season, have been demonstrated, and a standing fish biomass of about 7 t/ha is attainable.

Introduction

A simple material balance shows that with the exception of ruminant husbandry, all semi-intensive or intensive animal rearing consumes, rather than produces, energy and protein-rich foods that might otherwise be used directly for human consumption. This is because all animals, with the exception of those having a rumen, must have their entire protein and energy requirements presented in easily assimilable form. Only the ruminant, through microbial activity within its rumen, can thrive on coarse fiber-rich foods. In many parts of the world this net loss of available food is unacceptable.

Yield Comparisons

THE CONVENTIONALLY FED FISH POND

Conventional fish culture is no exception to this pattern. If grains are used as a supplemental feed and annual yields of 5 to 10 t fish/ha are sought, then the feed conversion ratio (FCR) will be about three, i.e., 3 kg feed (dry weight) are required to produce 1 kg (wet weight) of fish. If fish meal-enriched feed pellets containing a total of 25% protein are used, the FCR will be about 2.0 to 2.5. Assuming that fish contain about 20% dry matter, then with an FCR (dry weight food: wet weight fish) of 2.5, 12.5 kg feed will be required to produce 1 kg of fish dry weight. If the feed pellets contain 10% fish meal (a typical level), then 1.25 kg of fish meal will be required to produce 1 kg of fish dry weight. This fishpond consumes not only grain but also fish.

This balance is discouraging from the viewpoint of alleviating food scarcity and from economic considerations. The cost of supplemental feed is consistently the largest single operating cost in conventional, semi-intensive fish culture, usually comprising 50% of the total operating costs.

THE MANURE-LOADED FISH POND

There is an alternative method for achieving the costly but relatively high yields attained in conventional, semi-intensive fish culture. This is to use the pond, not only as the medium in which the fish grow, but also as the environment in which their food is grown. For centuries, fish culturists, especially in the Far East, have added animal manure to family fishponds. With pond management based on the experience of past generations, the average yield of manured ponds in China is estimated by the Food and Agriculture Organization of the United Nations (FAO) at about 3 t/ha/yr. While this is below the yields produced in semi-intensive culture (5 to 10 t/ha/yr), it does point to an approach for solving the net loss of food encountered in conventional fish culture.

The characteristics of a pond make it an excellent environment for converting crude, inedible nutrient materials into high quality fish food. Nutrients and minerals originally bound in relatively indigestible form are released by intense microbial activity in the water column and at pond bottom, and provide substrates for photosynthetic (autotrophic) and microbial (heterotrophic) production of basic fish food.

A COMPARISON OF THE USE OF MANURE TO FERTILIZE WATER AND LAND

Fish yields in manure-loaded ponds, with no supplemental feeding, can reach 5 to 10 t/ha/yr, but this requires attention to pond design and management. The types of fish stocked and the stocking densities used must be appropriate to the rates of production of natural foods. Manuring must also be adjusted to fish densities and pond conditions.

In farms raising land animals and field crops, the feeds supplied to the non-ruminants are used once as feed and then the animal manure is returned to the field. Introducing fishponds to such farms allows better recycling of the animal feeds as the manure nutrients are used by microbial growth in the pond and the fish crop the food organisms produced. This is especially true for poultry farms. The high biochemical oxygen demand (BOD) of poultry manure, as compared with ruminant manure, reflects the higher food value both of the feed eaten and the manure produced. A high BOD implies rapid digestion and conversion to microorganisms upon introduction to the pond.

The water from manured ponds is also useful for irrigation. The mineral component of the manure increases the plankton production. Standing crops of plankton in well-managed ponds will provide several ppm of dry organic matter equivalent in carbon (C): nitrogen (N): phosphorous (P) ratio to a good fertilizer.

The use of manure as a substrate for growth in fishponds is not without its cost to the farm. Extensive field experiments in China (FAO 1977) have demonstrated the benefits of using compost and manures for soil fertilization. Their nutrients and organic matter increase the water-holding capacity of soil, decrease the rate of evaporation and increase enzymic activity, all of which increase fertility and crop yield. Twenty to 40 t of compost-manure/ha (assume about 5 t/ha dry matter) applied during the growing season produces about a 1-t/ha increase in yields of rice, maize, wheat and millet over nonmanured yields of about 3 t/ha/season. This same amount of manure, when applied to fishponds receiving no supplemental feeding at the Fish and Aquaculture Research Station in Dor, Israel produced 1.0 to 1.5 t of fish, with an average daily yield of 30 kg/ha, and 3 to 4 t of fish, with an average daily yield of 20 kg fish/ha. (Schroeder and Hepher 1976; Moav et al. 1977; Schroeder 1978). To attain 20 kg fish/ha/d, a lower fish stocking density and lower manuring rate was used than was used to attain 30 kg fish/ha/d. The utilization of the manure was more efficient at the lower rate. Hence the given amount of manure could be used over a larger pond area producing a higher total fish yield although a lower yield per unit area of pond.

The relative value of using manure for land or fish crops must therefore be decided by the farmer when his supply of manure is limited. On a dry weight basis, the available energy of wheat (3,000 kcal/kg) is similar to that of fish meal (2,600 kcal/kg) (Shiloh and Viola 1973) but the dry weight yield of wheat due to manuring is considerably greater than the dry weight yield of fish. Hence, for energy source production, the manure is better used for producing grain. The protein value of fish, however, considerably exceeds that of grain and it is often protein that is limited in subsistence farming, in which case the manure would be better used for fish production.

The Food Web

Supplies of manure are limited and their use as a nutrient source in aquaculture incurs costs of collection and application, as well as the loss of availability for land fertilization. Understanding the paths that lead from manure application to fish production is of benefit in optimizing use of the organic and mineral components of the manure. A knowledge of the relative intensity of production of the various niches within the natural food web could enable us to tailor fish stocking densities to a polyculture that would harvest the natural foods according to their production.

The present understanding of the dynamics of the food web is incomplete. Few, if any studies have started with manure application and followed its components through to fish production in the way that nutrient pathways have been followed in ruminants (IAEA 1975).

Manure may enter the food web in several ways: as a food consumed directly by the fish, as a source of minerals used in photosynthetic production of phytoplankton (and hence as one of the first links in a food chain), and as a source of organic substrates and minerals for heterotrophic microorganisms, which in turn may be consumed either directly by the fish or by zooplankton.

MANURE AS A DIRECT FEED

The effectiveness of cow, chicken and pig manure as a direct fish feed has been tested in a variety of fish: common carp (Shiloh and Viola 1973; Campos and Sampaio 1976; Kerns and Roelofs 1977), tilapias, (Stickney and Simmons 1977), channel catfish, (Fowler and Lock 1974; Lu and Kevern 1975) and goldfish (Lu and Kevern 1975). The usual approach in these experiments was to incorporate the dried manure into a standard feed pellet as a replacement for higher quality components. In this manner, the first exposure of the fish to the manure was by direct consumption of the pellet. Experiments conducted in tanks or cages (the fish not having access to either the decay products of the uneaten pellets or to fish feces) showed that manures are poor substitutes for the components normally included in fish feed pellets. Consistently, with each increase in manure concentration in the pellet, there was a decrease in fish growth rates. Experiments conducted in open ponds, however, (the fish having access to the feed pellet decay products) gave results such that feeds containing as high as a 30% manure produced fish growth equal to the growth obtained with conventional fish feed pellets.

These results are explicable if we consider pond food chains. Feeding trials in which fish are isolated from the decay products of their feces or uneaten pellets allow only that fraction of the pellet directly digestible by the fish to be utilized. Metabolizable energy in cow and chicken manure is reported to range from 600 to 800 and from 900 to 1,200 kcal/kg, respectively, as compared to 3,000 kcal/kg for conventional feed pellets (Shiloh and Viola 1973) and 3,000 to 4,000 kcal/kg for zooplankton (Yurkowski and Tabachnek 1979). Ash comprises 20% to 40% of the dry weight of manure (Shiloh and Viola 1973; Bellamy 1975). Usually more than half of the crude protein content (determined as Kjeldahl N on the dried sample x 6.25) is not actually protein, but rather uric acid or other non-protein nitrogen (NPN) compounds that are not normally assimilable by the fish. Clearly, from the aspects of available energy and protein, cow and chicken manure are inferior foods.

In feeding trials conducted in open ponds, however, the fish can utilize the directly assimilable fractions of the pellet plus those organisms which grow on the undigested part of the pellet after it has fallen to the pond bottom, either as uneaten pellets or as fish feces. In this sense the pond fish combination becomes an aerobic version of a rumen and its owner. Within the rumen, sources of crude fiber and NPN are incorporated into microbial production which in turn serves as effective food for the animal (Abdo et al. 1964; Hobson 1976). A similar succession appears to occur in the pond. The fish crops the food web that originates with the decaying pellets or feces, and can apparently satisfy its nutritional requirements and maintain a high growth rate.

NATURAL FOODS AND FISH GROWTH

Twenty-six commercial Israeli fishponds stocked with common carp *(Cyprinus carpio), Sarotherodon aureus* and mullet were studied to determine factors affecting the FCR (Schroeder 1973). Supplemental feeds (sorghum and/or fish meal-enriched pellets) were supplied daily at 3 to 4% of the fish biomass. In spite of the high supplemental feeding rate, the most important factor affecting the FCR was the abundance of natural foods. Interestingly, the main correlation between FCR and natural foods was for heterotrophs and not for autotrophs. The reason for this should become clearer below.

MANURE AS A FERTILIZER FOR AUTOTROPHIC (PHOTOSYNTHETIC) PRODUCTION

Upon addition of manure to a fishpond, several concurrent biological activities are started which produce the natural food web. The average mineral composition of several manures is listed in Table 1. This mineral fraction is directly available for photosynthesis or heterotrophic growth of bacteria. Bacteria, digesting dead plankton or the organic fraction of manure, liberate bound minerals and produce carbon dioxide, both of which become available for further photosynthetic production (Kajak and Hillbricht-Ilkowska 1972; Anderson and Macfayden 1976).

In the presence of adequate nutrients, primary production reaches a maximum value set by the amount of solar energy penetrating the pond water. In tropical and subtropical climates, this is about 10 g Carbon (C)/m^2/d (Tamiya 1957; Anon. 1977), and is observed in algae production ponds. Schroeder (1978) measured primary production in fishponds receiving inorganic fertilizers at rates of 70 kg superphosphate and 70 kg ammonium sulfate/ha/2 wk and ponds receiving 100 kg chicken or cow manure dry matter/ha/d. Primary production was the same in the manured ponds as in those which received the inorganic fertilizers alone. Had the primary production been limited by carbon, minerals or soluble nutrients, the added manure would most likely have produced an increase over the inorganic fertilizers. The limit in these tests apparently was due, however, to the available solar energy penetrating the pond. The range of primary production levels, observed in Israeli fishponds (subtropical climate) by Hepher (1962), Schroeder (1978) and Noriega (in press), was 1 to 5 g $C/m^2/d$ in the spring and fall, and 4 to 8 g $C/m^2/d$ in the summer. These values are below the maximum value of 10 g $C/m^2/d$ observed in algae production ponds in the same region. The fishponds studied had 5,000 to 10,000 fish/ha. There was considerable turbidity due to bottom sediments being mixed into the water column by the fish. This reduced light penetration and hence photosynthesis.

Of the total primary production, 90% is in the nannoplankton size range, i.e., passing through a 30 to 40 μm net (Hillbricht-Ilkowska et al. 1972; Schroeder 1978). This is available as a natural food for fish only after entering further food chains or conglomeration to increase its effective size.

When trout are fed a nutritionally balanced diet, the carbon conversion ratio, is five, i.e., 5 units of feed carbon consumed produce 1 unit of carbon fixed in fish growth (Schroeder 1978). Assuming that this ratio is broadly applicable to other fish species and that natural foods provide a balanced diet, we can predict the fish yield attainable by direct harvesting of plankton larger than 30 to 40 μm.

In manured fishponds with no supplemental feeding, during a period when fish yield was 30 kg/ha/d, primary production ranged from 2 to 5 with an average of 4 g $C/m^2/d$ (Schroeder 1978). Only if the entire primary production was cropped and utilized by the fish could the observed fish yield be accounted for, assuming a carbon conversion ratio of five. Observations on sedimentation ponds showed that plankton sedimentation to the sediments (based on accumulation rates of protein accompanied by microscopic analysis) was at a rate similar to that of the primary production. This is consistent with the observation that 90% of the primary production was nannoplankton and, therefore, only a small fraction was harvested directly by the fish. Hence, only a small fraction of the fish yield could be accounted for by direct harvesting of autotrophic-photosynthetic production. Noriega (in press) also found no correlation between primary production (range 1.3 to 8.5 g $C/m^2/d$) and fish yields (about 20 kg/ha/d) in manured ponds with no supplemental feeding. Attempts to predict fish yields from measured primary production gave values less than 25% of the observed fish yields.

Work in progress (Edwards & Sinchumpasak, pers. comm.) shows that the gut contents of *Sarotherodon niloticus* fed on the effluent from a high rate oxidation pond, contain large quantities of the algae *Scenedesmus sp., Micractinium sp.* and *Microcystis sp.* These algae generally are classified as nannoplankton. Small amounts of detritus were also observed.

Clearly, however, food chains additional to autotrophic production must be involved in fish production in manure-loaded ponds.

MANURE IN THE HETEROTROPHIC FOOD WEB

Tang (1970), working in Taiwan with a 6-ha pond receiving frequent additions of night soil, made detailed analyses of the natural food organisms present (phytoplankton, zooplankton, benthic insects, worms and larvae) in relation to the traditionally accepted feeding habits of the fish species used and their growth. From the amounts of these foods present, he could account for only half of the total 30 kg/ha/d measured fish yield. He attributed the remainder to direct consumption of the night soil by the fish. Other researchers (Odum 1968, 1970; Mann 1972; Terrell and Fox 1974; Marias and Erasmus 1977; Buck et al. 1978), when presented with observed fish yields in excess of the generally accepted natural foods available, found that heterotrophic production of bacteria and protozoa could account for the discrepancy.

This microbial community flourishes on manure added to the pond, using the organic and mineral fractions as sources of energy and nutrients. These microorganisms are eaten by pelagic as well as bottom feeding fish (Odum 1970; Kuznetsov 1977), and are good food for fresh and saltwater fish (Tacon and Ferns 1976; Beck et al. 1979; Bergstrom 1979; Matty and Smith 1978; Atack et al. 1979). Kuznetsov (1977) further observed that more than half the bacteria present in the waters tested were in the form of flocs of 21 to 60 μm: a size range available to many pelagic feeding fish.

Spataru (1976, 1977), by analyses of gut contents, has shown that bottom feeding tilapias and the pelagic filter feeding silver carp *(Hypophthalmichthys molitrix)* consume detritus as well as plankton in significant quantities. Summerfelt et al. (1970) found detritus to be the major component of the gut contents of common carp feeding in five Oklahoma reservoirs. Several authors (Fish 1955; Newell 1970; Hargrave 1976) conclude that the microbial community in detritus provides essentially all the nutritional requirements of fish feeding on it. The detritus substrate itself passes through the fish gut relatively unaffected and when voided as fish feces, it is recolonized by microorganisms and can be eaten again by the fish.

The data presented in Table 1 indicate that manure is a good substrate for microbial growth. Unpublished research at Louisiana State University has shown that good microbial production in crawfish-rice paddies, and hence a good crawfish yield, requires a C:N of about 17:1. This is quite similar to the C:N of many manures. Usually the C:N:P of a bacterial growth medium is about 20:1:0.2.

Aerobic digestion of organic matter by bacteria fixes 20 to 50% of the available C as bacteria cells. The remainder is used for metabolic energy (Doetsch and Cook 1973). Anaerobic digestion is less efficient. Measured cellulose digestion rates, demonstrating heterotrophic microbial production in manure-loaded fishponds, are consistently highest at the pond bottom-water interface (Schroeder 1978). The rate here is 2 to 10 times greater than in the water column. Within the bottom sediments, anaerobic after 1 to 3 mm of depth, there is only slight digestion.

Microscopic examination of detritus also shows a consistent pattern: a coarse matrix of organic matter surrounded by dense populations of protozoa (often ciliates) actively grazing on what appears to be a bacterial layer coating or focused on the matrix (Plate 1).

The detritus or seston (i.e., all organic and inorganic suspended solids) provided by the added manure appears to supply a base for colonization by microorganisms essential to the food web. Total production of all organisms larger than 37 μm, both autotrophic and heterotrophic, in pond water and on the pond bottom, in manure-loaded ponds with no supplemental feeding, can account for less than half the 20 to 30 kg fish yield/ha/d consistently observed (Schroeder 1978). The evidence points to microbial production being the key to the high yields.

Table 1. Average composition (%) of several manures (figures in brackets are based on the present author's estimates of the organic matter in the manure as originally reported).

	Water	N	P	K	Organic matter	C:N:P
Dairy cows*	79	0.5	0.1	0.5	(17)	17:1:0.2
Fattening cattle*	78	0.7	0.2	0.5		
Sheep*	64	1.1	0.3	1.1		
Sheep**	–	0.7	0.3	0.3		
Pig*	74	0.5	0.2	0.4		
Pig**	–	0.6	0.2	0.4	15	13:1:0.3
Hen*	76	1.1	0.4	0.4	(19)	9:1:0.4
Poultry**	–	1.6	0.7	0.7		

*Morrison 1959
**FAO 1977

TROPHIC NICHES WITHIN THE FOOD WEB

The food web is complex and dynamic. Under conditions of low fish density, the concept of specific trophic niches for different fish type is probably valid. In such cases, the growth rates of each fish type remain high. At high densities, however, the demand for food in a given niche may exceed its supply. This will force the fish to exploit additional trophic niches. Generally, competition will force the fish to feed at lower trophic levels where the production will be higher (May 1976). The growth rate of fish, such as common carp, which are highly specific in their feeding will suffer more than that of detritus feeders, accustomed to a lower trophic level.

The dynamic nature of the food web was demonstrated by Yashouv (1971), who showed a strong feeding interaction between common carp and silver carp. Polyculture gave higher yields of each species than the sum of separate monocultures. The common carp stirred benthic material (detritus) into the water column, making it available for the silver carp. The feces of the silver carp, containing partly digested plankton and detritus, became available as a bottom manure. Each species therefore increased the growth potential of the other.

Ecological Characteristics

The manure-loaded fishpond can be considered as a system to which mineral-rich organic matter is added in the form of manure and removed in the form of harvested fish. In a properly managed pond there will be an ecological balance that avoids the extreme fluctuations so commonly observed in highly eutrophic water bodies.

The addition of manure to a pond provides a nutrient base for dense blooms of phytoplankton, particularly nannoplankton which in turn triggers intense zooplankton development. The zooplankton have an additional food source in the bacteria which thrive upon the organic fraction of the added manure. The zooplankton community therefore develops from two food chains, and its development soon exceeds the corresponding production of phytoplankton if it is left unexploited. The zooplankton then overgraze the phytoplankton and photosynthetic oxygen production becomes inadequate to supply the respiration demands of the total pond community (bacteria, protozoa, zooplankton and phytoplankton). The pond becomes anaerobic; the zooplankton population dies, gradually decays and a new cycle of phytoplankton growth starts.

It has been clearly demonstrated, however, that ponds receving high loadings of manure or other nutrient rich organic matter, do not have these extreme cycles when stocked with a proper polyculture of fish (Schroeder 1975a; Allen and Carpenter 1977; Buck et al.

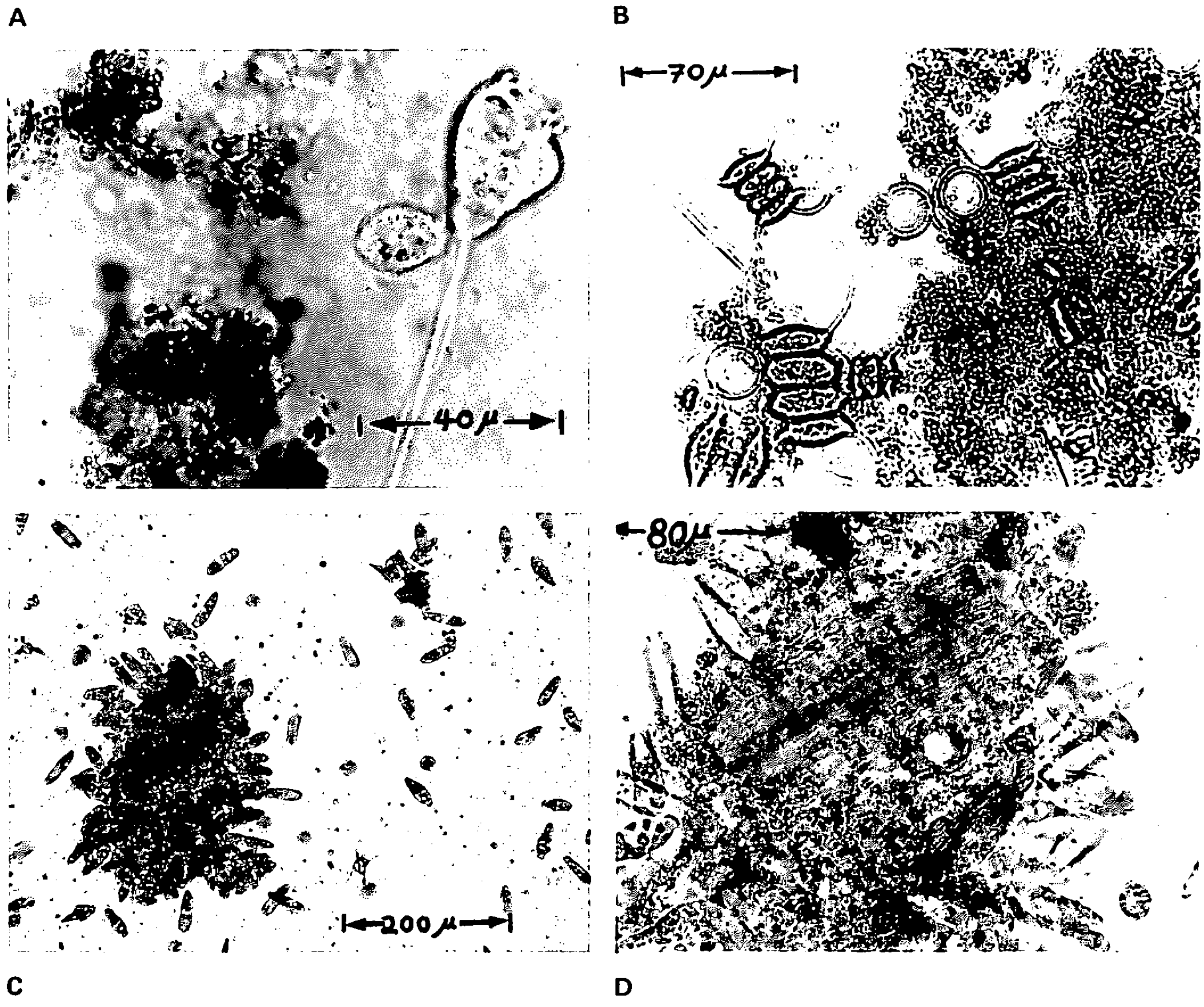


Figure 1. Microorganisms active among the detritus of a pond bottom.

1978). The fish grazing on the plankton community maintain the balance between plankton production and consumption. The pond remains aerobic with higher average levels of dissolved oxygen (DO), higher pH and lower standing crops of phytoplankton, zooplankton, benthic chironomid larvae, and pelagic bacteria (Tables 2 and 3). Table 2 shows that here the daily DO cycle, and especially the critical early morning DO, is not adversely affected by intense manuring. This is in accord with observations that the BOD of the added manure is not a main oxygen consumer in a properly manured pond (Schroeder 1975b).

Unpublished data and observations at Dor, Israel have shown that when the basic nutrients for microbial growth (cf. Rodina 1972) were added to aquaria, there is greater flocculation and precipitation of microorganisms (bacteria and protozoa) in the presence of fish than in their absence (A. Razin, pers. comm.). This may be one factor contributing to the lower bacteria concentrations observed in eutrophic ponds stocked with fish than in eutrophic ponds without fish.

Standard aerobic bacteria plate counts from 19 samples of water, comparing manured ponds without supplemental feeding with conventionally-fed non-manured ponds, showed the same bacterial concentration range: 1 to 5 x 10^4 colony-forming bacteria/ml. Thirty similar analyses of the surface sediments also showed the same bacterial concentration range in both types of pond: 2 to 35 x 10^6 colonies/ml. In the presence of adequate organic matter, whether originating from added manure or added feeds, there appears to be a maximum standing stock of bacteria.

Since the fish productivity in a manure-loaded pond is dependent on aquatic production of natural foods, it is essential that adequate chemicals are present. Very soft water (e.g., 10 mg/l total hardness and alkalinity, Almazan and Boyd 1978) will not support adequate production. At least 0.2 ppm P is required (Jhingran 1977). Extractable P in the soil of the pond may supply part of this. With either soft waters or acid bottoms, agricultural grade limestone (2 to 6 t/ha, $CaCO_3$) and inorganic fertilizer (50 kg/ha, 20 (N): 20 (P): 0 (K) are needed to increase total alkalinity, pH and general production (Thomaston and Zella 1961; Boyd and Scarsbrook 1974; Wiederholm and Eriksson 1977; Sreenevasan, undated).

In several representative commercial ponds in Israel, the water contained: Na, 300 to 800 ppm; Mg, 55 ppm; Ca, 70 ppm; K, 30 ppm; P, 0.3 to 0.6 ppm and Cl, 400 to 1400 ppm. These slightly brackish ponds are highly productive.

MANURING THE POND

It is essential in a fish farming system based on aquatic production of natural foods that the growth substrate, in our case manure, is adequate both in quality and quantity. There are few data in the literature which quantify these parameters in relation to attained high fish yields. The remarks in this section are based on observations by the author and his colleagues at the Fish and Aquaculture Research Station, Dor, Israel, during experiments in which fish yields in manured ponds with no supplemental feeding averaged 20 to 30 kg/ha/d over entire 100 to 125-d test periods (Schroeder 1974; Moav et al. 1977; Schroeder 1978; Wohlfarth 1978).

Table 2. Some characteristics of ponds with and without fish and manure-loading: a) Water temperature 9 to 15°C; no organic or chemical input was supplied to the ponds other than manure (adapted from Schroeder 1975a). b) Water temperature 25 to 30°C; July to September; 6 ponds; manured ponds received pellet feeds daily at about 3% of fish biomass; all ponds received 70 kg superphosphate and 70 kg ammonium sulfate/ha/2 wk (adapted from Schroeder 1978).

	No fish + manure	Fish + manure	Fish, no manure	No fish, no manure
a) DO at 9:00 AM (ppm)	0.7-9.5	9.0-15.9	10.0-13.8	–
pH	7.9-8.3	8.3-8.9	8.6-8.7	–
zooplankton retained on a 150 micron net (g dry wt./m^3)	0.3-42.4	0.1-1.0	<0.06	<0.06
phytoplankton retained on a 50 micron net (g dry wt./m^3)	0.2-4.3	0.3-1.4	<0.06-0.2	<0.06
chironomids (100's/m^2)	79-215	1-4	0-2	1-7
water column bacteria (1000's/ml)	17-27	1.6-6.7	0.7-4.3	–
b) average early morning DO (ppm)	–	4.9-5.4	3.3-5.0	–
average late afternoon DO (ppm)	–	14.7-15.9	12.0-15.3	–

Table 3. Some characteristics of ponds with and without fish receiving sewage (condensed from Allen and Carpenter 1977).

	Fish	No fish
5-d BOD (ppm)	6	21
Suspended solids (ppm)	12	37
Total nitrogen (as N)	3	10
Total phosphorous (as P)	2	8
pH	8.3	7.9

QUALITY CONTROL

The major problem affecting manure quality is the inclusion of foreign, non-essential materials. With cow manure from dairy herds, it is essential that a minimum of wash water and disinfectant chemicals enter the manure pit. It has not been uncommon to find that manure from a pit under a milking room contains 99% water and 1% solids. Fresh cow manure should contain not less than 10% dry matter, of which the maximum ash level should be 30%.

A similar contamination problem sometimes arises with chicken manure scraped from the pen floor. Its ash content, due to added soil, can exceed 55% of the total dry weight. Unless there are large pebbles or stones, the soil is virtually undetectable by casual observation. The ash content of poultry manure should not exceed 20%. Higher ash levels may also result from long-term storage during which microbial digestion causes consumption of nutrients and organic matter or leaching by rain water. Long-term storage of any type of manure is undesirable, but if unavoidable, it should be performed in a sheltered area, with minimum loss of the liquid content, since much of the nitrogen is in the urine.

The C:N:P:K ratios of the manures listed in Table 1 show that they are good substrates for autotrophic and heterotrophic growth. In all cases there is a slight deficiency of C relative to N for bacterial growth. Since part of the manure N will be used for phytoplankton production, without a corresponding use of C, there is in fact not an excess of N, except possibly in poultry manure.

Our unpublished analyses of cow manure show crude protein levels (Kjeldahl N x 6.25) of 10% to 15% of the dry weight. Of this, less than 1% was digestible by pepsin, Fish digestive systems rely on trypsin rather than pepsin, but the two types of enzymes should give similar results (S. Viola, pers. comm.). Hence, essentially all the manure nitrogen is in the form of non-digestible fractions (e.g., uric acid). Chicken manure has approximately a total of 25% crude protein and 10% pepsin-digestible protein, on a dry weight basis.

Lignin is 14% to 20% of the dry weight of cow manure. Crude fiber (not lignin) is about 30% to 40%, and total fiber (crude fiber, lignin and hemicellulose) about 60%. In chicken manure, lignin is about 10%, crude fiber 25% and total fiber 45%. The starch content and reducing sugar content of chicken and cow manure are both usually less than 1% of the dry weight.

During manure storage, fermentation occurs and produces a general increase in ash, lignin and hemicellulose, and a decrease in crude fiber. This is logical since, with fermentation, the most digestible fractions are consumed first.

The BOD of a manure is a useful measure of its potential biological activity and quality. A 24-hr BOD is often adequate to estimate these values. The chemical oxygen demand (COD) is less useful since it partly derives from highly indigestible fractions. The 24-hr BOD (at 20°C) of a good cow manure, containing 12% dry matter and most of the original urine, is about 2.5 g 0_2/kg manure. A higher BOD, as is observed in chicken manure, is an indication of an even better substrate for the pond food web.

MANURE DISTRIBUTION OVER THE POND

Distribution of manure over as much as possible of the pond area is desirable. Although as much as 40% of the total solids of fresh cow manure can remain suspended in the water column, 50 to 60% of this suspendable matter is inorganic minerals. Approximately 90% of the coarse organic matter settles to the pond bottom within 1 to 2 hr (Lombrozo and Schroeder, in prep.). Accumulation of more than a few mm of this at any bottom location will result in anaerobic digestion, producing an interstitial pH of about 6.5 (characteristic of organic acid fermentation). Ammonia concentrations in the manure layer will reach 30 to 100 ppm, even though 5 cm above, in the overlying water column, the ammonia concentration may be less than 1 ppm. H_2S generation will also soon start. There will be a general reduction of microbial production in the area and the danger of sudden release of large amounts of toxic substances (NH_3, H_2S) from the bottom interstitial water into the water column. Only within the initial one or 2 mm of sediments will there be high microbial activity and production.

It is interesting to note that even in polyculture ponds containing 4,000 adult common carp/ha, there is not sufficient stirring of the settled bottom manure to mix the interstitial water with the overlying water and thus reduce this accumulation of ammonia.

Locating animals adjacent to or directly over the pond allows a continuous gradual supply of manure to the water column and bottom. Since much of the organic matter settles rapidly, this gradual addition is valuable in that it allows the water column as well as the pond bottom to be active in microbial production.

RATE OF MANURE APPLICATION

Proper manuring rates are essential if maximum fish yields are to be attained. The rate is determined by several factors.

The temperature of the pond must be adequate for microbial digestion of the organic matter. In tropical and subtropical climates this is not usually a limiting factor during the growing season. There is adequate production of natural foods when the water temperature is above 18°C. At temperatures of 10 to 15°C, there is moderately rapid digestion of cellulose, but the fish studied at the Fish and Aquaculture Research Station, Dor, Israel—common carp, *Sarotherodon aureus* and silver carp—do not grow well at these temperatures.

Thirty measurements of pond bottom respiration in Israeli fishponds (Schroeder 1975b) plus similar measurements in European ponds and lakes (Edberg and Hosten 1973) and in fishponds in the southern part of the United States (Boyd et al. 1978), gave a maximum value of 3.5 g O_2/m^2 pond bottom area/24 hr. This indicates heterotrophic activity. That there seems to be a maximum value indicates that there is a maximum amount of organic matter that a pond can digest per unit area per unit time. Adding manure at a rate in excess of this amount results in accumulation of organic matter on the pond bottom with resulting undesirable anaerobic interstitial conditions. From our experience, this maximum amount is estimated to be 100 to 200 kg manure dry weight, or 70 to 140 kg organic matter/ha/d.

If the oxidation of organic matter is represented by

$$CH_2O + O_2 = CO_2 + H_2O$$

then on a weight (not molal) basis, for each gram of oxygen consumed, approximately 0.9 g organic matter are oxidized. The measured bottom respiration (3.5 gm $O_2/m^2/d$) would therefore represent consumption of about 32 kg organic matter/ha/d. If a similar amount of oxidation occur in the overlying water column (the total number of aerobic bacteria in 1 m of water column is approximately equal to the number of aerobic bacteria in the underlying pond bottom), then this oxidation rate is adequate to account for the aerobic digestion of 70 kg organic matter or 100 kg manure dry weight/ha/d. A similar amount would be fixed in microbial growth. There is also digestion, though less, by anaerobic bacteria.

We add cow manure organic matter to the pond at a daily rate of 3 to 4% of the standing fish biomass. Chicken manuring rates may be lower, 2.5 to 4.0%. Note that the calculation is based on organic matter, exclusive of the ash content. This corrects for contamination by soil or water. At this manuring rate, with a polyculture of 9,000 fish/ha, the fish yields are 20 to 30 kg/ha/d. It is interesting that supplemental feeding tables call for daily feeding rates of grains and pellets also at about 2 to 4% of the fish biomass, depending upon fish size and species.

It must be emphasized that if a pond is experiencing critically low early morning DO, no organic matter, whether supplemental feed or manure, should be added until the problem is rectified.

TYPES OF MANURE

The value of manure as a substrate for microbial growth is directly related to the feed the animal received. If the feed was of high quality, the manure will be an excellent substrate. If, however, the animal has consumed primarily crude fiber, its manure will be of lower value.

Feeding patterns vary with the availability of animal feeds. It is not practical, therefore, to characterize manures on an absolute scale. The relative values of specific manures can, however, be evaluated by measuring their BOD. Generally, the value of the manures, in increasing order is: cow and sheep manure, followed by a grouping of pig, chicken and duck.

In areas where feeds are plentiful, ducks receive a ration containing 18% protein (calorific value, 2.9 kcal/kg). They can be grown on ponds at 100 to 125/1,000 m^2. These ponds give fish yields of 30 to 40 kg/ha/d (I. Polovnick and H. Barash, pers. comm., Volcani Research Center, Bet Dagan, Israel). On natural foods alone, however, ducks are grown at about one-tenth of this density. The value of raising ducks that receive supplemental feeds over fishponds is that the unavoidable wastage of the food that they spill (about 10%) falls into the pond (Polovnick, pers. comm.) and is directly available to the fish. Ducks, being in a more natural habitat on the pond, remain healthier than those raised on land.

FISH YIELDS FROM MANURE-LOADED PONDS

Quality of Fish Grown with Manure

Having demonstrated that fish grow reasonably well in manured ponds, it is essential also to demonstrate that they are of adequate quality for human consumption. Sobol (pers. comm., Research Station, Dor, Israel) analyzed the fat content of approximately 100 carp grown on manure, grains and on fish meal-enriched pellets. The fat concentrations were 6%, 20% and 15%, respectively. The taste quality of the manure-grown fish was considered superior.

Public health aspects must also be considered. Manure contains fecal bacteria and may also harbor parasites. These may be transmitted to man via the fish. It would seem wise to consume manure-grown fish only after thorough cooking. This is advisable, however, for all fish, even those caught in the open sea. Gjerde (1976) reports bacterial evaluations of 200 samples of raw frozen marine fish, packed for sale. Fecal streptococci were found in 53% of the samples. Fecal coliforms (50 to 100/g) were found in 16% of the samples including *Escherichia coli* (50 to 100/g) in 10%. Such contamination is possibly ubiquitous within the food fish industry.

THE RANGE OF FISH YIELDS FROM MANURED PONDS

To get from published data the maximum values of manure or other organic waste needed as substrates for in-pond growth of natural foods, it is necessary to concentrate on those tests in which pond management was appropriate for a manure-loaded system. This is usually reflected by high fish yields. Tests in which manure was directly incorporated into the feed pellet are not discussed here as this approach gives poor fish growth, as discussed above.

There are reports of manuring ponds in Europe, in which manure is applied in large amounts (usually in heaps) once or a few times during the growing season. Fish yields here are usually below 1,000 kg/ha/yr and often as low as a few hundred. Such examples should not be imitated since such low yields can be attained anyway by appropriate stocking with or without occasional chemical fertilization. Work at the Centro de Pesquisas Ictiologicas, Fontalega, Brazil in 1977 (L. Lovshin, pers. comm.) is better suited to manuring ponds at high ambient temperatures. Here, yields of 3 to 4 kg/ha/d were attained using monoculture of a tilapia hybrid and applying 800 to 1,400 kg cow manure/ha once a week. This yield range is also, however, well below the target of 20 to 30 kg/ha/d.

There are reports from the Research Station at Ginossar, Israel for pond culture using supplemental feeding (grain pellets enriched with 15% fish meal) plus manuring. Yields of 30 to 50 kg/ha/d are reported, but much of these result from the supplemental feed: a luxury which cannot be afforded in much of the world.

Fish yields of 20 to as high as 32.5 kg/ha/d, averaged over approximately 120-d growing seasons, were attained by Buck et al. (1978) in Illinois with swine manure and at the Research Station, Dor, Israel, using primarily a polyculture system of common carp, tilapia hybrids and silver carp with cow or chicken manure applied daily at a rate increasing with the fish biomass, from 20 to approximately 150 kg dry organic matter/ha, 6 times per week.

SOME REASONS FOR LOW FISH YIELDS ATTAINED IN MANURE-LOADED PONDS

Poor yields in fish culture, as in animal husbandry in general, are usually the result of poor management. Unforseeable losses may result from prolonged periods of unseasonal cloudy weather (and hence low photosynthetic production, anoxia and fish kills) but proper management must consider such general climatic conditions as well as the pond environment.

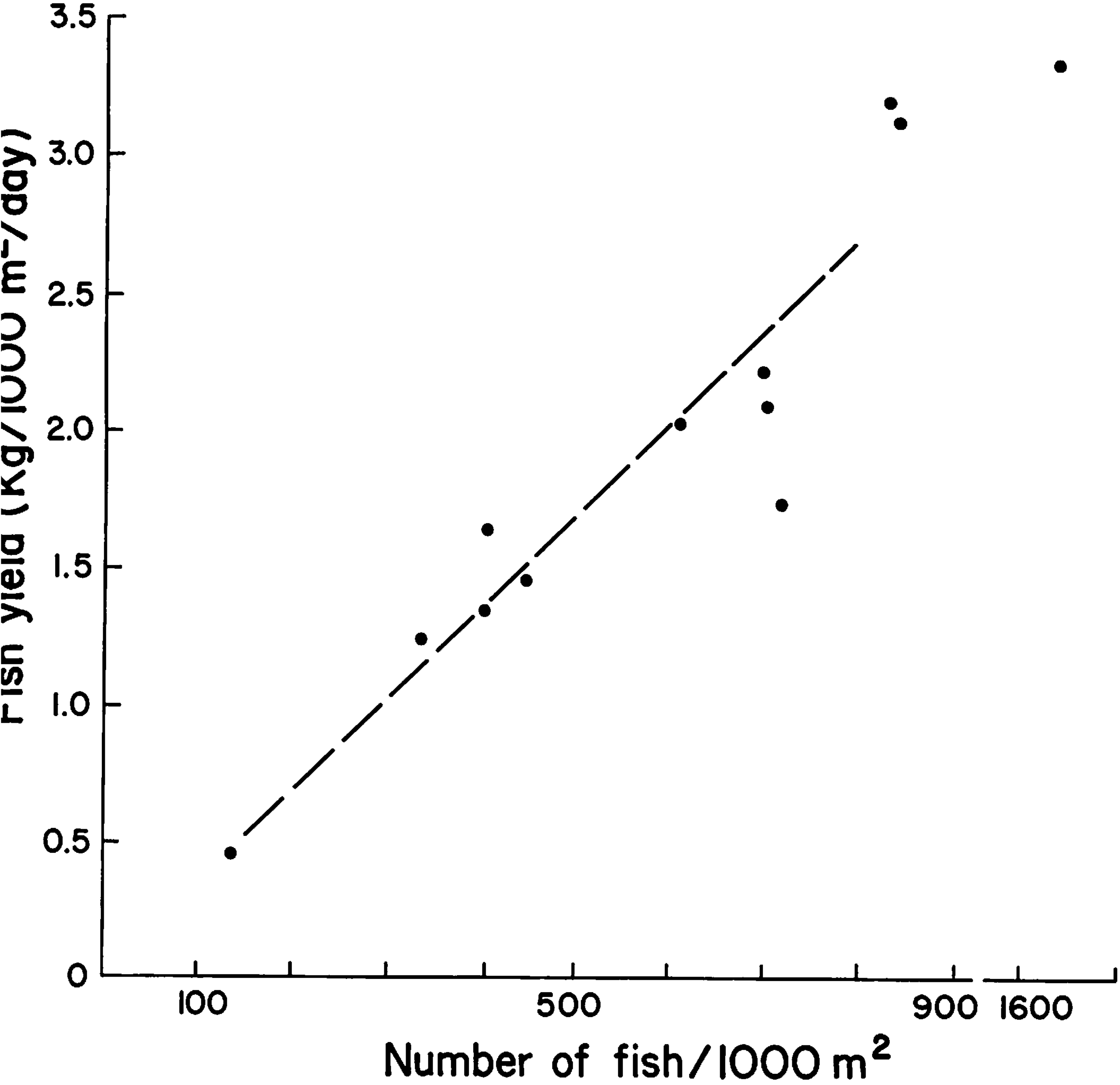
The low fish yields discussed above result primarily from two deficiencies: improper fish stocking and improper use of manure. Monoculture, unless using a species that has adaptable feeding habits, e.g., the milkfish, *Chanos chanos* (Odum 1970), results in inefficient utilization of the natural food. Polyculture requires species that will exploit all the available feeding niches (Tang 1970). Adequate stocking densities are also required (Figure 1) as fish yields will increase with increasing fish density up to the carrying capacity of a pond (Hepher 1975). Exceeding the carrying capacity results in more of the available food energy going into fish maintenance and giving decreased total yields.

Inadequate amounts of manure fail to supply the substrates required for microbial growth. Also, with large piles of manure in the pond, aerobic digestion and high microbial activity occur only at the surface of the pile. A few mm within the pile, conditions are anaerobic, giving inefficient conversion of substrate C into microbial cells, low microbial activity, and production of three toxic agents: H_2S, NH_3 and CH_4.

Poor microbial development, poor digestion of the manure and hence low autotrophic-photosynthetic and heterotrophic productivity, can also result from ponds having acid soils and/or very soft water. Fish yields here will be correspondingly low.

SOME REASONS FOR HIGH FISH YIELDS IN MANURE-LOADED PONDS

Pond design and construction appropriate to manuring will help in attaining good fish yields but insufficient data exist to give exact parameters for this. The following recommendations are derived from experience at Dor and those of Buck et al. (1978).


3.5
3.0
2.5
2.0
1.5
1.0
0.5
0
100
500
900
1600
Number of fish/1000 m²

The pond bottom should contain adequate fines for suspension in the water ("muddying"). These can provide colonization foci for microorganisms. The banks of the pond should be accessible to allow manure distribution along the pond. Relatively shallow ponds (0.7 to 1.0 m deep) have given good yields. Small ponds (0.04 ha) give yields of 30 to 32 kg/ha/d throughout the season. One pond of this size can supply the entire protein requirement for a family of six. Ponds of 0.1 ha gave yields of 20 to 22 kg/ha/d throughout the season. These ponds were deeper (maximum depth 1.7 m) and appear to have had fewer fine particles in the pond bottom than the smaller ponds. A 1.5-ha test pond, much of which was less than 1 m deep, gave yields of 30 kg/ha/d for 40 d after which the common carp (at 300 to 400 g) ceased to grow. Wild tilapia fry appeared at about this time, but it is not certain that their competition was the problem. Nitrite accumulation in the pond water has on occasion been found concurrently with decreased fish growth rate (D. Engstrom, pers. comm., New Alchemy Inst.).

Although all the above ponds are considered as standing water, the small ponds have more frequent water changes than the large ponds according to rough metering of the water used to replace evaporation and seepage. Their water is completely changed about every 40 to 60 d.

Ponds should be drainable to remove or kill all the fish. If excessive uncontrolled breeding occurs, this will place high demands on the available natural foods and retard the growth of adult fish. These fry must be removed.

Stocking an adequate number of fish is essential. Figure 1 shows the relation between polyculture stocking densities and fish yields. At a harvested density of 8,400 fish/ha, the carrying capacity of these ponds was not exceeded, but increasing the harvested density to 16,000 fish/ha produced no increase in yield. For these conditions, therefore, the carrying capacity of the ponds lay between 8,400 and 16,000 fish/ha. Fewer than 8,400 fish/ha produced consistently lower yields.

Polyculture, or use of species with diverse feeding habits, is essential. The pelagic and benthic niches must both be cropped to give complete food utilization. In the initial work at Dor, common carp, *Sarotherodon aureus* and silver carp fingerlings were stocked in the ratio of about 5:2.5: 1.5. It was found that the relative density of the tilapia could be increased to make it the dominant species, while still maintaining the yield of about 30 kg/ha/d. Fish may cross specific feeding niches when faced with a shortage of their preferred feeds (Summerfelt et al. 1970; Terrell and Fox 1974); see Table 4.

Table 4. Normal feeding habits of some cultured fish species.

Feeding habit	Species
Algae and plankton	Silver carp
	Milkfish *(Chanos chanos)*
	Sarotherodon galileus
	Sarotherodon niloticus
	Grey mullet *(Mugil cephalus)*
Filamentous algae	Milkfish
Zooplankton	Bighead carp *(Aristichthys nobilis)*
Macrophytes	Grass carp *(Ctenopharyngodon idella)*
Benthos	Common carp *(Cyprinus carpio)*
	Black carp *(Mylopharyngodon piceus)*
	Mud carp *(Cirrhina molitorella)*
Detritus	*Sarotherodon aureus*
	Common carp
	Milkfish
	Sarotherodon niloticus
	Grey mullet

In manure-loaded ponds, there is a very high production of detritus in proportion to food organisms. The high heterotrophic microbial production has already been discussed. Zorn (pers. comm.) has demonstrated at Dor that there is higher recruitment of chironomid larvae in manure-loaded ponds than in conventional ponds with supplemental feeding. A stocking emphasis must therefore be placed on bottom feeding fish.

In the manure-loaded ponds that produced high fish yields, manure (dry organic matter) was added daily at a rate of about 2 to 4% of fish biomass. This rate was continued until maximum daily loadings of 150 kg dry organic matter/ha/d were reached. The manure was added in liquid form (cattle manure) or as moist solids (poultry manure), but the amount added was always calculated on a dry organic matter basis.

If the water is soft, or the pond bottom is acidic (excessive humus), addition of inorganic fertilizers may be necessary. In the Dor experiments, ammonium sulfate and superphosphate were added (Schroeder 1978) but it is not certain that this rate of inorganic fertilization was required. The C:N:P ratio of most manures is adequate for microbial production. The dual demand for N and P by photosynthetic and bacterial production may, however, warrant the use of inorganic fertilizers, or mixing manures (e.g., chicken and pig, with cattle), to maintain a suitable C:N:P ratio.

Summary

1. Daily manure application to a pond at one or several locations, gives maximum fish yields of about 30 kg/ha/d, averaged over the growing season.

2. The manuring rate, computed as dry organic matter, is at 2 to 4% of the fish biomass daily. The manure is supplied in liquid or moist form, retaining the urine and feces.
3. Fish yields appear to be based on a dual food web: autotrophic-photosynthetic, and heterotrophic (bacteria and protozoa).
4. Autotrophic production is limited by available solar energy penetrating the pond water. Heterotrophic activity is limited by digestion rate of the carbon-rich substrate (manure in this case).
5. Heterotrophic activity is maximum at the pond bottom-water interface. Therefore, layers of manure thicker than a few mm result in inefficient digestion and low microbial production.
6. Adequate chemicals must be present to allow high primary production and microbial development. This is especially important to consider in ponds with soft water or with very acidic soils.
7. Fish stocking in standing water ponds should be a polyculture or a fish type that harvests the various natural food niches. A high enough density of fish must be added to utilize the carrying capacity of the pond.
8. Water temperatures in excess of 18°C seem advisable for good microbial development in a manure-loaded pond.
9. Desirable pond characteristics are: accessible banks to permit spreading of the manure; water depths of about 0.7 to 1.0 m; adequate suspendable fines in the pond bottom; water with moderate alkalinity or hardness; non-humic pond bottom; bottom with minimum seepage and ability to drain the pond or to remove all the fish.
10. Experiments have produced high fish yields with standing stock fish biomass up to 700 g/m^2 pond area or 7 t/ha.

References

Abdo, K., K. King and R. Engel. 1964. Protein quality of rumen microorganisms. J. Anim. Sci. 23: 734-736.

Allen, G.H. and R.L. Carpenter. 1977. The cultivation of fish with emphasis on salmonids in municipal wastewater lagoons as an available protein source for human beings, p. 479-528. *In* F. D'Itri (ed.) Wastewater renovation and reuse. Marcel Dekker, Inc., New York.

Almazan, G. and C.E. Boyd. 1978. Plankton production and tilapia yields in ponds. Aquaculture 15: 75-77.

Anderson, J. and A. MacFayden, Editors. 1976. The role of terrestrial and aquatic organisms in decomposition processes. Blackwell Scientific Publ., London.

Anon. 1977. Algae production in the Negev, Israel. National Council for Research and Development Annual Report. Prime Minister's Office, Jerusalem. 7 p.

Atack, T., K. Jauncey and A. Matty. 1979. The utilization of some single cell proteins by fingerling mirror carp *(Cyprinus carpio)*. Aquaculture 18: 337-348.

Beck, H., J. Gropp, H. Koops and K. Tiews. 1979. Single cell protein in trout diets, p. 269-280. *In* J.E. Halver and K. Tiews (eds.) Finfish nutrition and fishfeed technology. Vol. II. Heenemann Verlagsgesellschaft mbH, Berlin.

Bellamy, W. 1975. Conversion of insoluble agricultural wastes to SCP by thermophilic microorganisms. *In* S. Tannenbaum and D. Wang (eds.) Single cell protein Vol. 2. MIT Press, Cambridge, Mass.

Bergstrom, E. 1979. Experiments on the use of Single Cell Protein in Atlantic salmon diets, p. 105-116. *In* J.E. Halver and K. Tiews (eds.) Finfish nutrition and fishfeed technology. Vol. II. Heenemann Verlagsgesellschaft mbH, Berlin.

Boyd, C.E., P. Romaire and E. Johnston. 1978. Predicting early morning dissolved oxygen concentrations in channel catfish ponds. Trans. Amer. Fish. Soc. 107: 484-492.

Boyd, C.E. and E. Scarsbrook. 1974. Effects of agricultural limestone on phytoplankton communities of fish ponds. Arch. Hydrobiol. 74: 336-349.

Buck, H., R. Baur and C. Rose. 1978. Polyculture of Chinese carps in ponds with swine wastes, p. 144-155. *In* R. Smitherman, W. Shelton and J. Grover (eds.) Culture of exotic fishes symposium proceedings. American Fisheries Society, Auburn, Alabama.

Campos, E. and I. Sampaio. 1976. Swine feces recycling in carp feeding. Arg. Esc. Vet. U.F.M. 28: 147-152.

Doetsch, R. and T. Cook. 1973. Introduction to bacteria and their ecobiology. University Park Press, Baltimore, Md.

Edberg, N. and B. Hosten. 1973. Oxygen uptake of bottom sediments studied in-situ and in the laboratory. Water Res. 7: 1285-1294.

FAO. 1977. China: recycling of organic wastes in agriculture. FAO Soils Bulletin 40, 107 p. FAO, Rome.

Fish, G. 1955. The food of tilapia in East Africa. Uganda J. 19: 1.

Fowler, J. and J. Lock. 1974. Inclusion of dried poultry waste as a feed ingredient in cat fish rations. Feedstuffs 46: 32-34.

Gjerde, J. 1976. Bacteriological evaluation of frozen raw fish products. Fisk Dir. Skr. Serv. Ernaering 1: 17-22.

Hargrave, B. 1976. The central role of invertebrate feces in sediment decomposition. *In* J. Anderson and A. MacFayden (eds.) The role of terrestrial and aquatic organisms in decomposition processes. Blackwell Scientific Publ., London.

Hepher, B. 1962. Primary production in fish ponds and its application to fertilization experiments. Limnol. Oceanogr. 7: 131-136.

Hepher, B. 1975. Supplementary feeding in fish culture, p. 183-198. *In* Proc. 9th Int. Congr. Nutrition, Mexico, 1972. Vol. 3. S. Karger Publ., New York.

Hillbricht-Ilkowska, A., I. Spodniewska, T. Weglenska and A. Kurabin. 1972. The seasonal variation of some ecological efficiencies and production rates in the plankton community of several Polish lakes, p. 111-127. *In* Z. Kajak and A. Hillbricht-Ilkowska (eds.) Productivity problems of freshwaters. PWN Polish Scientific Publishers, Warsaw.

Hobson P. 1976. Trends and innovations in rumen microbiology. *In* F. Skinner and D. Carr (eds.) Microbiology in agriculture,

fisheries and food. Academic Press, New York.
IAEA. 1975. Tracer studies on non-protein nitrogen for ruminants II: Proceedings. Research Coordination and Panel. Unipub, New York.
Jhingran, J. 1977. Fish and fisheries in India. Hindustan Publ. Co., Delhi.
Kerns, C. and E. Roelofs. 1977. Poultry wastes in the diet of Israeli carp. Bamidgeh 29: 125-135.
Kajak, Z. and A. Hillbricht-Ilkowska. Editors. 1972. Productivity problems of freshwaters. PWN Polish Scientific Publishers, Warsaw.
Kusnetsov, Y. 1977. Consumption of bacteria by silver carp. J. Ichthyol. 17: 398-403.
Lombrozo, E. and G. Schroeder. Some physical and chemical characteristics of fresh and fermented cow manure. (In preparation)
Lu, J. and N. Kevern. 1975. The feasibility of using waste materials as supplemental fish feed. Progr. Fish Cult. 37: 241-244.
Mann, K. 1972. Macrophyte production and detritus food chains in coastal waters. Mem. Ist. Ital. Idrobiol. 29 (Suppl): 353-383.
Marias, J. and T. Erasmus. 1977. Chemical composition of alimentary canal contents of mullet caught in Sworthops estuary. Aquaculture 10: 263-273.
Matty, A.J. and P. Smith. 1978. Evaluation of a yeast, a bacterium, and an alga as a protein source for rainbow trout. I. Effect of protein level on growth, gross conversion efficiency and protein conversion efficiency. Aquaculture 14: 235-246.
May, R. Editor. 1976. Theoretical ecology. Blackwell Scientific Publ., London.
Moav, R., G. Wohlfarth, G. Schroeder, G. Hulata and H. Barash. 1977. Intensive polyculture of fish in freshwater ponds. Aquaculture 10: 25-43.
Morrison, F. 1959. Feeds and feeding. Morrison Publ. Co., Iowa.
Newell, R. 1970. The role of detritus in the nutrition of two marine deposit feeders. Proc. Zool. Soc. London 144: 25-45.
Noriega, P. Primary productivity and related fish yields in intensely manured fish ponds. Aquaculture. (In press)
Odum, W. 1968. The ecological significance of fine particle selection by the striped mullet *Mugil cephalus*. Limnol. Oceanogr. 13: 92-97.
Odum, W. 1970. Utilization of the direct grazing and plant detritus food chains by the striped mullet *Mugil cephalus*, p. 222-240. *In* H. Steele (ed.) Marine food chains. Oliver and Boyd, London.
Rodina, A. 1972. Methods in aquatic microbiology. University Park Press, Baltimore, Md.
Schroeder, G. 1973. Factors affecting feed conversion ratio in fish ponds. Bamidgeh 25: 104-113.
Schroeder, G. 1974. Use of fluid cowshed manure in fish ponds. Bamidgeh 26: 84-96.
Schroeder, G. 1975a. Some effects of stocking fish in waste treatment ponds. Water Res. 9: 591-593.
Schroeder, G. 1975b. Night-time material balance for oxygen in fish ponds receiving organic wastes. Bamidgeh 27: 65-74.
Schroeder, G. 1978. Autotrophic and heterotrophic production of microorganisms in intensely manured fish ponds and related fish yields. Aquaculture 14: 303-325.
Schroeder, G. and B. Hepher. 1979. Use of agricultural and urban wastes in fish culture, p. 487-489. *In* T.V.R. Pillay and W.A. Dill (eds.) Advances in aquaculture. Fishing News Books Ltd., Farnham, Surrey, England.
Shiloh, S. and S. Viola. 1973. Experiments in the nutrition of carp growing in cages. Bamidgeh 25: 17-31.
Spataru, P. 1976. Natural feed of *Tilapia aurea* in polyculture with supplementary feed and intense manuring. Bamidgeh 28: 57-63.
Spataru, P. 1977. Gut contents of silver carp and some trophic relationships to other fish species in polyculture system. Aquaculture 11: 137-146.
Sreenevasan, A. n.d. Application of limnological and primary production studies in fish culture. Report from the Freshwater Biological Station, Bhavanisagar, India. 12 p.
Stickney, R. and H. Simmons. 1977. Growth responses of *Tilapia aurea* to feed supplemented with poultry waste. Texas J. Sci. 29: 93-99.
Summerfelt, R., P. Mauck and G. Mensinger. 1970. Food habits of carp *Cyprinus carpio* L. in five Oklahoma reservoirs. Proc. Ann. Conf. Southeast. Assoc. Game Fish Comm., 24: 352-377.
Tacon, A. and P. Ferns. 1976. Use of activated sludge from domestic sewage in trout diets. Nutr. Rep. Int. 13: 549-562.
Tamiya, H. 1957. Mass culture of algae. Ann. Rev. Plant Physiol. 8: 309-334.
Tang, Y. 1970. Evaluation of balance between fishes and available fish foods in multi-species fish culture ponds in Taiwan. Trans. Amer. Fish. Soc. 99: 708-718.
Terrell, J. and A. Fox. 1974. Food habits of grass carp in the absence of aquatic vegetation. Proc. Ann. Conf. Southeast. Assoc. Game and Fish Comm., 28: 251-259.
Thomaston, W. and H. Zelda. 1961. Results of 6 years investigation of chemical soil and water analysis in Georgia fish ponds. Proc. Ann. Conf. Southeast. Assoc. Game and Fish Comm. 15: 236-245.
Wiederholm, T. and L. Eriksson. 1977. Benthos of an acid bottom lake. Oikos 29: 261-267.
Wohlfarth, G. 1978. Utilisation of manure in fishfarming, p. 78-95. *In* C.M.R. Pastakia (ed.) Report of the Proceedings, Fishfarming and Wastes, Institute of Fisheries Management and Society of Chemical Industry, London.
Yashouv, A. 1971. Interaction between common carp and silver carp in fish ponds. Bamidgeh 23: 85-92.
Yurkowski, M. and J.L. Tabachnek. 1979. Proximate and amino acid composition of some natural fish foods, p. 435-448. *In* J.E. Halver and K. Tiews (eds.) Finfish nutrition and fishfeed technology. Vol. I. Heeneman Verlagsgesellschaft mbH, Berlin.

A Theoretical Comparison of Waste Treatment Processing Ponds and Fish Production Ponds Receiving Animal Wastes

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Abstract

The characteristics of waste treatment ponds and fish culture ponds, as they relate to an integrated waste/aquaculture system, are described. Both pond types have a common purpose to promote the efficient transfer and circulation of water in order to provide oxygen for a biological community, and to maintain a suitable environment for aquatic life.

Biological models are provided of two integrated systems that provide a continuous harvest of fish in association with an acceptable effluent.

Introduction

The world's energy and food crises are redirecting attention to a wiser use of all resources. One major resource is the waste from agriculture of both animal or vegetable origins, either directly from the farm or as a by-product of processing plants.

Animal wastes have many qualities which make them resources to be valued, in addition to their use for refertilization of the soil through land spreading. Some wastes have fuel values comparable to the oil bearing shales; others can be readily converted to methane gas by anaerobic digestion. They contain proteins, amino acids and nutrients which can be processed into animal feeds or into feed components. The reexamination of animal wastes for practical applications is increasing in importance across a broad technological front and is enhanced by advancing techniques to reduce odor and to remove the dangers of infectious contaminants and pollutants.

Aquaculture has made use of animal wastes as fertilizers for centuries, increasing pond production of both animals and plants through direct and indirect utilization of nutrients. All of the traditional practices for pond fertilization, however, have been conducted at an empirical level using extensive production techniques. Present economic pressures for maximizing pond production and minimizing production costs for aquaculture crops are now compelling reasons to place more emphasis on understanding the limits of fertilization, and also to explore the integration of aquaculture and waste treatment. In particular, there is the need to enumerate and define these specific limits for production, design and engineering of the optimum-production facilities.

It is important to note in any reference to animal waste/aquaculture integration systems that "treatment" ponds are required by regulation to produce an effluent that meets certain standards for quality, whereas ponds receiving animal waste as a fertilizer for fish production are under no such regulations in most countries, and may or may not produce any effluent at all. The extent to which a waste treatment pond or lagoon can be used for fish culture is therefore contingent on the standards set for the effluent from the system. Although the waste treatment pond is often regarded as the ultimate in nutrient resources for fish culture, the controlled production of fish in a treatment pond as a part of the dynamic treatment process to remove nutrients is a complex problem.

As a general rule, the principle of using fish culture as a method of treatment of animal wastes to meet strict standards is not desirable, but is an acceptable practice that can recover and redirect some of the valuable components found in treated wastes. However, as the use of animal wastes as fish pond fertilizers continues to increase, and the volumes of fertilizer used and the production weights of fish increase dramatically to higher and higher levels, the distinction between the intensive pond fertilization process, complete with pond aeration, and the waste treatment process becomes less and less. The major difference continues to be the requirement of the treatment process to meet defined standards for the effluent.

Comparison of Animal Manures and Human Sewage

There are several parallels between animal manures and human sewage, but there are significant differences in composition and treatments. The successful culture of fish, shellfish and water fowl in dilute sewage plant effluents has been demonstrated in many countries. The necessary conditions for success given by Babbit and Baumann (1958) are: settled sewage in a pond not more than 2 m deep, adequate diluting water to enter at a number of places to assure adequate distribution and mixing of the sewage solids. The oxygen content must be at least 4 mg/l, and the system should exclude toxicants, oily wastes and other materials deleterious to the health of the livestock. They also report that the sewage from up to 5,000 persons per hectare (45 kg BOD) can be treated with over 90% efficiency provided that the dilution and aeration are adequate in association with the fish production.

Undiluted animal manure is similar to sewage sludge and can be treated by anaerobic microbial digestion in lagoons. Integration of agricultural animal waste treatment practices and aquaculture, however, has centered on the aerobic secondary treatment processes for handling diluted and aerated manures, because of the more suitable form of nutrients at that level of decomposition and the similarity of the types of facilities used. The management of animal wastes involves four principal operations, namely, collection, storage, treatment and utilization or disposal. The traditional aquaculture practice of keeping animals in buildings raised over fish ponds bypasses the need for collection, storage and treatment, and deals solely with utilization or disposal. This also effectively eliminates one of the more expensive requirements of animal waste handling before use, namely, drying.

Comparison of Facilities

WASTE TREATMENT PROCESSING PONDS

The treatment of animal waste is usually achieved by biological decomposition in lagoons or stabilization ponds. The types and varieties of lagoons are many, depending on their use of aerobic or anaerobic conditions to fulfill the decomposition processes. Aerobic lagoons are often called oxidation ponds. Raceway structures are called oxidation ditches.

Oxidation ponds are relatively cheap wastewater treatment facilities and are widely used in rural areas. In ponds, the wastewater is mixed physically to some degree by the natural elements and internal biological and chemical interactions, but it is often moved more violently by mechanical agitation. Intensive oxidation ditches are more expensive, but efficient in land utilization.

The biology and chemistry of the dynamic interactions of oxidation ponds are complex. Dead organic matter, in the presence of free oxygen in the pond system, goes through the following decomposition cycle. Firstly, some anaerobic decomposition of the easily decomposable products takes place. This produces carbon dioxide, ammonia and hydrogen sulfide. The latter two are both malodorous. Secondly, direct aerobic decomposition takes place using oxygen in the water and from the atmosphere. This process produces carbon dioxide, nitrite nitrogen and sulfur. The same processes continue producing more carbon dioxide, nitrate nitrogen and sulfates. Thirdly, these chemical products are utilized by algae to produce more algal cells and oxygen by photosynthesis. The oxygen, in turn, adds to that already entering the water mass through the surface, and is used by bacteria to decompose further the original waste. The products of this continuing cycle are proteins, carbohydrates and fats in the form of living plants. Plants, in turn, enter the animal food chain with the production of further proteins and fats in the form of living animals. The complex process is simplified diagrammatically in Figure 1.

The biological and chemical symbiosis between bacteria and algae in the oxidation ponds leads to

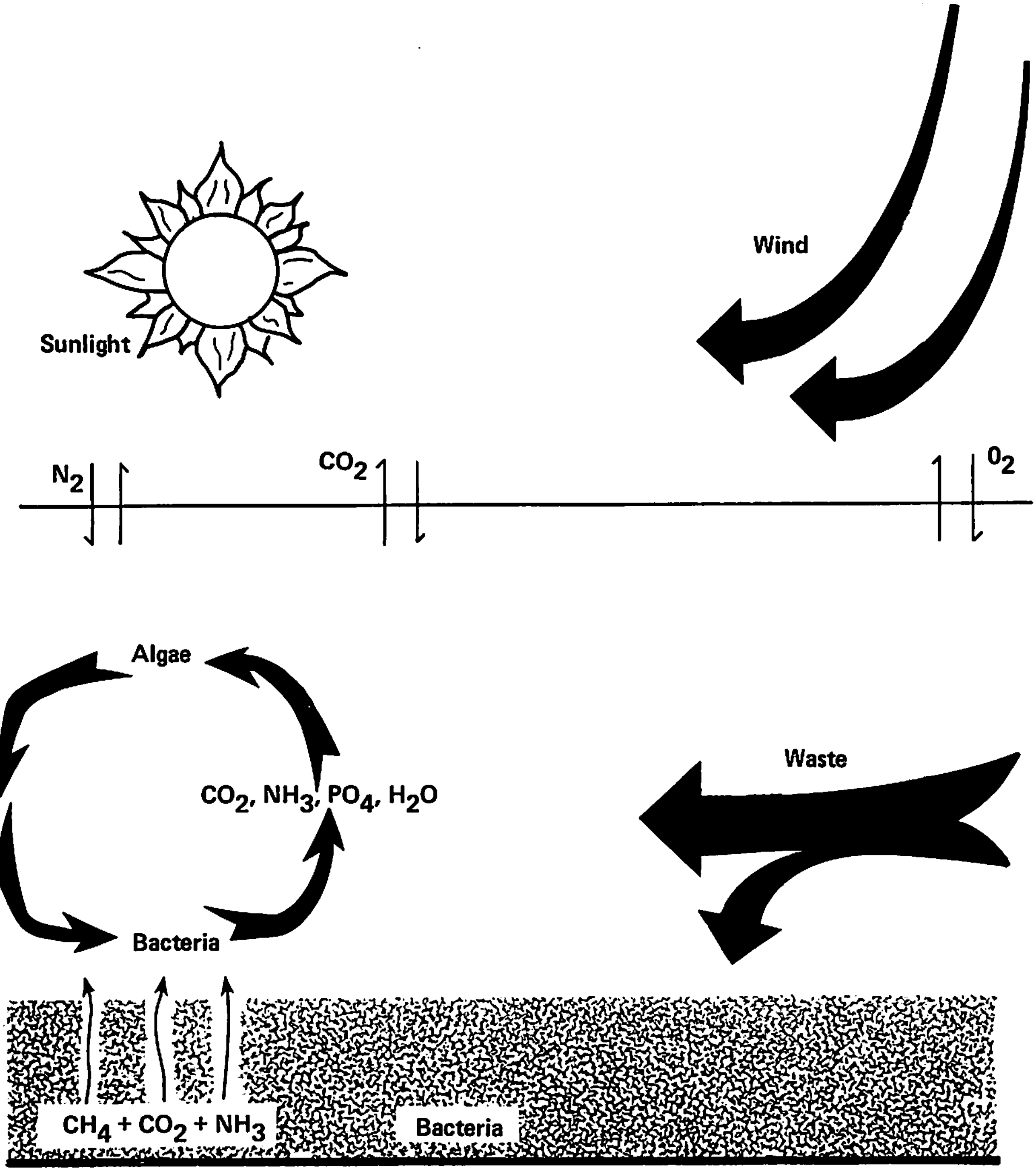

Figure 1. Biological processes in an oxidation pond.

stabilization of the incoming organic waste with time. The length of time required for stabilization is affected by environmental considerations, such as temperature, pH, light and oxygen availability, as well as the presence or absence of such toxic compounds as pesticides, heavy metals, ammonia, chlorine and detergents.

In order to stabilize in the shortest time and to function efficiently, oxidation ponds or lagoons require certain design criteria to be fulfilled. The parameters considered in the design of oxidation ponds are: 1) oxygen supply and mixing, 2) organic loading, 3) retention time, 4) temperature and 5) physical configuration. All are important parameters, but two will be enlarged upon here, namely, temperature and physical configuration.

The depth of oxidation ponds is usually between 1 and 2 m, to allow light penetration without additional agitation. Facultative aerobic lagoons, which are similar to oxidation lagoons but are designed to permit accumulation of solid waste for further anaerobic digestion, are much deeper.

The design standards for oxidation ponds and lagoons are usually set by regulatory authorities. Some typical standards include embankment slopes (1 in 3, or 1 in 4), organic loading rate (2.2 to 5.5 g $BOD_5/m^2/d$ depending on climate), hydraulic retention time (60 to 120 d), permissible seepage (0 to 6 mm/d), and liquid depth (not less than 0.6 m).

Much of the animal waste treatment process developed to date has been engineered for pig wastes, although it is readily adaptable for treatment of wastes from cattle (both beef and dairy animals) and poultry (ducks and chickens)(Woynarovich 1979). Pig waste has been easier to deal with as it is usually in a slurry which is more manageable. There also has been a greater need because of the heavy odor problem. Manure from cattle is higher in solids and is more fibrous, often causing a buildup of floating matter on the surface of the pond. Poultry waste is usually well mixed with feathers which are a problem, thus encouraging flies and other disease organisms around the pond. Pig houses have been readily adaptable to fish culture ponds, and the slurry wastes from the pigs have been a manageable and effective source of nutrients.

The dimensions of an oxidation pond are, therefore, very specific to the scale of its function, namely, the decomposition and treatment of organic waste from a certain population of people or from a number of animals or birds in an intensive production system. As a general rule, a surface area of 1 ha per 250 people is needed. This is equivalent to a BOD load of about 25 to 50 kg/ha/d. Higher loads increase the retention period and require supplemental aeration.

Large capacity ponds are buffered to changes in many of the components of the dynamic biological and chemical processes, but their efficient operation can be altered by changes which interfere significantly with their balance. Such changes could be brought about by the loading of the biomass in the water body. This loading could be the use of the facility for the farming of other animals, such as ducks, fish or shellfish.

FISH PRODUCTION PONDS

Just as the criteria for the configuration and design of an oxidation pond are important for effective waste treatment, so too are criteria for a fish (or shellfish) pond for effective environmental habitability. There are, of course, many similarities between them. Both facilities have the common purpose to promote the efficient transfer and circulation of water throughout, in order to provide oxygen for a biological community and to maintain a suitable environment for aquatic life.

As a rule, little engineering design work is ever included in the configuration of a fish pond to make it an optimal production unit. This is usually because there is incomplete biodata for the species to be farmed, the site configuration is irregular, and there may be other more critical decisions, such as the source and discharge of water. For all intents and purposes, the engineering of fish ponds in the past has gone no further than the construction of suitable embankments with the inclusion of inlet and outlet sluices. As a result, many ponds have proved to be poor environments for the aquatic animals and have subsequently required additional installations, such as aeration systems, to enable them to meet the production levels originally calculated.

The biology and the environmental factors that affect the growth of fish in fish ponds, together with their particular behavior, dictate the limits of pond production. Furthermore, pond production cannot be estimated unless the water resources and drainage of the system are established. These parameters, in turn, are influenced by the dimensions of the pond, the engineering of the water systems, pond management, and, of course, water quality.

Much of the present design work is based on experiences and facts known to design engineers in hydraulics, soil mechanics and structural materials, and to their ability to interpret and apply data gained from existing fish ponds. The engineer has some basic biological information by which to reason the design of appropriate facilities. For example, large ponds are more stable environments than small ones and can buffer themselves against sudden changes in water quality, outbreaks of disease and poor management practices. They often have the disadvantage of difficulty with harvesting. Small ponds, on the other hand, are easier to maintain and manage, but are expensive to build and operate and have little with which to counter such emergencies as disease epidemics and environmental changes.

In addition to the importance of depth and surface area to aquatic animals, some consideration must also be made for the growth of other organisms which provide an important dietary component in a fish pond system. Most of the criteria for establishing natural food populations are related to satisfactory conditions for algal production which is a vital component of the food web in the pond system.

Fish ponds are designed and constructed for additional reasons other than the biological needs of the fish. Just as the land farmer needs to observe his stocks daily, so does the fish farmer need ready access for sampling and harvesting, and also continual daily observation. At these times, it may be necessary to drain and fill the pond rapidly without causing unnecessary stress to the fish populations.

The biomass of the fish population (or pond loading) is related to the weight and the length of the fish and to a suitable unit for either pond volume, volume to surface area ratio, or water flow rate through the pond. The biomass of fish (as distinguished from the total biomass of the pond) is first limited by the available oxygen levels in the water and, subsequently, by the buildup of ammonia. With some species of fish, the biomass is influenced by the individual behavior of the species toward territoriality. Oxygen saturation is the key factor in estimating the carrying capacity of any fish pond when the incoming water is the only source of oxygen. If mechanical aeration is used, increased oxygen demands can be met and the limiting factors become the nitrogen compounds. However, mechanical agitation requires energy and hence is an additional expense to the operation's budgets. Oxygen saturation levels in the pond are influenced greatly by temperature, the elevation of the pond system above sea level, and the accumulation of metabolic products.

In addition to influencing the oxygen level, water temperature is a parameter which influences fish growth. The water volume and water quality of a fish pond as they relate to temperature are, therefore, important. Ponds with little circulation and little water exchange may increase rapidly in temperature and suffer from abundant plant growth, fluctuations in oxygen and other dissolved gases, and pH changes.

Facility Sizing

The primary objective of the oxidation pond is BOD removal. The BOD of many animals and poultry wastes are established (Table 1). In an aerated lagoon or pond that does not receive incoming water continuously, the BOD is met by the oxygen introduced through photosynthesis, transfer from the atmosphere across the water surface, and sometimes by floating aerators. The retention time is based on the time required for treatment to achieve an effluent which will meet discharge regulations.

The primary objective of the fish pond is the maximum production of fish on a sustained basis. Production is directly influenced by management or manipulation of the carrying capacity or standing stock. The carrying capacity is directly and indirectly affected by many variables, some of which are critical and limiting. The three most limiting parameters which determine the maximum standing stock of fish and shellfish in a system are dissolved oxygen, gaseous ammonia (NH_3) and stock density. Other key variables are temperature, size of fish, feeding rates, natural processes within the ponds (such as primary productivity), and parameters such as pH, and soil and water chemistry. It is these wide but tolerable ranges of variables which permit the innumerable manipulations by management, produce variations in apparently similar management practices, and cause confusion in the interpretation of practices and observed results.

In a fish pond, oxygen is the first criterion which can influence the standing stock. For flow-through systems, the main source of oxygen is the water flowing into the pond. The following formula is used to determine the

Table 1. Production and some composition data of animal manures*

Animal	Live weight (kg)	Moisture content of waste (%)	Total solids in waste (dry wt g/d/animal)	BOD_5 (g/animal/d)	Approximate composition % total solids N	P
Man	68		91	91		
Pig	45	84-92	268-509	91-159	4.5	2
Beef cattle	454	70-86	1643-3269	463	2.5	1.5
Dairy cattle	454	87	3087-5085	599-835	2.5	0.5
Poultry	2.3	65-75	268-509	7.7	5	1.5

*Converted after various authors from Whetstone et al. (1974).

flow rate required to supply sufficient oxygen to maintain minimum oxygen supply:

$$\text{Flow in liters per minute} = C\,(A \times 1440)$$

where:
C = oxygen consumed in kilograms per day
A = ambient oxygen minus minimum acceptable oxygen concentrations in mg/l expressed as mg $\times 10^{-6}$
1440 = number of minutes in 24 hr

As an alternative or supplement to water flow, oxygen can be supplied mechanically. Increased standing stock, therefore, is not usually limited by the oxygen content of the incoming water, provided that supplemental aeration is used. However, for static or semi-static ponds, where the only sources of oxygen are exchange at the air/water interface and photosynthesis, the standing stock or pond carrying capacity is low and limited first by the oxygen level.

A similar calculation can be made to determine the flow rate necessary to insure that ammonia concentrations do not exceed lethal limits. By making certain assumptions for the total ammonia produced per unit weight of food consumed, the percent of unionized ammonia, and the tolerable level of unionized ammonia, the flow rate can be calculated which will support the animal populations and prevent fish kills. Although nitrifying bacteria are present in most ecosystems, their effects are not usually considered in such calculations. It is assumed that the added increased production of ammonia from decomposing uneaten food and fecal material (which are often not considered) would offset and balance the effects of nitrification.

A critical pathway has been developed (Figure 2) to illustrate the associations and relationships between the oxidation treatment process of nutrients in a lagoon or pond and the nutrient recovery process by fish in the same environment.

In order to get an understanding of the approximate balance of a nutrient recovery/fish production system, two models (Figures 3 and 4) have been developed. Obviously, many assumptions have been made to obtain the values used; thus, the models should be considered theoretical and are presented only for the purpose of giving relative dimensions to the system. As in any biological system, the paths of energy transfer, losses and efficiencies are poorly understood. No attempt has been made to delineate all of the components, but merely to group them in a few broad categories.

The first scenario (Figure 3) reflects a typical oxidation lagoon with a water exchange rate of once per 30 d. The size of the fish population that could be maintained is based on the availability of oxygen. The starting point for the model is a more or less standard oxidation lagoon loading of 34 kg BOD per hectare per day. The flow chart illustrates the pathways of this waste as it is lost from the system or consumed by the standing stock of omnivorous fish. Wastes from the fish are also recycled back through similar pathways: some of this waste will again be available to the fish. Different transfer efficiencies in the pathways of the pig waste and fish waste have been assumed due to a difference in composition of the wastes. It is assumed that the oxygen demand of the wastes is met by the primary production in the pond and transfers across the water/air interface. Although there will be some reduction of the BOD by direct consumption by the fish, it is assumed in this example that the increase demand of the BOD produced by the fish wastes will utilize any surpluses; therefore, all oxygen requirements of the fish are being met by water exchange. Because any increase in the flushing rate will increase washout of cells and detrital material, the effectiveness of the oxidation pond for wastewater treatment is directly related to water exchange rates. A low exchange rate of once per 30 d is utilized. The standing stock of fish which could be maintained on the available oxygen in such a system is 476 kg/ha.

The second scenario (Figure 4) is an attempt to utilize fully the nutrients available in the waste. Based on available nutrients, it appears that 2,200 kg/ha of fish could be supported, assuming a fish feeding rate of 5% body weight per day, and that 5% of the diet is nitrogen. An exchange rate of approximately once every 10 d is required to supply sufficient oxygen to support this quantity of fish. This assumes that 3.5 mg/l O_2 is available and the oxygen demand is 0.19 kg/100 kg of fish per day.

In both these scenarios, it is important to understand once more that the end results are: 1) a continuous harvest of fish in association with 2) an acceptable effluent of around 20 mg/l BOD.

A search of the literature (Table 2) indicates that the standing stock value of the second scenario is in keeping with practical results obtained under experimental production conditions. If harvests of the stock were based on a more practical operation mode (i.e., fluctuating standing stock with monthly or annual harvests only), the annual yield of the pond would not exceed that of the maximum reported in Table 2. The annual yield thus reflects a theoretical maximum based on nutrients.

The effluent under the two scenarios indicates the degree of treatment based upon retention time, dilution and waste products of the fish. Dilution is the major factor influencing scenario two and has the effect of producing a very acceptable effluent. However, the total weight of BOD discharged per day exceeds that of the first scenario.

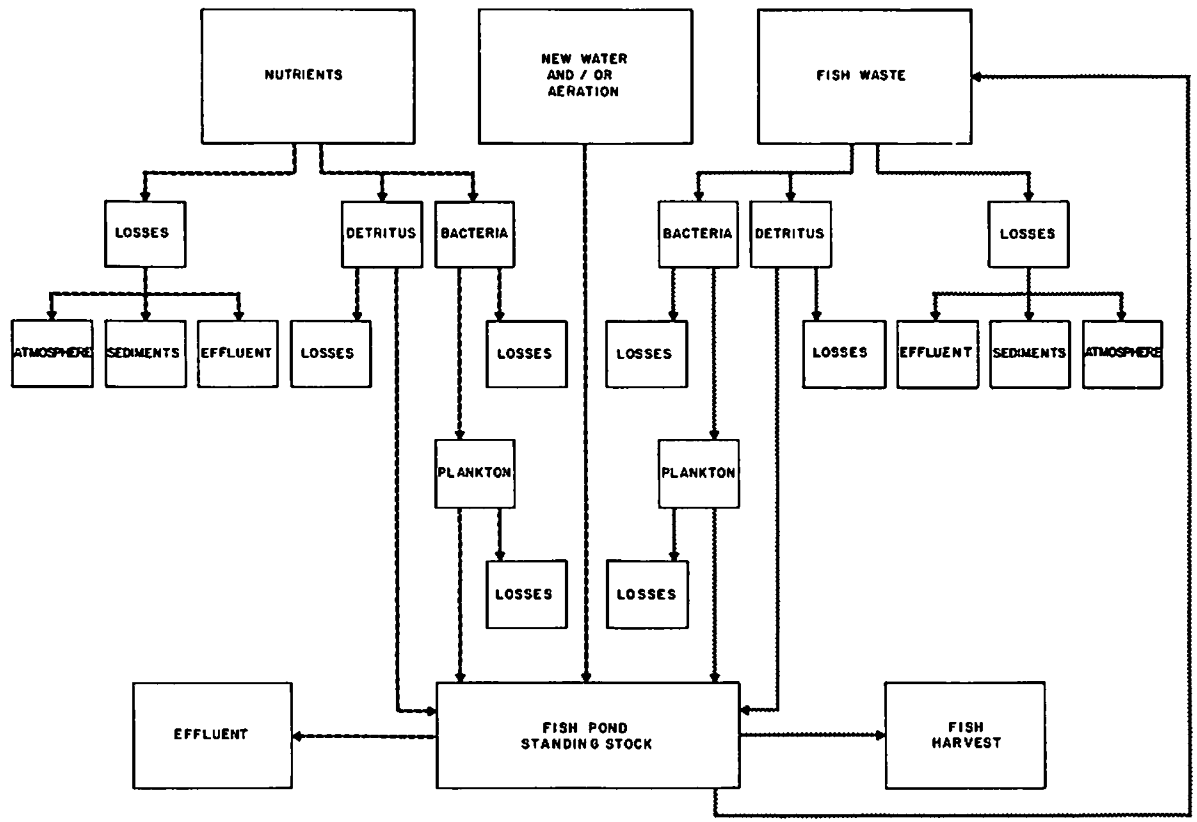

Figure 2. Theoretical pathway of nutrients for fish production.

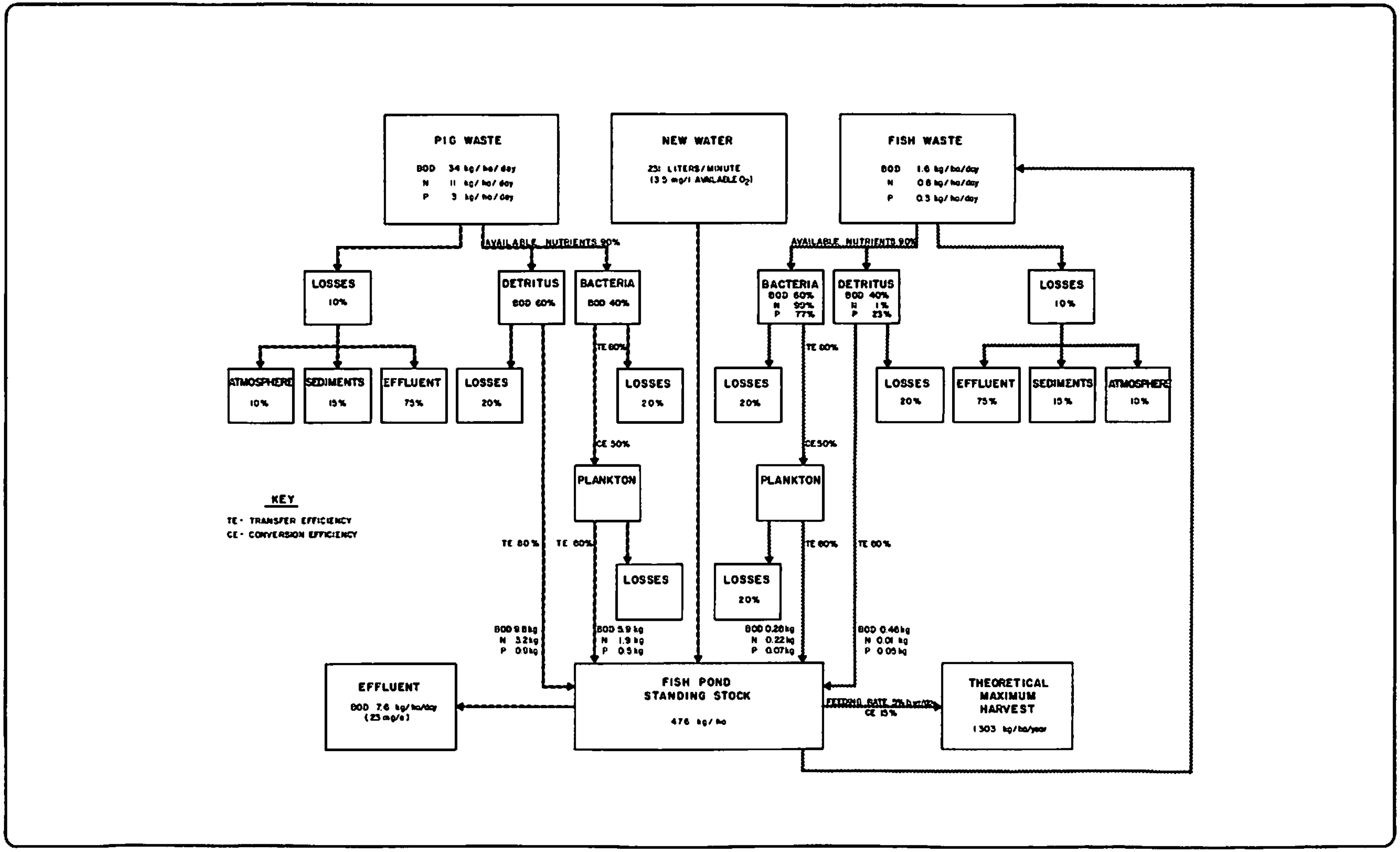

Figure 3. Fish production in oxidation pond with one exchange of water every 30 d.

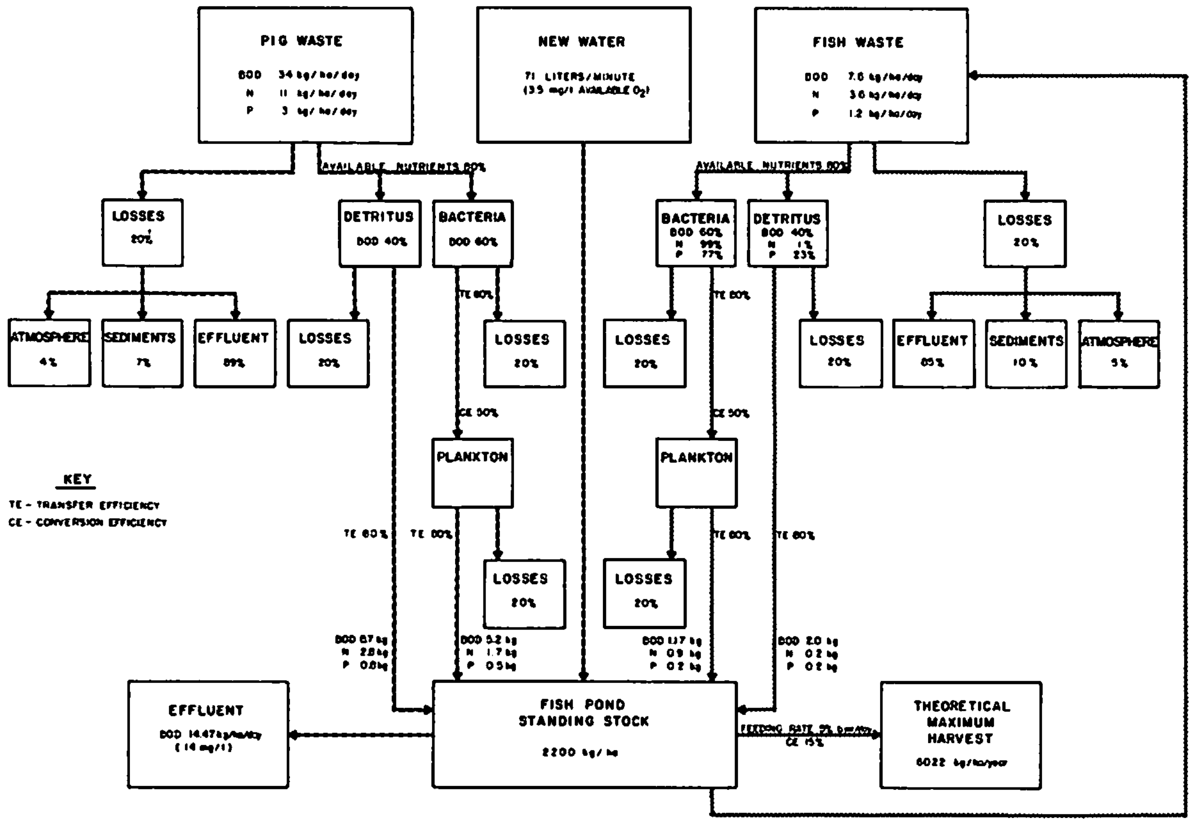

Figure 4. Fish production in oxidation pond utilizing available nutrients only.

Table 2. Annual production data of integrated aquaculture/agriculture waste utilization projects (after several authors).

Annual production (kg/ha)	Fish under culture	Manure source	Country	Reference
4,900	Carps	Fluid cowshed manure	Israel	Hepher and Schroeder 1977
3,500	Polyculture	Ducks	Southeast Asia	Ling 1977
4,140	Carps, catfish, largemouth bass, buffalo fish	Swine manure	USA	Buck, Baur and Rose 1979
2,729*	Silver carp, bighead carp	Sewage lagoons	USA	Henderson 1978
3,000	Polyculture	Domestic septic tank system	Java	Hickling 1962
3,700	Polyculture	Domestic wastewater storage reservoirs	Israel	Hickling 1962
1,000	Carp	Fish ponds receiving sewage waters	Germany	Schaperclaus 1961
2,000	Tilapia	Pig manure	Rhodesia	Van der Lingen 1960
4,000	Tilapia	1,000 ducks	Rhodesia	Van der Lingen 1960
3,000	Tilapia	Compost and farmyard manure	Madagascar	Gruber 1966
1,300	Carp	Town sewage effluents	Poland	Wolny 1962

*Area equivalents

Discussion

For a number of reasons, namely, 1) the need for the effluent to meet regulatory standards, 2) the relatively low standing stock of fish and 3) the imbalances which may occur to upset the system as a result of other priorities, it is not desirable to consider the utilization of animal waste with a fish culture system as a method of treatment or as a means of waste disposal in the proper sense of these terms.

This is far from saying that the utilization of animal wastes with fish culture systems is not practicable. Fish culture integrated with animal waste utilization is a highly recommended way to recover much of the nutrient value of animal wastes. However, it is not waste treatment per se. The ideal facility incorporates integrated animal waste/fish culture pond system(s) for the purpose of maximum fish production per unit area followed by a proper waste treatment pond for the purpose of purifying the effluent. Manure lagoons and oxidation ditches for animal waste treatment are now permanent fixtures of many agricultural systems. As treatment facilities, they have to be well designed, well operated, and well maintained if they are to be available at all times for processing waste. Fish ponds, on the other hand, are more flexible in management needs and must be harvested in response to fluctuating market demands. The recommended approach is a combination of two pond systems.

Fish production using a combination of waste nutrients and a high water flow, can be significant. However, under high rates of water flow, retention times are short and, although the effluents may be low in BOD concentration, it is a direct result of dilution and not the result of treatment.

The restraints to utilization of animal wastes in aquaculture have been well summarized by Allen and Hepher (1979). Briefly, they listed dissolved oxygen levels in the ponds, toxic materials in wastewaters, taste and odors in fish, parasites and diseases, public health problems, pond effluent standards and public acceptance. They did not include engineering as a constraint, which is correct. The engineering of good integrated pond systems is, however, very vital. Well-engineered systems are dependent on good biocriteria. For aquaculture, this is still woefully lacking; therefore, the possibility to engineer totally integrated animal waste/aquaculture systems that will reliably attain high yields of fish, as well as acceptable effluent quality, is still futuristic.

References

Allen, G.H. and B. Hepher. 1976. Recycling of wastes through aquaculture, and constraints to wider application, p. 478-487. *In* T.V.R. Pillay and W.A. Dill (eds.) Advances in aquaculture. Fishing News Books Ltd., Farnham, Surrey, England.

Babbit, H.E. and E.R. Baumann. 1958. Sewerage and sewage treatment. John Wiley & Sons, Inc., New York.

Buck, D.H., R.J. Baur and C.R. Rose. 1976. Experiments in recycling swine manure in fish ponds, p. 489-492. *In* T.V.R. Pillay and W.A. Dill (eds.) Advances in aquaculture. Fishing News Books Ltd., Farnham, Surrey, England.

Gruber, R. 1960. Considerations sur l'amélioration des rendements en pisciculture congolaise. Bull. Agric. Congo Belge. 51(1): 139-157. (In French)

Henderson, S. 1978. An evaluation of the filter feeding fishes, silver and bighead carp, for water quality improvement, p. 121-136. *In* R.O. Smitherman, W.L. Shelton and H.J. Grover (eds.) Culture of exotic fishes symposium proceedings. Fish Culture Section, American Fisheries Society, Auburn, Alabama.

Hepher, B. and G.L. Schroeder. 1977. Wastewater utilization in Israeli aquaculture, p. 529-559. *In* F. D'Itri (ed.) Wastewater renovation and reuse. Marcel Dekker, Inc., New York.

Hickling, C.F. 1962. Fish culture. Faber & Faber, London.

Ling, S.W. 1977. Aquaculture in Southeast Asia. Contribution No. 465. College of Fisheries, University of Washington, U.S.A. 108 p.

Schaperclaus, W. 1961. Lehrbuch der teichwirtschaft. P. Parey, Berlin.

Van der Lingen, M.I. 1960. The use of animal manures and the integration of animal keeping and fish culture in tilapia culture. Publ. Cons. Sci. Afr. S. Sahara. (63):212-216.

Whetstone, G.A., H.W. Parker and D.M. Wells. 1974. Study of current and proposed practices in animal waste management. EPA 430/9-74-003. United States Environmental Protection Agency, Washington, D.C.

Wolny, P. 1962. Przydatnosc oczysczonych sciekow miejskich do hodowli ryb. Roczn. Nauk Rol. (B), 81(2):231-250. (In Polish, English summary)

Woynarovich, E. 1979. The feasibility of combining animal animal husbandry with fish farming, with special reference to duck and pig production, p. 203-208. *In* T.V.R. Pillay and W.A. Dill (eds.) Advances in aquaculture. Fishing News Books Ltd., Farnham, Surrey, England.

REVIEWS AND BACKGROUND PAPERS: SPECIAL CONSIDERATIONS

Food Potential of Aquatic Macrophytes

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Abstract*

A review is presented of the pathways in which aquatic macrophytes may be involved in the food production process, directly as human food, as livestock fodder, as fertilizer (mulch and manure, ash, green manure, compost, biogas slurry), and as food for aquatic herbivores, such as fish, turtles, rodents and manatees. An attempt is made to identify the strategies which may have the greatest potential at present. The following research areas are suggested as worthy of attention: protein content and yield of *Ipomoea aquatica* and *Neptunia oleracea*, two vegetables which grow year round in the tropics and can be propagated from cuttings; protein content and yield of various types of duckweed in the tropics as a function of different concentrations of various organic wastes; *Azolla* and filamentous blue green algae as biofertilizers; composting aquatic macrophytes and the use of the compost as an organic fertilizer in fish ponds; aquatic macrophytes in biogas production and the use of the slurry as an organic fertilizer in fish ponds, and the feasibility of stocking herbivorous fish in irrigation systems with large aquatic macrophyte populations.

Summary and Research Recommendations

AQUATIC MACROPHYTES AS HUMAN FOOD

More than 40 species of aquatic macrophytes are edible but several clearly have little potential since they are eaten only rarely, particularly during food shortages e.g., water lettuce, *Pistia stratiotes;* water hyacinth, *Eichhornia crassipes;* and the seeds of the water lillies, *Nymphaea stellata, N. lotus* and *N. nouchali.* Others may have specific environmental requirements which restrict their distribution, e.g., water cress, *Rorippa nasturtium-aquaticum*, which is confined to cool, flowing water. However, certain species clearly have potential for more widespread use, e.g., taro, *Colocasia esculenta;* Chinese water chestnut, *Eleocharis dulcis;* water spinach, *Ipomoea aquatica;* and *Neptunia oleracea.* Two plants with a high protein content, the blue green alga *Spirulina* and the duckweed, *Wolffia arrhiza,* warrant further study, but social acceptability may prove to be a greater constraint to their utilization than technical problems of cultivation.

Aquatic macrophytes may be cultivated in water-logged or swampy soils not suitable for either terrestrial crops or aquaculture and thus increase the area of productive land in a given area.

Research recommendation 1: a study of the protein content and yield of *Ipomoea aquatica* and *Neptunia oleracea* as a function of different concentrations of

*The full text of this paper has been published separately by ICLARM as: Edwards, P. 1980. Food Potential of Aquatic Macrophytes. ICLARM Studies and Reviews 5, 51 p. International Center for Living Aquatic Resources Management. Manila, Philippines.

various organic fertilizers. The social acceptability of the plants will require study before attempts are made to introduce them into new areas. These two vegetables are easy to cultivate since they can be propagated from cuttings, and they grow year round in tropical areas.

AQUATIC MACROPHYTES AS LIVESTOCK FODDER

Many species of aquatic macrophytes are used as livestock fodder, but, due to their high moisture content, animals cannot usually consume enough fresh plant matter to maintain their body weight. Aquatic macrophytes must be at least partially dehydrated to serve as fodder, but with many species there is also a palatability problem, which restricts the amount of material consumed. Animals usually cannot consume more than about 25% of their diet as aquatic macrophytes on a dry weight basis without losing weight, and sometimes much less. The production of dry feed from aquatic macrophytes is not economically feasible because the cost of harvesting, transporting and processing plant matter with such a high moisture content is too high relative to the quality of the feed produced. The utilization of aquatic macrophytes as fodder is probably feasible only on a small scale using simple methods of dehydration, e.g., sun drying. Small amounts of aquatic macrophytes may be used in livestock diets on a regular basis, but large amounts should only be used in times of conventional fodder shortages.

Silage can be made from aquatic macrophytes, but since its nutritive value is low, due in part to its high moisture content, it should only be used when other feed is scarce.

There are several recycling systems in existence in which livestock waste is used to fertilize aquatic macrophytes, e.g., water hyacinth, water spinach, duckweed and *Spirulina*, which are used as animal fodder. Duckweed may have the greatest potential because of its rapid growth rate, high crude protein content, apparent absence of a palatability problem, and floating life form which facilitates harvesting. Particular emphasis should be placed on *Spirodela* since there is evidence that duckweed yield increases with thallus size.

Aquatic macrophytes are used in Europe and the U.S.A. in the treatment of domestic and industrial wastes, but the possible contamination of the plants by pathogens and toxic chemicals may restrict their subsequent use as livestock fodder. The use of aquatic macrophytes to treat less dangerous agroindustrial wastes may be useful in Asia, since the plants could possibly be used as fodder.

Research recommendation 2: a study of the protein content and yield of the various types of duckweed in the tropics, as a function of different concentrations of various organic wastes. Most of the research to date has been carried out in subtropical and temperate regions of the U.S.A.

AQUATIC MACROPHYTES AS FERTILIZER

Aquatic macrophytes are sometimes used as mulch and fertilizer, but the energy required to harvest, transport and spread them on land restricts such a practice to a small scale, adjacent to a source of aquatic plants. Allowing the plants to rot and using them as an organic fertilizer in fish ponds would probably produce a greater return than spreading them on land.

The production of ash from aquatic macrophytes for use as fertilizer is not economically feasible.

Azolla and certain species of filamentous blue green algae are used in some areas as biofertilizers to add nitrogen to rice paddies. Since the widespread use of biofertilizers could reduce the demand for inorganic fertilizers in developing countries, more effort is needed in this promising area of research.

Composting aquatic macrophytes may be the most promising method of utilization, since no mechanical devices or chemicals are required, little drying is needed, and transportation may not be necessary if the process is carried out close to the source of vegetation. The best way to use the compost may be as an organic fertilizer in fish ponds.

Aquatic macrophytes can be used in biogas digesters and the resulting slurry used as an organic fertilizer on vegetable crops, or better still as a fish pond fertilizer.

Research recommendation 3: a study of *Azolla* and filamentous blue green algae as biofertilizers.

Research recommendation 4: a study of composting aquatic macrophytes and the use of the compost as an organic fertilizer in fish ponds.

Research recommendation 5: a study of aquatic macrophytes in biogas production, and the use of the slurry as an organic fertilizer in fish ponds.

AQUATIC HERBIVORES

There are certain species of fish which are voracious eaters of aquatic macrophytes, e.g., grass carp, *Tilapia rendalli, T. zillii* and *Puntius gonionotus*, but unfortunately many plants which are prolific in warm waters, e.g., water hyacinth, are not readily consumed by herbivorous fish.

The food conversion ratios of aquatic macrophytes into fish tissue are high. Fish yields may be increased by polyculture, in which other fish species feed on the natural food developed in the pond as a result of the fertilization effect of the herbivorous fish faeces.

An integrated aquatic macrophyte-herbivorous fish system is not feasible with submersed vegetation *in situ*, since fertilizer, added to stimulate growth of the vegetation, would also increase the production of phytoplankton and eliminate the submersed vegetation through shading. Such a system may be feasible with the floating duckweed, but there may be management problems in balancing the macrophytes and fish growth.

The use of herbivorous fish to control aquatic macrophytes in irrigation systems appears to be a promising technique.

The rearing of other herbivorous animals, e.g., turtles, amphibious rodents and manatees may not be feasible at present.

Research recommendation 6: a study of the feasibility of stocking herbivorous fish in irrigation systems with large aquatic macrophyte populations.

HEALTH HAZARDS FROM THE CULTURE AND USE OF AQUATIC MACROPHYTES

The presence of aquatic macrophytes may lead to mosquito breeding, but *Pistia stratiotes*, the host plant for *Mansonia*, is unlikely to be cultivated since it has little value, and certain fish species can be stocked in the system to consume *Anopheles* larvae.

Contamination by pathogens through the use of animal and human waste as a fertilizer is more difficult to control. Ideally, wastes should be rendered inocuous by treatment prior to use as fertilizers.

The accumulation of toxic chemicals by aquatic macrophytes in waste recycling systems could be reduced by the separation of domestic wastes from industrial wastes.

Health Constraints to Integrated Animal-Fish Farming in the Philippines

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Abstract

Diseases communicable or potentially communicable to man via fish or the water of integrated animal-fish farming systems in the Philippines are discussed. There is evidence of potential public health hazards from some organisms. Areas requiring further research are noted.

The population increase in many parts of the world, notably in underdeveloped and developing regions, has brought problems of food production coupled with the need for maximal utilization of all natural resources, including aquatic flora and fauna.

Fisheries are destined to play an important role in human nutrition, but fish is becoming increasingly a luxury food in the Philippines. Integrated animal-fish or crop-fish farming (duck-fish, pig-fish, rice-fish culture, etc.) apparently offer a solution to the problem of increasing production.

Traditional farming has recycled animal wastes for a long time without noticeable harm to the environment. Progressive crop growers have used animal manure to maintain soil fertility. In thinly populated areas, low concentrations of animal wastes apparently cause no health hazards, and are taken up in natural nutrient cycles. Today, however, we run high risks of contamination of the environment from human activities coupled with high population density. In many tropical and subtropical countries, parasitic infections of animals and man exact a serious toll on life and health. Aquatic pollution (organic or inorganic) is also a matter of concern, not only to the parasitologists and health authorities but also to government and private citizens. Fish kills result in socioeconomic problems and contamination of food fish commonly causes gastroenteritis and other human ailments.

Environmental factors external to the host play a major role in the survival and success of parasites. Sunlight, temperature, pH and salinity are among the important physico-chemical factors. Little information is available in the Philippines on the use of animal wastes in relation to the diseases of aquatic animals, but we do know that aquatic pollutants produce physico-chemical changes, which may cause stress and result in diseases. For example, wastes high in nutrients can produce oxygen depletion and consequent stress. Domestic wastes can also introduce pathogens of aquatic organisms and man.

This paper discusses diseases communicable or potentially communicable to man via fish or the aquatic medium, using animal wastes in integrated animal-fish farming.

Bacterial Infections

The pathogenic bacteria carried by fish include *Escherichia coli, Shigella* spp., Streptococci, *Clostridium botulinum* type E. Gunnison et al., *Clostridium tetani* Flügge-Holland and *Staphylococcus aureus* Rosenbach, according to Shewan (1962), as cited by Reichenbach-Klinke and Elkan (1965). *Escherichia coli* Castellani and Chalmers have been carried by salmonid fish without harming the fish. Rankin and Taylor (1969), cited by Azevedo and Stout (1974), noted the gradual die-off of *Salmonella dublin, S. typhimurium, Staphylococcus aureus* and *Escherichia coli* in slurry but these were still detectable after 12 wk.

Tuberculosis has also been observed in a wide range of animals, including fish, frogs, alligators, snakes and turtles (Campbell and Lasley 1975).

Transmission of bacterial pathogens depends on environmental conditions coupled with release from the host at varying intervals, and may be enhanced if they breed freely in the water.

Table 1. *Leptospira* reported in the Philippines from farm animals and man (Arambulo 1971)

Serotypes	Host(s)
L. australis	pig, man
L. autumnalis	wild rat, dog, pig, sheep, cat
L. bataviae	wild rat, dog, pig, man
L. canicola	dog, cattle, man
L. grippotyphosa	wild rat, cat, dog, sheep, shrew, pig, man
L. hyos	wild rat, pig, man
L. icterohemorrhagiae	wild rat, dog, carabao, pig, man
L. javanica	wild rat
L. javiana	cattle, man
L. manilae	wild rat, man
L. pomona	cattle, carabao
L. poi	dog
L. pyrogenes	wild rat, pig, man
L. sejroe	cattle
L. tarassovi	wild rat, pig, carabao
L. wolfii	cattle, man

EXAMPLES:

1. Erysipelas

Erysipelas is a communicable disease of swine and poultry caused by corynebacteria, *Erysipelothrix insidiosa* Langford and Hensen, *E. mursepticum* Rosenbach, *E. rhusiopathiae, Bacillus erysipelatus suis* and *B. rhusiopathiae* (Morse 1963). Infected fish are not themselves affected and show no symptoms. Man contracts the infection through skin abrasions in handling materials of animal, fish or shellfish origin. It is often called "fish-handlers disease" in the United States and produces a condition called "Fish Rose." Severe inflammation may result when wounds are infected from the mucus of dead fish with a burning and itching skin sensation which may last for up to 3 wk.

2. Leptospirosis (Weil's disease, Canicola fever, haemorrhagic jaundice, Swine's head disease)

The disease is an occupational hazard of agricultural, fish and abattoir workers, sewer workers, etc., from exposure to water contaminated by the urine of wild or domestic animals. This disease is also hazardous to bathers and campers in infected areas; floods enhance its distribution. Table 1 shows the serotypes of Leptospira isolated from human cases and animals in the Philippines. The chief causative agent of leptospirosis in cattle, swine and carabo (water buffalo) in the Philippines is *L. pomona* (Arambulo 1971). Cases of leptospirosis in people swimming in water contaminated by *L. pomona*-infected animal excreta have been reported by Shaeffer (1951) and Gillespie and Ryno (1963), both cited by Azevedo and Stout (1974). Diesch (1970), cited by Azevedo and Stout (1974), reported that leptospira could survive in an oxidation ditch for 18 d. The possibility of fish being implicated in the dissemination of the disease is not remote if they are reared in contaminated waters.

3. Salmonellosis

About 45 species of salmonellae have been reported in the Philippines. Tables 2 and 3 list the species recorded in or regarded as transmissible from domestic animals to man.

Lewis (1975) found that under laboratory conditions, *S. typhimurium* was taken up by the gulf killifish *(Fundulus heteroclitus)*, pompano *(Trachinotus carolinus)*, striped mullet *(Mugil* sp.), channel catfish *(Ictalurus punctatus)* and lake shrimp *(Penaeus setiferus)* within 2 hr of exposure. Thirty days later, salmonellae were recovered from the alimentary tracts of the mullet, pompano and catfish; the latter also had symptoms of infection. *S. enteritidis* have been recovered from freshwater fish 110 d after exposure and some fish developed inflammation in the gut (Brunner 1974, cited by Lewis 1975).

Fish could, therefore, be important in the epidemiology of salmonellae.

Protozoal Infections

1. Amoebiasis (Amoebic dysentery) and Balantidiasis (Balantidial dysentery)

These two diseases occur in areas of poor environmental sanitation. Association with hogs and use of animal manure as fertilizer may result in higher incidence of the disease. Water-borne epidemics are not infrequent.

Helminth Infections

Fish as carriers of human helminthic infections are listed in Table 4. Most infection of piscivorous mammals, birds and man occurs upon ingestion of infected fish flesh, either raw or not well cooked. Cardiac and visceral complications in humans are known in the Philippines (Africa et al. 1940). Table 5 lists the helminth parasites of domestic animals for which cases of human infection have been recorded in the Philippines.

Table 2. Salmonellae reported from farm animals and man in the Philippines.

Serotype	Host(s), Source	Reference
S. aberdeen	fowl, cattle, cow, man	Arambulo 1971
		Tacal and Meñez 1968b
		Tacal et al. 1974
S. anatum	duck	Arambulo 1971
	chicken	Tacal et al. 1974
	turkey, cat, dog, pig	Tacal et al. 1972
	horse, carabao, cattle, man, fish meal	Tacal and Soriano 1970
S. choleraesuis	pig, man	Arambulo 1971
S. choleraesuis var. *kunzendorf*	pig	Arambulo 1971
		Tacal et al. 1974
S. derby	chicken, chicken ascarids,	Arambulo 1971
	dog, pig, houseflies	Tacal and Meñez 1967
		Tacal et al. 1974
		Tacal et al. 1972
		Tacal and Soriano 1970
S. enteritidis	cattle, various animals	Arambulo 1971
S. give	duck, fowl, pig, man	Arambulo 1971
		Tacal et al. 1974
S. havana	chicken, man	Arambulo 1971
		Tacal et al. 1972
S. javiana	chicken	Arambulo 1971
	pigeon, pig, cattle,	Tacal et al. 1972
	carabao, man	Tacal and Meñez 1968b
S. lexington	pig, man	Tacal et al. 1972
		Arambulo 1971
S. newport	dog, swine, man	–ditto–
S. panama	fowl, dog, swine, man	–ditto–
S. paratyphi (types A & B)	chicken, cattle, cow, man	–ditto–
S. potsdam	man	Arambulo 1971
S. pullorum	chicken (Table 3)	Tacal and Soriano 1970
		Topacio and Banci 1965
S. saint-paul	duck, turkey, man	Arambulo 1971
S. seftenberg	duck, dog, man	–ditto–
S. singapore	chicken	Tacal et al. 1974
		Tacal et al. 1972
		Tacal and Soriano 1970
S. stanley	chicken, turkey	Arambulo 1971
	pigeon, dog, pig	Tacal and Meñez 1968b
	cattle, carabao	Tacal et al. 1974
		Tacal et al. 1972
S. virchow	chicken, man	Arambulo 1971
		Tacal et al. 1972
S. weltevreden	chicken	Arambulo 1971
	turkey, pig, man	Tacal et al. 1974
		Tacal and Soriano 1970
S. worthington	fowl, pig, man	Arambulo 1971

EXAMPLES

1. Schistosomiasis

In the Philippines, the important reservoir hosts of the etiological agent, *Schistosoma japonicum*, are pigs, cattle, carabaos, horses, other domestic animals as cats, dogs and even field mice and wild rats. Infection is acquired through skin penetration by the cercariae released from the snail host, *Oncomelania quadrasi.* The distribution of the disease is limited to areas inhabited by the snail. Contamination of water with feces of reservoir animals continues to be a public health hazard. It is not, therefore, advisable to use animal wastes for integrated animal-fish farming in such areas.

2. Heterophydiasis

Only two life cycles are known in the Philippines: *Haplorchis taichui* and *Procerovum calderoni* (Velasquez 1973a, 1973b). *Haplorchis taichui, H. yokogawai, Procerovum calderoni* and *Stellantchasmus amplicaecalis* are known to encyst in the tissues of fish listed in Table 4; they have been recovered from human intestines. *Melania juncea* Lea, the primary intermediate host of *Haplorchis taichui,* is commonly found in rice paddies. That of *Procerovum calderoni,* the brackishwater snail *(Thiara riquetti),* is found in bangus *(Chanos chanos)* fishponds.

Carneophallus brevicacea (Africa and Garcia 1935) Velasquez (1975) was originally considered as the causative agent of heterophydiasis in man in the Philippines. The developmental pattern is that of a microphallid, although the symptoms are those of a heterophyid (Velasquez 1975). It is proposed, therefore, that the disease be called microphalliasis. Continuous consumption of raw naturally-infected intermediate host, *Macrobrachium* sp., produces lethal or sublethal infections of the heart, spinal cord and other vital organs. In certain areas of the Philippines, the shrimp is eaten raw with table condiments, such as vinegar, tomatoes and salt.

Galvez (1979) has found that cysts of *Procerovum calderoni* "in situ" at 29.5°C in 5 to 15% saline solution died after 76 to 16 hr. Corresponding survivals in soy sauce and vinegar were 20 and 7 hr, respectively. Cysts in fish refrigerated at 8.5°C and then marinated in 5 to 15% salt solution, survived for 220 to 70 hr. Corresponding survivals in soy sauce and vinegar were 30 and 240 hr, respectively. Freezing of infected fish for 120 hr, sun-drying for 9.5 hr and smoking for 1 hr killed all cysts. Frying or boiling killed all cysts in 10 to 15 min.

Table 3. Salmonellae reported in the Philippines from animals and potentially transmissible to man.

Serotype	Reservoir host	Source/reference
S. alchua	carabao	Arambulo 1971
S. blockley	chicks, rabbit	Arambulo 1971
S. choleraesuis var. *kunzendorf*	pig	Tacal et al. 1974
S. derby	pig	Tacal and Meñez 1967
S. dublin	carabao	Arambulo 1971
S. heidelberg	pig	Tacal et al. 1974
S. hvittingfoss	carabao, cattle	Tacal and Meñez 1968b
S. java	pig, carabao, cattle	Tacal and Meñez 1968a, b Tacal et al. 1974
S. kentucky	pig	Arambulo 1971
S. lexington	pig	Arambulo 1971
S. pullorum	chicken	Topacio and Banci 1965
S. newington	dog, pig	Tacal et al. 1974
S. saint-paul	duck	Tacal and Soriano 1970
S. ocerro	duck	Tacal and Soriano 1970
S. seftenberg	dog, ducks and turkeys	Tacal and Soriano 1970
S. sieburg (Group K)	dog, horses	Arambulo 1971
S. thompson	cat	Arambulo 1971
S. typhimurium	duckling, chicks, pigeons, dog, pig, cattle	Tacal and Meñez 1968a, b Tacal et al. 1974 Tacal et al. 1972
S. typhimurium var. *copenhagen*	dog	Arambulo 1971
S. utah	pig	Arambulo 1971

Table 4. Philippine freshwater fishes harboring the larvae of parasitic helminths transmissible to man.

Fish species	Local name (Tagalog unless otherwise indicated)	Habitat	Helminth parasites	
			Trematodes	Nematodes
Anabas testudineus	"martiniko"	freshwater	*Procerovum calderoni* *Stellantchasmus amplicaecalis* *Centrocestus caninus*	*Gnathostoma spinigerum*
Arius manilensis	"kanduli"	freshwater	*Haplorchis yokogawai*	
Clarias batrachus	"hito"	freshwater	*Haplorchis yokogawai*	
Glossogobius giurus	"bia" or "biang puti"	freshwater	*Procerobum calderoni* *Haplorchis pumilio* *Centrocestus caninus*	*Gnathostoma spinigerum*
Ophicephalus striatus	"dalag" or *"bulig"*	freshwater	*Procerovum calderoni* *Haplorchis yokogawai* *Haplorchis pumilio* *Haplorchis taichui*	*Gnathostoma spinigerum*
Puntius binotatus	"bitngo" (Maranao)	freshwater	*Haplorchis pumilio* *Haplorchis taichui*	
Puntius palata	"bitngo" (Maranao)	freshwater	*Haplorchis taichui*	
Therapon plumbeus	"ayungin"	freshwater	*Haplorchis pumilio* *Centrocestus caninus*	
Therapon argenteus	"ayungin"	freshwater brackishwater and marine		*Gnathostoma spinigerum*
Ambassis buruensis	"langaray"	freshwater brackishwater and marine	*Stictodora guerreroi* *Stictodora manilensis* *Procerovum calderoni* *Haplorchis pumilio* *Heterophyopsis expectans*	
Pelates quadrilineatus	"babansi"	marine and brackishwater (occasionally freshwater)	*Stictodora manilensis* *Procerovum calderoni* *Heterophyopsis expectans*	
Scatophagus argus	"kitang"	marine, brackishwater and freshwater	*Procerovum calderoni*	
Chanos chanos	"bangus"	marine and brackishwater, also estuarine	*Procerovum calderoni*	
Gerres kapas	"malakapas"	marine, brackishwater and freshwater	*Haplorchis yokogawai* *Heterophyopsis expectans*	
Gerres filamentosus	"malakapas"	marine, brackishwater and freshwater	*Stictodora manilensis* *Heterophyopsis expectans* *Procerovum calderoni* *Haplorchis pumilio*	
Hemiramphus georgii	"kansusuit" or "buguing"	marine and brackishwater (occasionally freshwater)	*Stictodora guerreroi* *Procerovum calderoni* *Haplorchis yokogawai*	
Mugil dussumieri	"talilong" or *"banak"*	marine, brackishwater and freshwater	*Stictodora guerreroi* *Stictodora manilensis* *Procerovum calderoni* *Haplorchis yokogawai* *Stellantchasmus amplicaecalis* *Heterophyopsis expectans*	

Table 5. Helminth parasites of domestic and other animals with aquatic intermediate hosts for which human infections have been reported in the Philippines (from Tubangui 1947, unless otherwise indicated).

Parasite	Natural final host(s)	Intermediate host(s)	Common name of intermediate host (Tagalog unless otherwise stated)	Locality for recorded human case(s)	Organ(s) affected
Trematoda (Digenea)					
Family Echinostomatidae					
Echinostoma ilocanum Garrison, 1908	rat	1° snail		Northwestern Luzon,	intestines
		Anisus convexiusculus	suso	Manila, Zambales, Mindoro,	
		2° *Pila luzonica*	kuhol	Leyte and Mindanao	
Family Fasciolidae					
Fasciola hepatica and *Fasciola gigantica*	cattle, carabao	1° snail *Lymnaea* spp.		Albay and Bicol provinces	liver, bile duct
Family Heterophyidae					
Stellantchasmus amplicaecalis (Katsurada, 1931) syn. of *Diorchitrema pseudocirrata* (Witenberg, 1929) syn. of *S. falcatus* Onji et Nishie, 1915	dog, cat, mouse (experimental), birds	1° snail (not known)		Manila, Luzon	intestines
		2° fish			
		Anabas testudineus	liwalo		
Procerovum calderoni	dog, cat, duckling	1° snail		Biñan, Laguna,	intestines
		Thiara riquetti		Luzon Island	
		2° fish–species listed in Table 4, also *Creissen validus*	bia		
		Amphacanthus javus	samaral		
		Eleutheronema tetradactyla	mamali		
		Butis amboinensis	biang sunog		
		Platycephalus indicus	sunog		
		Mollienesia latipinna	bubuntis		
		(Velasquez, 1973b)			
Haplorchis taichui	cat, dog, cattle, egret, chick (experimental)	1° snail		Manila, Luzon, Leyte	intestines
		Melania juncea			
		2° fish			
		Ophicephalus striatus	dalag		
		Puntius binotatus			
		Puntius palata			

(Continued next page)

Table 5 (cont'd.)

Haplorchis yokogawai	cat, dog, cattle, egret,	1° ?		Manila, Luzon	intestines
	monkey (experimental)	2° fish			
		Ophicephalus striatus	dalag		
		Gerris sp.	kapas		
		Amplacanthus javus	samaral		
		Ambassis buruensis	langaray		
		Hemiramphus georgii	kansusuit		
		Mugil sp.	banak		
Carneophallus brevicacea	wild bird	1° ?		Manila	intestines
		2° shrimp			
		Paratenic: fish			
		Glossogobius giurus	bia		
Family Troglotrematidae					
Odhner, 1914					
Paragonimus westermani	cat, rat (experimental)	1° snail		Albay (Guinobatan),	lung
Kerbert, 1878		*Brotia asperata*	Tabaguang	Camarines Sur (Naga),	
		2° crab	(Bicol)	Sorsogon (Gubat),	
		Parathelphusa		Luzon, Samar, Leyte	
		(Barythelphusa) mistio		and Mindanao	
Family Philopthalmidae					
Philopthalmus sp.	conjunctival sac of bird, chicken	not known		Ilocos (Velasquez 1978)	conjunctival sac
Family Schistosomatidae					
Schistosoma japonicum	cat, dog, pig, goat, cattle, horse	snail–*Oncomelania quadrasi*		Mindoro, Leyte, Samar,	blood vessels,
	wild rats, guinea pig (experimental),			Mindanao and Bicol	portal and
	white rat, mouse, monkey				mesenteric veins
Nematoda					
Family Ascaridae					
Ascaris lumbricoides	pig, man	none		widely distributed	intestines
Family Gnathostomidae					
Gnathostoma spinigerum	dog, cat, civet	1° copepods		Manila, Luzon	subcutaneous
		Cyclops			
		Eucyclops serrulatus			
		c. *(Microcyclops) bicolor*			
		2° fish			
		Ophicephalus striatus	dalag		
		Anabas testudineus	liwalo		
		Glossogobius giurus	bia		

Nematode Infections

Ascaris lumbricoides in man and pig are morphologically identical but serologically and physiologically different. In some instances, cross-infections may occur. Velasquez (1954) showed that ascarid ova from pig are viable for as long as 535 d in stagnant pools. Ascarid ova from man, pig, dog, horse and calf can embryonate after up to a year in sewage (Furchner 1952).

Gnathostoma spinigerum from dog, cat and civet cat and *Gnathostoma hispidum* from pig have been reported to produce cutaneous abscesses in man. In the Philippines, the primary intermediate host is *Cyclops (Eucyclops) serrulatus. C. (Microcyclops) bicolor* and three freshwater fishes, *(Ophicephalus striatus, Anabas testudineus* and *Glossogobius giurus)* are the secondary intermediate hosts (Refuerzo and Garcia 1938; Tubangui 1947). A human case has been reported (Yogore and Juliano 1951).

Angiostrongyliasis is a disease of the central nervous system in man. It is caused by *Angiostrongylus cantonensis,* a nematode lungworm in rats. The meninges are involved, resulting in eosinophilic meningitis or meningoencephalitis. *Achatina fulica, Veronicella* sp. and *Pila luzonica* are the first intermediate hosts in this country (Velasquez 1972). Infection may be acquired by eating paratenic hosts as prawns, fish, land crabs, cattle and chickens. Lettuce and other vegetables generally eaten raw may also serve as sources of infection when contaminated by infected mollusks.

Conclusions and Recommendations

Available evidence indicates that some parasites of farm animals and freshwater fish may pose questions for public health. The farmer's responsibility in maintaining sanitation and hygiene cannot be overlooked and strong government regulations regarding health measures are required. Research could continue in the profitable and sanitary recycling of our wastes.

The following areas require further study:

1. Proper disposal of both animal and human wastes.
2. Use of treated manure as fertilizers or animal feed.
3. Sanitary living and working conditions.
4. Immunization of farm animals.
5. Public health education.

References

Africa, C.M., W. de Leon and E.Y. Garcia. 1940. Viseral complications in intestinal heterophyidiasis in man. Acta Med. Philipp. Monogr. Ser. 1:1-132.

Arambulo, P.V. III. 1971. A summary of zoonoses in the Philippines. American Veterinary Epidemiology Society. Georgia, U.S.A. 29 p. Edited by James H. Steele.

Azevedo, J. and P.R. Stout. 1974. Farm animal manures: an overview of their role in the agricultural environment. California Agricultural Experiment Station Extension Service. Division of Agricultural Sciences, University of California. Manual 44:56-62.

Campbell, J.R. and J.F. Lasley. 1975. *In* E.P. Young (ed.) The science of animals that serve mankind. 2nd Edition. McGraw-Hill Book Co., New York.

Furchner, H.O. 1952. Über die Lebensfähigkeit von Askarideneiern in Hauskläranlagen. Inaug. Diss. Munich. 531-574. Abst. in Vet. Bull. 23:12.

Galvez, Elvira R. 1979. Observations on the viability and resistance of the metacercaria of *Procerovum calderoni* (Africa and Garcia 1935) Price, 1940 (Trematoda: Heterophyidae) in *Scatophagus argus* Linn. Fish. Res. J. Philipp. 4(1):37-57.

Lewis, D.H. 1975. Retention of *Salmonella typhimurium* by certain species of fish and shrimp. J. Amer. Vet. Med. Assoc. 167(7):551-552.

Morse, E.V. 1963. Swine erysipelas, p. 186-208. *In* T.G. Hull (ed.) Diseases transmitted from animals to man. Charles C. Thomas Publ. Springfield, Illinois.

Refuerzo, P.G. and E.Y. Garcia. 1938. The crustacean hosts of *Gnathostoma spinigerum* in the Philippines and its pre- and intra-crustacean development. Philipp. J. Anim. Ind. 5(4): 351-362.

Reichenbach-Klinke, H. and E. Elkan. 1965. The principal diseases of lower vertebrates. Academic Press, London. New York.

Tacal, J.V. Jr. and C.F. Meñez. 1967. Salmonella studies in the Philippines. VII. The isolation of *Salmonella derby* from abattoir flies and chicken ascarids. Philipp. J. Vet. Med. 6(1/2):106-111.

Tacal, J.V. Jr. and C.F. Meñez. 1968a. Salmonella studies in the Philippines. VIII. Salmonella infections in young animals. Philipp. J. Vet. Med. 7(1/2):30-43.

Tacal, J.V. Jr. and C.F. Meñez. 1968b. Salmonella studies in the Philippines. IX. Salmonella isolations from apparently healthy carrier cattle and carabaos. Philipp. J. Vet. Med. 7(1/2):125-142.

Tacal, J.V. Jr. and J. Soriano. 1970. Salmonella studies in the Philippines. XII. Salmonella isolations from apparently healthy native ducks and turkeys. Philipp. J. Anim. Sci. 7(1):51-58.

Tacal, J.V. Jr., C.F. Meñez and J.A. Soriano. 1972. Salmonella market poultry and poultry dressing plant environments in the Philippines. Philipp. J. Vet. Med. 11(1):10-18.

Tacal, J.V. Jr., C.F. Meñez and M. L. Luis. 1974. Salmonella studies in the Philippines. XV. Salmonella isolations from miscellaneous non-human sources. Philipp. J. Vet. Med. 13(1/2):58-73.

Topacio, M. Teodulo and E.L. Banci. 1965. Isolation of *Salmonella pullorum* from reactor chickens. Philipp. J. Vet. Med. 4(1):94-103.

Tubangui, M.A. 1947. A summary of the parasitic worms reported from the Philippines. Philipp. J. Sci. 76(4):225-322.

Velasquez, C.C. 1954. Studies on resistance and dissemination of

Ascaris ova for the control of *Ascaris* infection in rural districts. Nat. Appl. Sci. Bull. 14:159-244.

Velasquez, C.C. 1972. Mollusks of parasitological significance in the Philippines. University of the Philippines Press, Manila.

Velasquez, C.C. 1973a. Observations on some Heterophyidae (Trematoda: Digenea) encysted in Philippine fishes. Amer. J. Parasitol. 59(1):77-84.

Velasquez, C.C. 1973b. Intra-molluscan stages of *Haplorchis taichui* (Nishigori) in *Melania juncea* Lea in the Philippines. Amer. J. Parasitol. 59(2):281.

Velasquez, C.C. 1973c. Life cycle of *Procerovum calderoni* (Africa and Garcia 1935) Price, 1940 (Trematoda: Digenea: Heterophyidae) Amer. J. Parasitol. 59(5):813-816.

Velasquez, C.C. 1975. Observations on the life cycle of *Carneophallus brevicaeca* (Africa and Garcia 1935) comb. n. (Digenea: Microphallidae). Amer. J. Parasitol. 61(5):910-914.

Velasquez, C.C. 1978. Some parasitic helminths as environmental hazards in the Philippines. U.P. Press, Professorial Chair Lect. Ser. Monogr. No. 53:1-25.

Yogore, M.G. and S.J. Juliano. 1951. Report of a case of human gnathostomiasis. Acta. Med. Philipp. 7:239.

COUNTRY REPORTS AND CASE STUDIES

Integrated Animal-Fish Husbandry Systems in Hong Kong with Case Studies on Duck-Fish and Goose-Fish Systems

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Abstract

The various combinations of pig, duck, goose, pigeon and fish farming in Hong Kong are reviewed with particular emphasis on production data and marketing. In 1978, fish production from integrated farms ranged from 1.5 to 4.7 t/ha. The increasing demand for land in Hong Kong may limit future expansion, but integrated farming has advantages over other food producing systems as it is efficient in both land and water utilization. Research needs to increase this efficiency are discussed.

The paper includes two case studies on duck-fish and goose-fish farms with detailed economic analyses. The returns on capital invested were 15 to 19% for the duck and goose farming and 43 to 58% for the fish culture components.

Introduction

In Hong Kong, the predominant inland fish culture region is located on the alluvial plain north of the agricultural town Yuen Long, in the northwestern New Territories (Figure 1). The present total pond area is 1,975 ha. Freshwater fish are produced by monoculture and polyculture systems, the majority of the latter incorporating production of fish in ponds with pig, duck, goose and pigeon rearing, termed pig-fish, duck-fish, goose-fish and pigeon-fish systems to distinguish them from polyculture of mixed fish species. The production management of all these systems is intensive and well-organized with coordinated supporting industries and marketing services.

This paper presents an overall country statement of the various integrated animal-fish husbandry systems in Hong Kong, based largely on a survey conducted in early 1979. Case studies of duck-fish and goose-fish systems are also included.

Integrated Systems in Use

Sin and Cheng (1976) have described the major fish culture management systems in Hong Kong: the monoculture of carnivorous fishes, such as the catfish, *Clarias fuscus*, and the snakehead, *Ophicephalus maculatus;* the polyculture of herbivorous fishes, such as the Chinese carps and the grey mullet *(Mugil cephalus)* and duck-fish systems. Other minor integrated systems, such as the pig-fish, duck-pig fish, goose-fish and pigeon-fish systems also exist. Both duck-fish and pig-fish systems are scattered randomly throughout the major fish culture region. The goose-fish system, however, is located mainly in Lak Ma Chau and Tin Shui Wai, while the pigeon-fish system is distributed only sporadically. A survey conducted in early 1979 revealed the proportions of polyculture and the various integrated systems in operation in Hong Kong, as shown in Table 1, which demonstrates that duck farming is the most important operation integrated with fish farming. Duck-fish and

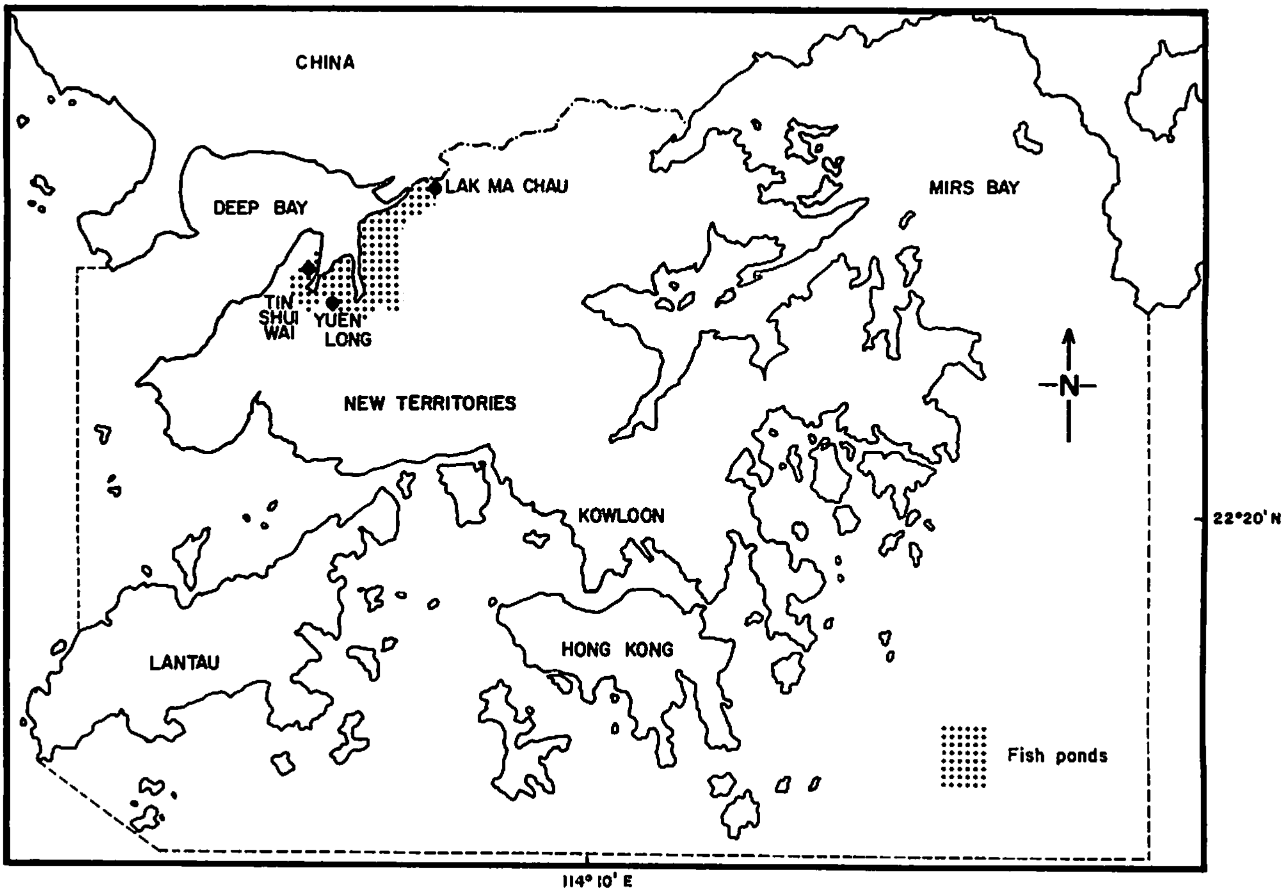

Figure 1. The major inland fish culture area in Hong Kong.

duck-pig-fish systems combined are practiced by 65% of all integrated farms and occupy 60% of the total pond area. The pig-fish system ranks second and is practiced by 10.5% of the fish pond farmers.

The fish culture operation of both the pure fish polyculture and the integrated systems are very similar (Sin and Cheng 1976). In both, the fish stocked are grey mullet and Chinese carps, viz, the silver carp, *Hypophthalmichthys molitrix*, big head, *Aristichthys nobilis*, grass carp, *Ctenopharyngodon idella*, and common carp, *Cyprinus carpio*. Recently, *Sarotherodon* species have been introduced into the systems due to the scarcity of grey mullet fry.

Available Information on Integrated Systems

According to a retired veteran fish culturist, integrated farming, particularly the duck-fish system, has been practiced for over 60 yr. There is, however, no record available of its origin. Lin (1940) probably first mentioned such an association of fish and duck in ponds, but did not describe the management technique. More recently, duck farming and its disease control methods have been described on several occasions (Anon. 1972; Chan 1972; Lau 1972, 1973; Mui 1969 and Wong 1969, 1972a, 1972b). Subsequent work has included studies of the nutritional effects of duck droppings as a fertilizer for fishponds (Lo 1970) and comparisons of the management techniques and economics of polyculture and duck-fish systems (Sin and Cheng 1976). There is no

Table 1. The percentage representation by number and area of pure fish polyculture and the various integrated animal husbandry and polyculture systems in Hong Kong (1979).

Management systems	Production units (%)	Area (%)
Polyculture (fish only)	21.1	25.5
Duck-fish	57.9	48.1
Pig-fish	2.6	1.6
Duck-pig-fish	7.9	12.2
Goose-fish	7.9	12.5
Pigeon-fish	2.6	0.1

information available, however, on other integrated systems.

The Relative Importance of Integrated Systems

Fish farms are classified as small (below 1.4 ha), medium (1.4 to 4.0 ha) and large (over 4.0 ha), which represent by number 26.3, 55.3 and 18.4% of the total. Seventy-nine percent of all fish farms, irrespective of size, are associated with the production of livestock and poultry. As over 80% of these integrated farms belong to the small and medium classes which are operated at a subsistence level, their animal husbandry operations play an important role in their economics even though animals are only treated as secondary crops to fish from the same piece of land.

An integrated farm is usually run by a single farmer alone, first because it facilitates controlling the scale of animal husbandry, thereby maintaining a suitable level of pond fertility for fish growth and survival, and second because the income generated by the combined systems is higher than that from pure polyculture alone by HK$9,600-HK$17,000* net annual earnings per hectare. The integrated farms combining livestock and poultry with fish may, however, be separately owned and managed to the mutual economic benefit of both owners. The fish farmers obtain free pond fertilization, thereby reducing their operating costs, and the livestock and poultry owners receive rent-free land and free pond water for animal husbandry purposes. In almost every case, they have to be financially responsible for their own ventures.

The yields of fish obtained in 1978 from pure fish polyculture and integrated farms were similar and ranged from 1.5 to 4.7 t/ha. In addition, an average of 9 t of ducks, 2.3 t of geese or 2.6 t of pigs per hectare was produced by the integrated farms. The food production capability per unit area of land is much increased by integrating animal husbandry with fish farming.

The integrated systems are more efficient than pure fish polyculture systems in the utilization of primary resources such as fertilizers and feeds, water, labor and land. The ponds receive animal wastes and uneaten feedstuffs which serve as fertilizers and fish food. Schools of the grass carp *(Ctenopharygodon idella)*, common carp *(Cyprinus carpio)* and tilapias (*Sarotherodon* spp.) can be found feeding on these substances close to the animal sheds. The integrated systems therefore constitute a continuous process of disposal and recycling of animal wastes which would otherwise be accumulated on land or washed via watercourses to the sea, creating pollution problems. The ponds provide water to meet the various needs of animal husbandry: drinking water for livestock and poultry and water for cleaning the animal sheds.

In both small and medium farms, family members are the regular labor force undertaking routine operations, though part-time skilled workers are employed for fish harvesting. The production programs adopted on fish farms enable two to three skilled workers to manage efficiently farms of not less than 3.5 ha. In smaller farms, labor is evidently underutilized and here the additional management of 500 to 2,000 ducks or 1,500 to 2,500 geese per farm would be a complementary arrangement improving labor utilization. In Hong Kong, a large quantity of potential agricultural laborers have become industrial workers and commercial employees as a result of the increasing industrialization and commercialization in the agricultural regions. In addition, emigration of the agricultural population will continue to worsen the shortage of skilled labor. Therefore, the integrated systems, which enable better utilization of skilled and unskilled labor, are highly suitable for Hong Kong.

The 1979 survey revealed that the operation of the existing scale of animal husbandry practiced in the fish farm requires 50 to 400 m^2 of land and water per farm. More space within the fish farms could be made available for its further expansion, but the problem of excessive inputs of crude animal wastes into the ponds inhibits development beyond the present level unless efficient waste pretreatment and disposal is practiced. If this could be achieved, the consequent intensification of livestock and poultry production inside the fish farms would reduce competition for expansion with other priority land development. The integrated systems, with all their merits of better utilization of fertilizers, feeds, water, economics of labor and land use, are highly suited to Hong Kong conditions and should be considered as an alternative approach to agricultural and inland fishery development.

Disposal and Marketing of Products

The farm products, i.e., fish, ducks, geese, pigs and pigeons, produced locally are consumed almost entirely by the local populace. Live fish are transported by lorries with water tanks equipped with aerators or water pumps. Livestock and poultry are carried in wooden bamboo or metal crates on lorries. Because of the small size and dense population of Hong Kong, the disposal of the farm products presents no major difficulty. The transportation distances between the primary producers and the consumers are usually under 50 km: relatively short when compared with other countries.

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*US$1.00 = HK$4.8.

The sale of the products is arranged in either or both of the following ways:

1. Direct transactions of the farm between the primary producers and the buyers or retailers.
2. Handled by private 'laan,'* which charge the primary producers a commission for handling the sale of their products to the buyers or retailers.

A buyer is, in fact, a middleman reselling purchased products to retailers or restaurants. The marketing procedures for pond-fish, ducks, geese and pigs are as follows:

Pond Fish

Pond fish are sold alive to consumers, except for the grey mullet which is chilled in ice. There are a number of private freshwater fish laan at Yuen Long and in a temporary wholesale market administered by the Department of Agriculture and Fisheries in Kowloon. The fish are usually transported to the laan after midnight, and kept in aerated water tanks. The sale of fish divided into smaller lots is conducted by hired personnel of the laan. Prices are negotiated based on supply and demand. In times of high demand, auction will replace negotiation. A commission of 6% of the sale value is charged by the laan for handling the sale and use of the facility.

Ducks

The duck trade is carried out through the wholesale markets on Hong Kong Island, Kowloon and Yuen Long in the New Territories and at the farm sites. In the Hong Kong and Kowloon markets, each of which accommodates a number of private laan, duck selling is conducted daily. The ducks are delivered to the laan in the early morning and are sold in lots on a weight basis. The prices initially offered by the laan management are based on those at the Yuen Long market and on the supply and demand situation; these are then negotiated. The sale commission and other service charges at these laan total 6% of the sales value (Table 2). The marketing procedures at the Yuen Long market, however, operate differently. This market only provides space for the display of ducks and the sale transactions which are handled directly between producers and buyers. The price of ducks sold here is fixed on a per duck basis rather than on a weight basis. A commission of HK$0.1 per duck sold, split up equally between both parties, is payable to the market management. The marketing dates, 'Hui Kee,' are the 2nd, 5th, 8th, 12th, 15th, 18th, 22nd, 25th and 28th days of each lunar month.

*'Laan'—a private wholesale market for negotiating the selling price of agricultural produce.

The prices of ducks sold at the farm sites, though fixed by negotiation, are based on those at the Yuen Long market and are usually HK$0.5 to HK$1.0 lower, since transportation and other charges are born by the buyers.

Table 2. The commissions and service charges for sale of ducks at laan in Hong Kong (1978).

Deduction items	Rate of charges
Laan's commission	3%
Duck buyers' commission	1%
Labor charge	HK$8.25/100 kg
Sales tax	0.5%

Geese

The locally-produced geese are not marketed through a wholesale market. They are usually ordered in advance from the primary producers by restaurants and food-stalls. The required quantity of geese will then be delivered at a specified date. The prices are fixed on a weight basis and differ according to the type of goose. Transport is arranged by the producers who pay HK$0.3 per goose as a transportation and service charge. Commission is not, however, involved in the goose trade.

Pigs

Pigs are marketed as weaners (9 to 12 kg), roasters (36 to 50 kg) and porkers (over 60 kg) through various market outlets. The first two categories are roasted and sold as roasted pork in restaurants and roasted-meat shops, while the porkers are sold as fresh meat by the porkstalls. The marketing procedures are different. Nearly all weaners and 5 and 50%, respectively, of roasters and porkers are sold at the farm sites while the remaining proportions of the various categories are handled through the laan. The prices offered at the laan are about 5% higher than sales by direct negotiation because the commission and other service charges, amounting to 5% of the total sales value, have to be deducted (Table 3).

After purchasing the pigs from the laan or pig farms, the meat merchants send them to the abattoir for slaughtering. On Hong Kong Island and at Kowloon, the government abattoirs handle the slaughtering, whereas in the New Territories, slaughtering is done at the licensed private abattoirs. The meat merchants are charged HK$8.0 per pig for day slaughtering and HK$13.0 for night slaughtering at the government abattoirs. The pigs are collected and transported immediately after slaughtering, by the meat merchants or their authorized agents. About 10% of the slaughtered pigs are delivered by the abattoir vehicles to the meat-shops, charging them HK$4.0 per pig. The former arrangement is preferred as fast delivery and fresher meat guarantee a better market and turnover.

Table 3. The commissions and service charges for sale of pigs at 'laan' in Hong Kong (1978).

Deduction items	Rate of charges
Laan's commission	2%
Pig buyers' commission	1%
Labor charge	HS$2.0/pig
Transportation charge to abattoir	0.5%
Loading charge	HS$1.2/pig

Current Research and Development Initiatives

The Agriculture and Fisheries Department is responsible for undertaking research and development work in the primary food production sector. Currently, there are research and development inputs into the fish (marine and pond-fish), chicken and pig farming industries, with the overall objective of developing them into highly efficient and profitable production systems.

On the research side, the Livestock Division continues to engage in genetic improvement of the local breeding stocks of pigs and chickens for higher growth rate and egg production, better body conformation and plumage color (Nichols 1978). The Fisheries Research Division is currently investigating methods for improving pond productivity, apart from its activities in other fields of fisheries. Projects in progress include intensive culture trials of freshwater polyculture and monoculture systems employing aeration and studies on the causes and prevention of fish kills.

On the development side, financial assistance, in the form of loan funds at low interest, is made available to the primary producers from two funds administered by the Agriculture and Fisheries Department for development and management needs. The technical and veterinary teams, whenever necessary and possible, attend to all the problems of animal husbandry and fish culture. These include advice on prophylaxis and treatment of fish diseases, livestock and poultry farming, provision of artificial insemination services and pig breeding stocks at low cost, and the monthly announcement of feedstuff prices for animal husbandry. In the inland fish culture sector, technical assistance is also provided, with free distribution of pH paper and drugs, and the loan of water pumps for pond management. In addition to the government inputs, progressive farmers of fish, livestock and poultry play a role in improving their farming techniques by modifying the traditional methods from their experience and advances made in other countries. Despite this, the more specific problems associated with the integrated systems have received attention only recently. The fertilizing effects of duck wastes and resulting fish growth and the economics of polyculture and duck-fish systems have been studied. The frequent fish mortalities occurring in integrated systems are also being studied with the aim of reducing these.

Future Trends

Because of increased land use for urbanization in Hong Kong, the suitable land available for agricultural development has decreased. Efficient use of land space for food production is therefore essential. Moreover, the rising cost of living requires high income generation to small-scale fish culturists and livestock and poultry farmers. There are, therefore, two possible development trends: 1) improving the production efficiency of the various types of animal husbandry, including fish culture and 2) promoting integrated farming systems resulting in further intensification of management. While there is continuous effort by the government and industry towards the former, the latter is hampered by a lack of understanding and more information on existing systems has to be collected. The 1979 survey suggested that the duck-fish system, already developing ahead of other integrated systems, might deserve a large development input. Other integrated systems, such as goose-fish, pig-fish and chicken-fish, may also be worthy of parallel development.

Research Needs

The assessments of the research needs for developing the integrated systems are based on the assumption of their recognition and recommendation in the national fisheries policy. The existing land development trends resulting in the reduction of agricultural land, the increasingly stringent supply of skilled labor, and rising living standards also have an impact on determining the research inputs. While research and developmment inputs continue to be required for further intensification of the various types of pure livestock and poultry farming, prime concern should be given to the development of more efficient integrated systems, such as duck-fish, pig-fish and goose-fish.

There are various major problems needing prior investigation and solution. For instance, excessive inputs of animal wastes into fishponds through the maintenance of high populations of livestock and poultry, often cause fish mortality. Dual improvements are required to optimize the scale of livestock and poultry rearing in a fish farm and to maintain a suitable aquatic environment for fish survival and growth. The former illustrates the need for a better understanding of waste production relative to species, size and age and its corresponding pollution potential for the fish ponds. The stocking density of fish and the species composition may also have to be modified to achieve the maximum benefit from integrated systems. Seasonal factors will also have to be considered. Pretreatment of wastes to reduce their biological oxygen demand, together with the application of aeration, should be investigated. This would decrease pond eutrophication and the risk of pathogen transfer.

The maintenance of integrated systems depends very much on favorable financial returns requiring low production cost and high earnings. To achieve this, the management techniques for duck, pig and goose farming will have to be improved. Feeding technology to give lower feed costs, faster growth and better yield, particularly for duck and geese, is already available in other countries, and should be systematically introduced to Hong Kong. The survival of livestock and poultry, though high, could also be improved if the farmers would recognize the importance of prophylactic measures and the need for rapid treatment in cases of disease outbreaks. Modification in farm designs and layout, to allow better efficiency in waste recycling and water utilization, would further render the investment more economically feasible.

CASE STUDIES

The duck-fish and goose-fish systems were studied in detail. As management techniques vary within both systems, a number of farmers were interviewed to obtain sufficient data from which to establish the usual practices, while also noting specific examples. Comparison of economic returns is restricted to the large farms (over 4 ha).

1. DUCK-FISH

The duck-fish system has existed for over 60 yr in Hong Kong and is practiced throughout inland fish culture areas. About 58% of the fish farms, occupying 49% of the pond area, are now integrated with duck rearing (Table 1). Both operations are usually managed by a single operator. Basically, pond management for polyculture and integrated farming systems are the same, differing only in some aspects such as stocking, manuring and feeding.

Pond Layout

Ponds vary in size from 0.13 to 6 ha and are rain-fed. They are also influenced by tidal water with salinity usually between 2 and 5 ppt. Recent ponds range in depth from 1.8 to 2.4 m and older ponds are dredged about every 3 yr to maintain this. Sluice gates are not a standard item in new ponds as they were in the past. The size of the farms surveyed ranged from 0.5 to 7 ha, with 76% under 3 ha (Table 4) and which are operated by family labor at subsistence level. Half the farms have two ponds each and nearly 30% have only one pond each (Table 5).

Table 4. The area distribution of Hong Kong fish farms in 1979.

Area (ha)	No. of farms observed	Occurrence (%)
0.1-1.0	5	13.2
1.1-1.5	8	21.1
1.6-2.0	7	18.4
2.1-2.5	3	7.9
2.6-3.0	6	15.8
3.1-3.5	1	2.6
3.6-4.0	0	0
4.1-4.5	3	7.0
over 4.5	5	13.2

Table 5. Variation of number of ponds in Hong Kong fish farms (1979).

No. of ponds	No. of farms observed	Occurrence (%)
1	11	28.9
2	19	50.0
3	4	10.5
4	4	10.5
5	0	0

Fish Species

The fish species cultured and their stocking densities in the polyculture, duck-fish and goose-fish systems are shown in Table 6. The stocking densities differ slightly with respect to the silver carp, big head, grass carp and common carp. The grey mullet, however, is stocked more heavily in February and March in the polyculture system than in the two integrated systems. On the other hand, tilapias (mixed populations of species and hybrids, such as *S. mossambicus, S. niloticus* and Fushou Yu, a hybrid of male *S. niloticus* × female *S. mossambicus)* are less densely stocked in polyculture than in the duck-fish system. This is because the ponds used for the integrated systems are the more eutrophic, favoring a higher

Table 6. Stocking density of different species in pure fish polyculture as compared with duck-fish and goose-fish integrated systems in Hong Kong (1978).

Fish Species	No. of fish/ha Polyculture Range	Average	Duck-fish Range	Average	Goose-fish Range	Average
Grey mullet	4,800-18,000	11,900	1,750-18,750	7,910	4,630	4,630
Silver carp	420-2,570	1,470	460-4,500	1,250	930-1,290	1,110
Big head	600-2,250	1,420	300-3,750	1,590	860-1,390	1,130
Grass carp	625-1,875	1,600	500-3,750	1,760	2,315-3,230	2,770
Common carp	1,500-5,450	2,800	680-6,920	3,150	2,315-2,800	2,560
Tilapias	130-10,500	3,740	1,200-35,290	12,090	-	-

density of tilapias but a lower density of grey mullet. In the past 2 yr, wild grey mullet fry have been in short supply. Its stocking density was therefore lower in 1978 than in 1976 (Sin and Cheng 1976). This was compensated for by increasing the stocking density of other species, including tilapias, to maintain the past yield rate and economic return.

Manuring

In the pure polyculture farms, heavy fertilization with cow or chicken manure is generally practiced. The respective application rates are 14,500 and 10,000 kg/ha/annum applied weekly or monthly during the growing season (March to November). In the integrated farms where the farm wastes pass directly into the ponds, additional deliberate manuring is unnecessary. At present, the number of ducks raised in a year is variable, ranging from 750 to 13,125 (average 4,640)/ha,which is higher than the 2,000 to 2,500/ha/annum recorded by Sin and Cheng (1976). This has led to summer fish kills in those farms where more than 3,000 ducks/ha/annum are kept. The continued raising of poultry throughout in the cold months results in the accumulation of wastes which create oxygen depletion in spring when the water temperature rises, often causing additional fish kills. In view of this, the optimum population of duck has to be determined to avoid oxygen depletion in fishponds, but this has not yet been accomplished in Hong Kong. In goose-fish farms, however, fish kills seldom occur at a stocking density of 4,000 to 4,500 geese/ha/annum.

Feeds and Feeding

Supplemental feeds, such as peanut cake, corn meal, rice or wheat bran, bean fragments and grass, are applied daily. It is the practice to feed cereals at the beginning of the growing season and protein-rich feeds later in the season when the standing crop in a pond is high. The average feed conversion ratios achieved in the polyculture, duck-fish and goose-fish systems were similar in 1978 (3.8:1, 4.0:1 and 3.2:1, respectively). In some well-managed farms which avoided fish kills, a better conversion rate of 1.5 to 2:1 was obtained, but in unfertilized polyculture ponds, the rate was worse at 5 to 6:1.

Harvesting

Basically, one crop per year is produced, but there are farms producing two or more crops by initially stocking fish of different sizes, followed by repeated harvesting and stocking. The silver carp, big head and grass carp attain a marketable size of 1.0 to 1.5 kg and the common carp 300 to 400 g. The minimum marketable size for grey mullet is 100 g, which is usually reached in July or August following stocking. Management is adjusted to take advantage of differential size and weight. Thus in the first half of the growing season, it is possible to use a high stocking density of grey mullet when the total biomass in the pond is low and the growth rate of other fish species is not affected, and to thin them out later for marketing in July and August. The reduction of the fish biomass in midsummer ensures that the growth of other species is not hampered. The available water volume is thus fully utilized.

The 1978 fish yield was generally unsatisfactory due to the following reasons:

1. Insufficient stocking of grey mullet because of wild fry shortage.
2. Unfavorable rain distribution for fish growth and excessive duck rearing, encouraged by a good market price and which over-fertilized ponds, resulting in frequent kills of grey mullet, silver carp and grass carp.

Harvesting is carried out from July to February or March by skilled workers using cast nets. Seining is a less commonly used method.

Duck Rearing on Fishponds

A small section of the pond is enclosed by wire netting and connects with duck sheds, each about 18 to 75 m^2 in area, either built on adjacent land or in the pond. The sheds are usually walled with wire netting floors and wooden platforms are fixed inside the enclosure as a resting place for ducks (Plate 1). A shed of 20 m^2 is capable of acommodating about 350 ducks. (average) and up to 400 (maximum). A single farm may have more than one shed, allowing production cycles to overlap.

The pond-reared ducks are of two types: the local breed and the Taiwan hybrid (male Peking Duck crossed with female Denmark duck–see Plate 2). The local breed comprises about 80% of the total stock. The ducklings are hatched artificially from fertilized eggs imported from Thailand and Taiwan. Thailand ducks were introduced from Hong Kong and are therefore still called local breed. Each Thailand duckling sells for HK$1.9. The Taiwan hybrid costs HK$3.6.

Management Methods

The number of ducks raised varies from farm to farm: 750 to 13,125/ha. These are divided into 3 to 18 batches and each batch is sold after 65 to 75 d. An optimal density appears to be 2,500 to 3,500 ducks/ha/annum, beyond which fish kills occur more frequently. Day-old ducklings are kept inside the sheds which are insulated and heated in winter.

There are three feeding stages during the rearing period. In the first stage, lasting for 2 to 3 d, the ducklings are given soaked cooked-rice two to four times per day. In the second stage, the traditional mixed feedstuffs, trash fish, sorghum, rice and other cereals have been almost totally replaced by high protein pelleted feeds (Sin and Cheng 1976). The commonly used pelleted feeds are given over two periods. 'Broiler starter' (22 to 24% protein) is fed ad libitum for 16 to 20 d. For the next 41 to 45 d, 'pig grower' (16% protein), with or without the addition of cereals or beans, is fed twice daily at a rate of 70 to 100 g/duck/feed. Alternatively, in some farms, feeds formulated for ducks are used for this second stage, e.g., 'duck starter' (18 to 20% protein) is given for 7 to 10 d, followed by 'duck grower' (16 to 17% protein) for another 48 to 50 d. A duck grows to an average weight of 1.8 to 2.0 kg in about 63 days, i.e., until the end of the second stage. It is then fattened to 2.5 to 3.0 kg, an increase of 40-50%, in the third or final stage. The final fattening mixture used consists of broiler starter, sorghum, corn fragments and broken rice in the proportion of 5:6:3:1 by weight and is fed for 13 to 15 feeds over 7 to 8 d, starting with 150 g per feed and increasing to a final 300 g. The food is blown, either by hand pump or a mild air pump through a small metallic funnel inserted into the throat of a duck. The quantities of feedstuffs required to grow 100 ducks to marketable size are shown in Table 7. The overall feed conversion

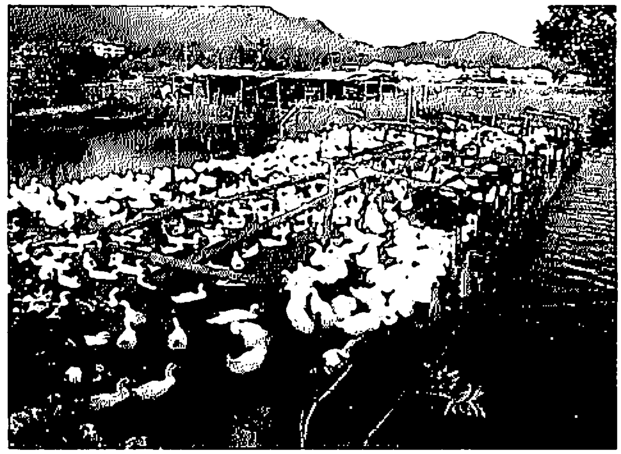

Plate 1. A duck enclosure in a Hong Kong fish pond.

Plate 2. Taiwan hybrid ducks used in duck-fish farming in Hong Kong.

Table 7. The feed quantities required for growing 100 ducks from ducklings to a marketable size of 2.7 kg per duck (1978).

Feed types	No. of days fed	Weight (kg)
Soaked cooked-rice	2	3
Broiler starter	16	110
Pig grower	45	800
Fattening cereal mixture*	7	300
Total	70	1,213

*The fattening cereal mixture consists of sorghum, 40%; corn fragment, 20%; broken rice, 7%; and 'broiler starter,' 33%.

ratio is 4 to 5:1 and survival is between 70 and 90%. The average yield of pond-reared ducks in 1978 was 9 t/ha, about 50% higher than in 1976. In some duck-fish farms, high yields of 20 to 25 t/ha were obtained, but at constant risk of fish kill. The wholesale price of ducks weighing 2.5 to 3.0 kg each averaged HK$6.5 to 8.0/kg.

2. GOOSE-FISH

The goose-fish system has been practiced in Hong Kong for over 25 yr. Land-based goose raising is also practiced in agricultural areas.

Management of Fish Culture Operation

Basically, the management techniques of pond fish culture are similar for both the duck-fish and goose-fish systems. The pond layout, species cultured, stocking density, feeds, and feeding and harvesting methods are as described above. The fish kill problem, however, is more easily overcome in the goose-fish than the duck-fish system for the following reasons:

1. Fish, such as the common carp, tilapias and grass carp, feed directly on the goose droppings, thereby reducing their accumulation.
2. The shorter production cycle and the daily and continuous marketing of geese can effectively lower the standing goose population, often reducing the likelihood of a fish kill.

Goose Production

The geese are fattened in covered wooden sheds built over the water. The shed floor is covered with wire netting supported by a wooden framework and allows passage of goose droppings into the pond. The shed, about 360 m^2 in area, is divided by a central corridor about 1.5 m wide (Plate 3). A slanting platform extends from one end of the shed into the pond water to allow the geese to enter the pond (Plate 4). Metallic drinking troughs, filled from suspended perforated water pipes, are placed on both sides of the compartments (Plate 5).

Three breeds of geese are used for fattening: the flat-head goose, yellow goose and black goose, all of which originated in the southern and eastern provinces of China. They are imported through the laan. The scale of importations varies seasonally: abundant from September to October and April to May, but scarce from July to August and January to February. The initial sizes for fattening are 2.5 to 3 kg for the flat-head and 1.8 to 2.5 kg for the yellow and black geese. Their corresponding market sizes are 3.5 to 4.5 kg and 3.0 to 3.5 kg after fattening for 17 to 20 d. Although slower growing, the yellow and black geese fetch a higher wholesale price.

Plate 3. The interior view of a goose shed in Hong Kong, showing the compartments.

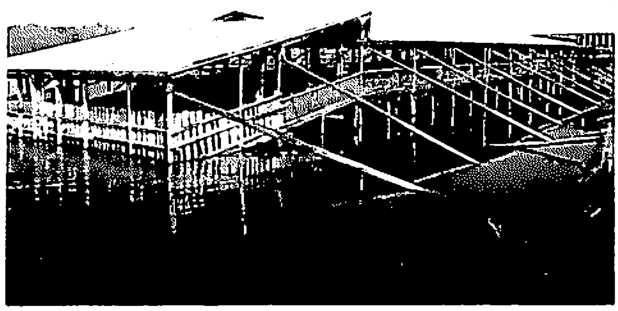

Plate 4. The slanting platform at the end of a Hong Kong goose shed allowing access to the pond.

Plate 5. Drinking water troughs for geese in Hong Kong.

Management Methods

Newly stocked geese are allowed to bathe for a few days in pond water before being transferred to fattening pens. Each pen, measuring 7 m^2, is able to hold 55 to 70 geese. For ease of marketing and handling, the pens are arranged so as to hold geese of either individual stocking batches or selected geese of similar body weight. They are treated with an antibiotic, streptomycin, for disease prevention. Feeds consisting of sorghum, wheat and broken rice mixed in the proportions of 10:15:17 by weight, and are given at a daily rate of 40 kg/100 geese. In addition, 12 kg of tender grass is fed in order to judge their health condition from their appetite. The feed conversion ratio is 7 to 8:1. Pond water is used as drinking water for the geese and for cleaning the sheds periodically. Unlike duck rearing, deliberate boost-fattening is not necessary and labor is therefore saved.

Marketing and Economics, including a Comparison of Returns from Polyculture, Duck-Fish and Goose-Fish Systems

Goose fattening is a fast turnover operation, with an annual yield of about 2.5 t/ha. The wholesale prices are HK$7.5 to 9.0/kg for flat-head and HK$10.5 to 13/kg for yellow or black geese. For marketing purposes, 12 to 13 geese are packed in one bamboo container for delivery to customers.

The economic performances of selected large polyculture, duck-fish and goose-fish farmers are compared in Table 8. Although they are not entirely representative of their respective systems, the input-output relationships can be deduced. The annual capital costs for fish culture operations are similar for all three. The polyculture system has to meet a higher running cost because of higher feed and labor requirements but

Table 8. Input-output and economic returns of the selected large pure fish polyculture, duck-fish and goose-fish farms, on a per-hectare basis, in HK$ (1978).

	Polyculture	Duck-fish		Goose-fish	
	Fish operation	Fish operation	Duck rearing	Fish operation	Goose fattening
A. Production (kg)	3,840	3,472	7,389	3,689	2,253
B. Capital cost					
1. Pond clearance	1,016	806	–	313	–
2. Construction			139		348
3. Store facilities	247	300	–	242	–
4. Equipment	830	1,127	17	1,423	130
Total	2,093	2,233	156	1,978	478
C. Running cost					
1. Rent	1,547	4,725	–	1,739	–
2. Fish fry/duckling/goose	2,813	3,229	6,454	2,546	83,612
3. Fertilizers & feeds	11,250	4,167	43,030	8,696	29,189
4. Pond/shed maintenance	565	1,806	938	2,174	761
5. Fuel & power	475	1,000	–	652	–
6. Disease control	19	–	807	100	1,043
7. Labor charge*	4,219	1,000	–	1,096	–
8. Road maintenance	375	100	–	378	–
9. Harvesting & transportation	342	130	–	141	3,424
10. Market services	2,376	2,126	–	1,826	–
Total	23,981	18,283	51,229	19,348	118,029
D. Total costs = B + C	26,074	20,516	51,385	21,326	118,507
E. Gross earnings	39,600	30,415	60,958	30,435	135,978
F. Net earnings = E – D	13,526	9,899	9,573	9,109	17,471
G. Ratio of net earnings/total costs	0.52	0.58	0.19	0.43	0.15
H. Ratio of net earnings/running costs	0.56	0.54	0.19	0.47	0.15
I. Costs/earnings (HK$/kg)					
1. Total costs	6.79	5.91	6.95	5.78	52.60
2. Gross earnings	10.31	8.76	8.25	8.25	60.35
3. Net earnings	3.52	2.85	1.30	2.47	7.75

*Charges for routine operations handled by the family labor are not included. Note: 1US$ = 4.8 HK$.

achieves better economic returns, due to its efficient maintenance of the aquatic environment which favors the growth and survival of the more expensive fish (grey mullet and grass carp). The yields per hectare in all the systems are almost the same as is illustrated by the input-output relationships. It requires HK$6.79, HK$5.91 and HK$5.78 to produce 1 kg of fish by the polyculture, duck-fish and goose-fish systems, respectively, but the sale value of 1 kg of fish is HK$10.31 when produced by the polyculture system as compared with HK$8.76 and HK$8.25 by the other two systems.

The capital costs of investing in duck and goose farming in the integrated systems are relatively low. Their running costs, though, appear high when compared with those required for the fish culture operation, but the actual cash requirements are only 20 to 30% of the stated amounts of HK$51,230 and HK$118,030/ha/annum, respectively, since they are both short-cycle operations enabling quick economic turnover. Feed and stock materials are the main items of expenditure. Feed comprises 84 and 28%, respectively, of the total running costs of the duck and goose farming operations, while stock materials account for 13 and 71%. This difference arises because geese stocks cost more than the ducklings. Neither duck or goose farming is as profitable as the fish culture operation because the net income they generate amounts to only 15 to 19% of capital invested while the fish return 43 to 58%.

The benefits gained by the integrated systems are obvious. In financial terms, the duck-fish and the goose-fish systems are capable of yielding additional income of from HK$9,600 to HK$17,500/ha by utilizing the same land more economically than with fish culture alone. From the production point of view, animal wastes are recycled for fish protein production. In addition to the total fish yield, both duck and goose production operations increase the production capability for food protein per unit area of cultivable land.

Acknowledgments

I should like to thank ICLARM for inviting me to participate in the conference and the Hon. Mr. E.H. Nichols, O.B.E., J.P., Member of the Legislative Council and Director of Agriculture and Fisheries, for permitting the publication of this paper and my attendance. I wish to express my sincere gratitude to Mr. J.M. Riddell-Swan, J.P., Deputy Director of Agriculture and Fisheries, and Mr. A.K. Murray, Assistant Director of Agriculture and Fisheries, for their encouragement, guidance and criticism during the preparation of the manuscript. I am also indebted to Dr. W.L. Chan and Mr. R.M. Chilvers for their valuable advice in this work, and Messrs. K.W. Cheng, C. Wong, K.C. Tsui, and Mrs. Y.Y. Lo, for their valuable assistance in providing relevant information and survey data.

References

Anon. 1972. Photographic pictures of duck farming. Hong Kong Farmers 5(1):29-32.

Chan, T.C. 1972. Cholera disease in ducks. Hong Kong Farmers 5(1):7-9. (In Chinese).

Lau, S.K. 1972. The basic requirements of duck farming in Hong Kong. Hong Kong Farmers 5(1):4-6. (In Chinese).

Lau, S.K. 1973. Feeding and management of duck farming. Hong Kong Farmers 5(4):22-23. (In Chinese).

Lin S.Y. 1940. Fish culture in ponds in the New Territories of Hong Kong. J. Hong Kong Fish Res. Sta. 1(1):161-193.

Lo, R. 1970. A study of the nutritional effects of duck droppings on pond fish in the New Territories. B.Sc. Thesis. Hong Kong Baptist College MS. 17 p.

Mui, K.H. 1969. Feeding and management of duck farming. Hong Kong Farmers 2(2):21-27. (In Chinese).

Nichols, E.H. 1978. The Annual Report of the Agriculture and Fisheries Department for the financial year 1977-78. Government Printer, Hong Kong. 71 p.

Sin, A.W. and K.W.J. Cheng. 1976. Management systems of inland fish culture in Hong Kong. Indo-Pacific Fisheries Council, 17th Session. Symposium on the development and utilization of inland fishery resources. Colombo, Sri Lanka, 27-29 October 1976. IPFC/76/SYM/51. 9 p.

Wong, Y.C. 1969. The duck diseases in the New Territories of Hong Kong. Hong Kong Farmers 2(3):9-12. (In Chinese).

Wong, U.C. 1972a. The viral hepatic diseases in ducklings. Hong Kong Farmers 5(1):10-12. (In Chinese).

Wong, Y.C. 1972b. The Newcastle disease in ducks. Hong Kong Farmers 5(1):13-14. (In Chinese).

Utilization of Piggery Wastes in Fish Ponds

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Abstract

The biological basis of pig waste utilization in fish ponds is discussed with special reference to waste composition and degradation. Waste loading of ponds and waste delivery techniques are compared. The total manure loading per ha of pond surface is identified as between 40 to 80 pigs/ha in Hungary. Stocking densities for common carp and Chinese carps in manured ponds in Hungary are also discussed and are summarized as follows: first year, 60,000 fingerlings (20 to 30 g ea.)/ha; second year, 20,000 common carp with 4,000 to 8,000 Chinese carp advanced fingerlings/ha, yielding 2.5 to 2.7 t/ha with supplemental feeding; third year, 2,000 common carp and 600 to 800 silver carp/ha, yielding 2.5 t/ha of fish exceeding 1 kg individual weight.

Biological Basis of Waste Utilization in Fish Ponds

The basic requirements of the primary production of organic matter in aquatic ecosystems are suitable temperature, light energy, green plants and the inorganic nutrients necessary for photosynthesis. If these requirements are met, living organic matter will be produced by photosynthesis. The most important primary producers in the water column are the phytoplankton. Their small size and area-to-body volume ratio facilitate photosynthesis as light energy and nutrient intake occur across the body surface, but they are unable to accumulate large quantities of produced organic matter and propagate instead. The percentage composition of biological material is given in Table 1.

The nutrients and materials necessary for photosynthesis are water, carbon (C) compounds (both inorganic and simple organic), nitrogen (N) compounds and phosphorous (P) compounds.

Water itself is limiting only in terrestrial ecosystems where the CO_2 content of the air is stable and therefore also nonlimiting. In aquatic ecosystems, however, carbon compounds may be a limiting factor in photosynthesis. Photosynthesis can be greatly increased by regular provision of suitable C compounds. This emphasizes their importance, without denying the importance of P and N compounds.

The composition of a very common alga, *Chlorella*, is given in Table 2. This illustrates the importance of various elements in the production of phytoplankton. Practical experiments have shown that photosynthesis is accelerated most significantly by fertilizing with fresh wastes which have the highest C content.

Organic wastes, such as animal manure, when suitably introduced to a fish pond, are decomposed by bacteria and their nutrients utilized by algae in photosynthesis, provided that the other requirements for this process are met. It is important that the waste reaches the water column in a dissolved and/or dispersed form during daylight hours, when photosynthesis is possible. Otherwise, the decomposition processes will consume the oxygen in the water and endanger the life of the fish and other higher aquatic organisms. Because oxygen is a product of photosynthesis, however, the oxygen balance will not be seriously disturbed if the wastes are introduced into the water column in daylight (preferably between 0700 and

1200 hr) and overloading with decomposable materials is avoided.

Characteristics and Chemical Composition of Piggery Wastes

Piggery wastes contain two mixed components: solids and liquids. In small piggeries where the wastes are collected manually, or in those where the wastes are washed immediately into the fish pond, both components are utilized. In large commercial piggeries, however, where the wastes pass through a drainage system and collect in a sedimentation basin, the solid component remains in the basin and the liquid can be utilized for pond fertilization. This includes part of the feces, urine and the washing water of the piggery platforms. Since the sedimentation of the waste is always incomplete, the liquid component also contains small, floating and colloidal particles, besides the soluble materials from the feces and urine. This can be termed "concentrated sewage."

The average waste production per pig in Hungary is given in Table 3.

These data are only approximate because waste output depends on the quality and quantity of the food and drinking water, and the feeding and watering procedures, etc. The chemical composition of some total wastes from pigs of different ages is given in Table 4, and the composition of wastes from commercial piggeries, in Table 5.

Table 1. Approximate percentage composition of biological materials.

Element	Protein	Fats	Carbohydrates
C (carbon)	55 to 56	79	44
H (hydrogen)	6.5 to 7.5	11	6
O (oxygen)	21 to 24	10	50
N (nitrogen)	15 to 18	–	–
S (sulphur)	2.4 to 0.3	–	–
P (phosphorus) >	1		

Table 2. Composition by weight of the common phytoplanktonic alga, *Chlorella* (Elster, pers. comm.: Limnological Institute of Freiburg University).

Carbon (C)	100	parts
Nitrogen (N)	15	parts
Phosphorus (P)	5	parts
Magnesium (Mg)	2.8	parts
Potassium (K)	1.8	parts
Sulphur (S)	1.6	parts
Iron (Fe)		traces

Waste Loading in Fish Ponds

The critical question is how much pig waste can be utilized as fertilizer per unit area of fish pond without running the risk of a fish kill from oxygen depletion. Practice has shown that the usable quantities of pig, or other animal, wastes in fish ponds depend on the waste delivery and distribution methods employed. For example, in Hungary, where the fish growing season is 150 to 180 d/yr, 1,500-2,000 kg/ha/yr can be used when pig manure is placed in the pond in localized heaps. When the carbon manuring technique is applied, however, it is possible to distribute 300-600 kg/ha/d of manure, 1,000-1,500 kg/ha/d of the thick liquid phase of the manure, or 1.2-2.5 m^3/ha/d of commercial piggery sewage, over the pond surface.

The maximum possible waste loading in fish ponds has not yet been determined experimentally. Theoretical calculations can show, however, that the quantity of waste that can be processed per unit area of fish pond, without the risk of oxygen defiency, can be two to three times more than the quantities indicated above. This can only be verified through well-controlled experiments. As one fattening pig produces an average 7.0-7.5 kg of manure per day, the total manure output of 40 to 80 pigs can be distributed over one hectare of pond surface on a daily basis.

Piggery Waste Delivery Techniques

The above considerations show that the wastes must be mixed with air when delivered to the pond surface, to promote quick decomposition, and widely distributed over the pond surface to avoid localized overloading. It is, however, unnecessary and impractical to attempt to distribute the wastes "evenly" over the whole pond surface. The wastes should be distributed in the morning (from 0700 to 1200 hr) to allow enough time for decomposition and oxygen replacement by photosynthesis. Phytoplankton filter-feeding fish should be stocked to crop the phytoplankton and avoid auto-

Table 3. Output of feces and urine from various types of pig in Hungary (I. Csávás, pers. comm.).

Pig type	Age	Feces (kg/d)	Urine (l/d)	Total (kg/d)
Piglet	30 to 60 d	0.9 to 1.4	1.6 to 2.0	2.5 to 3.4
Fattening	60 to 220 d	3.0 to 3.4	3.5 to 4.0	6.5 to 7.4
Young pig	average 1 yr	4.0 to 6.0	4.5 to 6.5	8.5 to 12.5
Sow	average 1 yr	7.5 to 8.5	8.0 to 9.0	15.5 to 17.5
Boar	average 1 yr	7.0 to 8.0	7.0 to 8.5	14.0 to 16.5

Table 4. The chemical composition (%) and pH of total wastes from pigs of different ages, see also Table 3 (I. Csávás, pers. comm.).

Component	Pig type		
	Piglet	Fattening	Sow
Dry matter	6.50	6.62	7.95
Organic matter	2.98	3.34	4.76
Total carbon	2.72	3.35	4.00
Total nitrogen	0.40	0.57	0.68
Ammonia N	0.24	0.27	0.24
P_2O_5	0.10	0.12	0.10
K_2O	0.36	0.37	0.17
CaO	0.11	0.20	0.20
Na_2O	0.03	0.05	0.04
pH	6.6	6.8	6.7

shading. If the pond tends to become overgrown with water weeds, herbivorous fish, such as the grass carp *(Ctenopharyngodon idella)*, should also be stocked in adequate numbers.

Construction of the pigsty on the pond bank, so that the wastes are washed in or fall directly into the water, ensures continuous delivery of manure. The distribution of the organic matter throughout the water column can, however, be a problem. In small ponds (less than 0.5 ha), wind action and water currents provide acceptable mixing, provided that the sty is suitably placed by the pond to facilitate manure distribution. This method of delivery is inadequate, however, in bigger ponds receiving wastes from 20 to 30 pigs or more, where the concentration of the manure near the sty will be too high for adequate mixing by wind action alone, and water fouling will occur near the sty. The same may happen if an excessive amount of solid manure is delivered to the pond bottom, or when liquid manure (which is heavier than the pond water) is drained directly into the pond without adequate dilution and/or mixing.

To meet the requirements of proper waste delivery—the proper dilution and dispersion of organic matter—a manuring boat with an outboard motor can be used. The manure is shovelled into a grading "basket" of parallel iron rods (2.0-2.5 cm apart) suspended 10-20 cm below the water line of the boat. As the boat moves forward, the water current and the turbulence generated wash out, dilute and disperse the manure over a strip of the pond surface. Another method utilizes a pump built into the boat's hull. The manure is shovelled into a hopper where it is diluted with pumped water and sprayed out into the pond through a hose equipped with an end plate which spreads out the "sewage" mixture. In small ponds where the use of machines is not practical, the manure can be diluted and distributed by hand from the shore or from a small boat.

Table 5. The composition, pH and conductivity of wastes from commercial piggeries in mg/l (wet wastes) and mg/kg (solid wastes) (I. Csávás, pers. comm.).

Component	Solid wastes (average)	Liquid wastes* minimum	Liquid wastes* maximum	Liquid phase
O_2 consumption	32,087	8,558	90,900	8,858
BOD_5	15,389	4,000	41,324	5,444
Sulphur	38	14	85	37
Total N	2,612	824	8,302	1,139
NH_4	1,421	260	6,150	543
PO_4 (water soluble)	1,038	300	1,840	432
P_2O_5 (water soluble)	776	224	1,375	323
Total P_2O_5	1,268	687	2,555	514
Total K_2O	2,345	720	6,300	1,233
Dry matter	38,367	12,600	113,310	11,171
Organic matter	31,240	8,520	97,060	7,984
Floating matter	31,923	8,810	98,090	7,418
Total dissolved material	6,444	2,896	16,095	3,752
Dissolved materials	2,873	950	6,070	1,863
pH	7.9	7.2	9.0	7.6
Conductivity	10,562	4,624	26,673	5,944

*1 part waste: 1 part water

The liquid phase of large quantities of commercial piggery waste can be transported to the ponds by a pipeline, similar to that used for overhead irrigation, and distributed over the pond surface by sprinklers placed 100-150 m apart. One sprinkler delivers about 200 l of sewage per minute. The sprinkler head should stand 0.5-1.0 m above the pond surface. The sewage is thus mixed with air and well distributed. The sprinkler system should be constructed such that pond water can also be sprinkled over the surface during times of oxygen deficiency, e.g., late at night.

Fish Stocking Rates and Species Composition

Common carp *(Cyprinus carpio)* is the main species cultivated in Hungary. Duck-fish farming and the utilization of pig manure in fish ponds started in the 1950s, when only common carp was stocked. At that time, a disagreeable side effect of heavy manuring was often experienced: blooms of *Aphanisomenon flosaquae* and other blue-green algae, which caused the disappearance of *Daphnia* species. These algae clog the filtering mechanism of *Daphnia* and kill them. When blooms occurred, manuring was suspended. Besides this problem, common carp cannot utilize the increased plankton directly, especially the phytoplankton, and fish yields attributed directly to manure application were considerably lower in carp monoculture ponds than in ponds stocked with plankton filter-feeding fish. Since the 1970s, the Chinese carps have been stocked in greater numbers together with common carp. Silver carp *(Hypophthalmichthys molitrix)* and, to a much lesser extent, bighead carp *(Aristichthys nobilis)* are the best suited cultured species to utilize the phytoplankton blooms resulting from waste enrichment and to control plankton populations. These species have fine filtering apparatus which strain plankton down to 20 μm in the course of normal gill ventilation. In warm water (above 22°C) the ventilation rate is faster and a greater quantity of plankton is filtered per unit time. *Sarotherodon galileus* and other cichlids cannot match these carps, according to my own observations. Grass carp is sometimes also stocked in limited numbers for the control and utilization of filamentous algae and submerged plants.

The composition of the fish stock will depend on several factors: the desired size of the fish at harvest; the initial weight of the stocked fish; the length of the growing season; the average water temperature, and the fish-carrying capacity and quality of the pond.

In Hungary, to raise advanced fingerlings of 20-30 g each, 60,000 early fingerlings of common and Chinese carps are first stocked per hectare, achieving a yield of 15-18 t/ha/yr.

In the second year, 20,000 common carp and 4,000 to 8,000 Chinese carps (silver carp, 90%; bighead, 10%) advanced fingerlings are stocked per hectare, achieving average individual weights of 250-300 g and a net yield of 2.5-2.7 t/ha (with supplemental feeding).

For market fish of over 1 kg (third year), 2,000 common carp and 600 to 800 silver carp are stocked, and 2.5 t are cropped per hectare. The supplemental food given is 2.0-2.2 kg grain for each kilogram of common carp. Thus, by including silver carp at a higher stocking rate, the yield can be increased and the feed decreased considerably.

Economic Aspects of the Piggery Waste Utilization

Piggery waste utilization in fish ponds, provided the conditions mentioned above are met, is bound to be economically profitable. In common carp monoculture, a yield increment of 2.5-3.0 kg can be obtained from 100-kg manure and, in well designed polyculture systems, yield increments of 3.5-4.0 kg can be realized, with common carp as the main species, and 6.0 kg, where silver carp is the main species and common carp a secondary species, from the same amount of manure.

In Hungary, one fish farm (254 ha pond surface area), which utilizes pig wastes, regularly produces an average of 2.0-2.3 t of fish per hectare per year. The gross income of this farm is 13.5 million forints* and the net profit 3.3 million forints. One person in the farm is concerned with fish production, which is valued at 520,000 forints, of which 127,000 forints is net profit. In this farm, 21 t of pig manure is distributed daily to the ponds which corresponds to the daily manure output of 2,000 pigs. It is evident also that the ponds could utilize more manure.

In the tropics and subtropics, where biological processes are faster due to the higher temperature, more pig manure can be utilized in fish ponds provided that 5,000 to 7,000 or more fish (20-30 g each), made up mainly of filter-feeding species, are stocked per hectare.

*US$1.00 = 20 forints.

Bibliography

Buck, D.H., R.J. Baur and C.R. Rose. 1979. Experiments in recycling swine manure in fish ponds, p. 489-492. *In* T.V.R. Pillay and W. A. Dill (eds.) Advances in aquaculture. Fishing News Books Ltd., Farnham, Surrey, England.

Maucha, R. 1924. Upon the influence of temperature and intensity of the light on the photosynthetic production of nannoplankton. Verhandl. Int. Ver. Limnol. 2:381-401.

Maucha, R. 1927. Zur Theorie der Assimilations und Dissimilations–Prozesses der Phytoplanctones [To the theory of the assimilation and dissimilation of the phytoplankton]. Int. Rev. ges. Hydrobiol. Hydrogr., 17: 239-248. (In German).

Maucha, R. 1952. Kölcsönhatasok a vizek anyagforgalmában [Interactions in the material turnover of the waters]. Magy. Tudom. Akad. Biol. Ostály Közl., Budapest p. 17-26 (in Hungarian.)

Woynarovich, E. 1956a. Das Carbondüngung Verfahren [The techniques of carbon-manuring]. Deut. Fischereiztg., 3: 48-52. (In German).

Woynarovich, E. 1956b. A halastavak szervestrágyázásának jelentösége [Importance of the manuring of fish ponds with organic manures]. Magy. Tudom. Akad. Agrar. Osztály Közl. 10: 308-319 (in Hungarian).

Woynarovich, E. 1956c. Versuchsergebnisse der Düngung von Fischteichen mit organischen Düngemitteln in Ungarn [Results of the manuring of fish ponds with organic manures in Hungary]. Deut. Fischereiztg. 3: 17-19. (In German).

Woynarovich, E. 1979. The feasibility of combining animal husbandry with fish farming, with special reference to duck and pig production, p. 203-208. *In* T.V.R. Pillay and Wm. A. Dill (eds.) Advances in aquaculture. Fishing News Books Ltd., Farnham, Surrey, England.

Raising Ducks on Fish Ponds

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Abstract

The history of duck-fish farming in Europe and Asia is reviewed and the quantitative aspects of duck manuring on carp culture in Hungary are described in detail. The rate of manuring is 300 to 500 ducks/ha in the summer season and 500 ducks can increase common carp production by 140 to 175 kg/ha. In contrast about 1,500 ducks/ha are recommended for the tropics and subtropics. Polyculture systems using Chinese carps are also discussed. Duck production and management techniques in Hungary are described in detail.

Introduction

Raising ducks on fish ponds on a small scale is an old practice in Europe and Asia, especially in China, but the interrelationships between ducks and fish and the commercial possibilities of such systems have only recently been evaluated. The first scientific experiments on duck-fish farming were made by Probst in Germany in 1934, but because of World War II the results remained unutilized. After the War, when there was a serious protein shortage in European countries, large-scale experiments were initiated in Hungary (1952), Czechoslovakia (1953) and East Germany (1955) to determine optimal husbandry methods for raising ducks on fish ponds in the climatic conditions of Central Europe. Studies were also made to define the interrelationships of ducks and fish.

Originally, duck raising on fish ponds was a semi-intensive practice raising hardy strains of Peking and local ducks, with low dietary protein demands, for meat production. Some Western European countries, however, developed another intensive duck raising system in pens and runs with fast growing duck strains and hybrids for meat production. These utilized feed more efficiently but required higher dietary protein levels and did not perform well on ponds. As these strains have spread over East Europe, duck-fish farming has declined. It has been demonstrated, however, that they can be raised successfully on ponds when enclosures are provided to prevent them from roaming freely on the whole pond surface. This reduces their manuring effect but their presence is still highly beneficial for fish culture.

The combined culture of ducks and fish can be justified economically if they are mutually beneficial and/or the profitability of the integrated system increases significantly. The first benefit of the combined culture of fish and ducks is that considerably more animal protein can be raised on the same area and, therefore, the rather high construction cost of fish ponds can be recovered earlier. Morever, the ducks benefit from the pond and fish growth is accelerated by the duck manure which provides a continuous supply of organic matter containing carbon (C), nitrogen (N) and phosphorous (P) sources. These boost biological production in the water column and increase the natural food supply for the stocked fish.

The manuring effect of ducks is highest when their resting and feeding places are fixed over the pond surface, but this brings high labor requirements for the daily distribution of feed. Therefore, resting and feeding places are often provided on flat areas of the pond shore, to allow easy access for vehicles.

If the ducks are of a suitable strain and are habituated to roam over the whole pond surface, approximately 50 to 60% of their manure will fall into the pond. They seek natural food in the pond and consume a wide variety of organisms, e.g., tadpoles, frogs, insects, insect larvae, snails and water weeds, some of which are harmful. The pond provides the ducks with a healthy environment.

Barrage type ponds made by damming shallow valleys are the most suitable for duck raising as the ducks are habituated to rest on the natural slopes of the pond. In fish ponds, with earth dikes on all sides, however, ducks can damage the dikes when searching in the soil for food and frequent repairs are needed.

Duck-fish farming developed in Europe at a time when common carp *(Cyprinus carpio)* monoculture was the only type of fish culture, and problems were experienced due to the excessive provision of nutrients from duck manure. Blooms of blue-green algae, oxygen depletion and ammonia accumulation were common consequences of rearing ducks on ponds. In spite of these problems, the practice flourished because of the high demand for animal protein and its high profitability. It was evident, however, that the common carp alone was not able to exploit all the natural food resources developed in the pond.

Quantitative Aspects of the Effects of Duck Manure on the Fish Production Potential of Ponds

In Europe, 300 to 500 ducks can be raised on 1 ha of water during one summer season. Each duck produces about 7 kg fresh manure over a 36-day period and 500 ducks therefore produce about 3.0 to 3.5 t in the same period. The manure contains 57% water and 26% organic matter and 100 kg contains about 10 kg carbon, 1.4 kg P_2O5, 1 kg N, 0.6 kg potash (K_2O), 1.8 kg calcium and 2.8 kg of other materials.

It was estimated that 100 kg of duck manure distributed continuously in the pond water increased common carp production in monoculture by an average of 4 to 5 kg/ha. This means that 500 ducks can increase common carp production by 140 to 175 kg/ha. There is also in Europe an indirect yield increase of about 50 kg/ha from higher carp stocking, as this allows recycling of the fish feces and full utilization of any remnants of the duck feed.

Proper utilization of the duck manure is essential and if possible, it should all reach the pond water in fresh condition. Screened resting places of the ducks should therefore be provided over the water and the ducks trained to range freely. If the resting places are on the shore or on earthen islets, then the manure will either not reach the pond or will be left until washed down by rains.

The composition of the fish population and the stocking density determine the fish yield. Phytoplankton and zooplankton production increases significantly in the pond due to the duck manure and, therefore, the fish chosen should be able to crop this food: e.g., a phytoplankton feeder, like the silver carp *(Hypophthalmichthys molitrix)*, and a zooplankton strainer, like the bighead carp *(Aristichthys nobilis)*. The natural food of the common carp (a bottom feeder) is increased mostly in an indirect way: the high plankton population increases the organic matter content of the pond bottom which in turn increases the benthic animal production. In tropical countries, a bottom feeder or scavenger would insure the full exploitation of the natural food resources in the pond.

FISH STOCKING DENSITY AND SPECIES COMPOSITION

In Europe, raising fish to market size takes three summers. Carps reach 20 to 50 g in the first summer. During the second summer, they grow in relatively dense polyculture (10,000 fish/ha) to 250 to 300 g and finally attain the 1.0 to 1.5 kg market weight at the end of the third summer. The stocking rate for the third year is 1,000 silver carp, 200 to 300 bighead carp and 1,500 common carp/ha. The common carp are fed with grain, adding about 2 kg supplemental grain feed to produce 1 kg of carp (part of this growth is from natural food). The feed is distributed over 100 to 120 feeding days.

In Hungary, a fish yield per hectare of 500 to 600 kg silver carp, 150 to 200 kg bighead carp and 1,000 to 1,200 kg common carp of market fish can be achieved. Only about 500 kg of the weight of common carp is derived from the supplemental feed and the balance of production results from the natural food resources of the pond. About 1,000 to 1,200 kg of ducks (2.0 to 2.4 kg each) are produced simultaneously.

Common carp is still the major species cultured in Europe due to market demand and climate (silver carp and bighead carp require higher temperatures). If the number of silver and bighead carp is increased to 2,000 to 2,500/ha, however, and the common carp decreased to 300 to 500/ha, the utilization of the duck manure will be higher and a fish yield of 2 t/ha can be achieved without supplemental feeding.

The density of fish and ducks can also be considerably increased in the tropics and subtropics. Here biological processes and the production of living organic matter are faster, fish feeding activity is higher and the exploitation of the natural food is more efficient than in temperate climates. The fish species mentioned above can therefore reach market size in one year.

Duck Production and Management

COMMERCIAL SCALE DUCK PRODUCTION

The requirements for this type of duck production on fish ponds are reliable sources of day-old or 10- to 14-d-old ducklings of good meat production strains, access to suitable ponds for keeping and raising the ducklings, reliable sources of suitable feed, suitable methods for demand feeding, and a good market for the ducks. These requirements will be considered in turn.

RELIABLE SOURCES OF DUCKLINGS

Duck rearing encountered great difficulties in the past before a reliable supply of ducklings was insured. Because the quality and ready availability of ducklings is critical, the larger farms have solved this problem by establishing their own breeding centers for suitable strains. Day-old ducklings and 10- to 14-d-old ducklings are also marketable and most of the breeding centers sell them as well.

Space does not permit a full description of the organization and management of a representative duck breeding center but some basic information is presented here.

The minimum number of breeders should be about 1,000 to 2,000 ducks of 1 to 2 yr of age, with a sex ratio of 1 male to 4 to 6 females. The breeders lay eggs up to 4 yr of age, but with decreasing returns. The breeding stock is usually selected after the first egg-laying season. Sexual maturity is achieved at 5 mo and egg-laying commences at 6 to 7 mo. A suitable protein-rich feed (20% protein), drinking water and proper illumination are mandatory. The daily feed ration is about 9 to 10% of the body weight (240 to 300 g/d). About 120 to 140 eggs per female per year are produced. The normal egg weighs 80 to 90 g and is 8 cm long and 5 cm wide. The incubation time is 28 d. The survival rate from incubation to day-old ducklings is 75%. Losses during the nursing (10 to 14 d) and rearing periods are 3% and 2 to 3%, respectively.

Day-old ducklings require special care and a controlled environment with respect to temperature, feed, drinking water, light, space, etc., up to an age of 10 to 14 d, after which they can be stocked on the ponds. During the first week, about 50 to 55 ducklings per square meters are kept in a heated room on a screen floor (0.2 cm wire; mesh size, 1.5 cm) to allow manure to fall through. The pelleted starter feed is offered in simple demand feeders and clean tepid water is provided in troughs, which permit access only to the beak to prevent the ducklings from becoming wet. The air temperature must be about 30 to 32°C. After the third to fourth day, the ducklings are released into a small yard where shallow splashing pools are provided to accustom them to contact with water. They are released into the yard only in fine sunny weather. Special care should be taken in the design of feeding stations to prevent adhesion of feed to the heads and backs of ducklings. Ducklings tend to peck such feed remnants off one another and remove fluff in the process.

During the second week, the ducklings are placed on a small conditioning pond where they can swim freely. A protecting roof is provided against bad weather. Food is offered in demand feeders. In early spring, the ducklings remain on this pond longer: up to age 18 to 20 d.

KEEPING THE DUCKS ON SUITABLE PONDS

In summertime, 14-d-old, water-habituated ducklings are ready to be released to the ponds. Demand feeders are placed on artificial islets, screen platforms or on shore adjacent to the resting places.

In earlier commercial duck-fish farming practice, the ducks were allowed to roam freely on large ponds, distributing their manure uniformly over the whole pond area while foraging for natural food. Today, however, some of the highly improved meat production strains are less inclined to range over the pond and are normally retained in a confined space to insure efficient utilization of expensive nutritionally-balanced artificial feed. Here, wire enclosures are provided for the ducks in the fish pond (called "water runs"), with suitable resting and feeding places on the shore or over the water. The enclosures keep the ducks in but allow the fish to enter the "water runs." Wave action carries the well-manured water out of the "water runs." About 0.5 to 1.0 m^2 of enclosed dry run and 2 to 4 m^2 of "water run" is allowed per duck.

Many experts are of the opinion that duck raising in screened enclosures in fish ponds has many advantages and that the effects of the duck manure on fish production are nearly the same as when the ducks range freely over the whole pond surface.

DUCK FEED

Duck feed contains only 14 to 15% protein on the assumption that outstanding protein requirements will be derived from natural food in ponds.

The present meat production strains are very fast growing. At age 48 to 52 d, they reach 2.3 to 2.8 kg and are marketable. Slower growing strains reach market size (2 to 2.4 kg) within 55 to 65 d.

The ducks are fed using demand feeders. Table 1 gives the general composition of feeds for the different stages of duck rearing and Table 2 the feed formulations used in Szarvas, Hungary. The most important ingredients are maize, wheat, barley, cereal bran, soybean flour, oil seed cakes (except mustard and peanut oil cake), yeast, fishmeal, meat meal, animal fat or similar product. The crude fiber content should not exceed 6 to 7%; otherwise, feed digestibility will be decreased.

The feeds are prepared in pelleted form because this reduces feed loss. The pellet size is 3 mm for starter feed and 5 to 6 mm for the other types of feed.

MARKET SIZE

In commercial duck raising, the ducks are usually removed from the ponds and marketed at an age of 48 to 50 d, with an individual weight of 2.2 to 2.6 kg. If kept for longer on the ponds, they usually start to moult and the efficiency of feed utilization decreases, with attendant losses in weight and market value. The ducks are transported to processing plants where all the processing wastes (feathers, blood and viscera) are utilized and the meat is marketed in an oven-ready (mostly frozen) form.

SMALL-SCALE DUCK RAISING ON FISH PONDS

Farmers, communities and cooperatives with access to small ponds can also capitalize on the benefits of integrated duck-fish farming, particularly in rural areas. The main difficulties associated with small-scale ventures are procurement of ducklings, safeguarding the ducks during the rearing period, and adequate feeding to obtain good growth and marketing. These difficulties will be considered in turn.

PROCUREMENT OF DUCKLINGS

When only a few ducklings are needed, these are obtained as in the past from local village stocks. This denies access to good growing improved strains, however, and where the demand exceeds 50 to 100 ducklings, a supply problem is encountered.

To overcome this difficulty, it is advisable to establish duck breeding and distributing centers. Cooperation between the center and growers is mandatory and the price of the ducklings should permit a suitable profit margin for the growers. One possibility is for the government to subsidize the price of ducklings, at least initially, to encourage duck-fish farmers.

SAFEGUARDING THE DUCKS

The nursing of young ducks for the first 10 days in a small-scale enterprise presents few difficulties, especially when the operators have poultry raising experience and when proper nursing practices are observed. To avoid difficulties, nursery practices and the installations required can be taught in short practical training courses.

The ducks have to be habituated to the pond life gradually and protected from predators. They are usually kept indoors during the night when feed, ample drinking water and illumination (if possible) should be provided; otherwise, growth will slow down.

FOOD AND FEEDING

The feed mixtures available for poultry are also usable for duck raising although the efficiency of utilization is lower. This reduces profitability. Homemade feed

Table 1. The general composition of different types of duck feed. (L. Balogh, pers. comm.: from a pamphlet issued to Hungarian state farms).

Components (values in %)	Type of feed			
	Starter	Rearing	Fattening	Layers
Dry matter	86	86	86	86
Carbohydrates	68	68	69	67
Digestible protein	18.0	15.0	11.5	16-18
Crude protein	20.5	18.0	14.0	19-20
Calcium carbonate (powdered limestone)	3	3	3	4.5
Calcium phosphate	0.8	0.7	0.7	1.6
Vitamin premix	0.5	0.5	0.5	0.5
Mineral premix	0.5	0.5	0.5	0.5

mixtures with less protein, including chopped lucerne, clover, nettles or other suitable tender fresh plants, mixed with cereal bran or crushed grain, may help to lessen the feed problem. Although duck growth is slower on such feed and its preparation is labor-intensive, small-scale duck-fish farming using homemade feed can still be a profitable enterprise. The cost of high protein feeds can account for 60 to 65% or more of production costs. The low cost of homemade feed mixtures reduces production costs and improves profitability.

MARKETING

The advantage of commercial scale duck farming is that marketable ducks are transported to the processing plant in bulk and the grower has no special marketing problems. The ducks are not kept on the pond for even 1 d more than is necessary. This conserves feed and increases profitability.

Small scale duck rearing suffers from marketing uncertainties, but these can be mitigated by good organization, including the establishment of processing plants and the provision of transportation to distant markets. Cooperation among interested farmers would be of great help in establishing the necessary infrastructure.

FISH AND DUCK YIELDS

In Central Europe, where the fish growing season is only 150 d, the highest annual fish yield attainable in well-manured ponds is about 2 t/ha. This can be at least doubled in subtropical and tropical countries due to the year-round growing season: assuming a year-round supply of manure and suitable pond management.

As stated earlier, filter-feeding fish are best able to capitalize on the beneficial effects of duck manure. Scavengers and bottom feeders, such as the mud carp *(Cirrhina molitorella)*, rohu *(Labeo rohita)* or common carp, also benefit from duck rearing on ponds. The number of ducks raised per hectare of pond is about 500 in Europe, compared to 1,500 in the tropics and subtropics. The highest fish yields are achieved by using suitable fish species stocked at optimum numbers and by continuous harvest of marketable fish and their replacement by young stock. Monoculture may fail to give acceptable yields.

Ducks should be left on ponds only until they reach market size. The duck stock should be replaced as soon as possible. It is desirable to have four to six duck production cycles per year. The expected yield per hectare from duck-fish farming is about 4 t of fish and 2.0 to 2.5 t of ducks. It is anticipated, however, that these yields can be exceeded with better management and utilization of available resources.

Table 2. Ingredients used for various duck feed formulations in Szarvas, Hungary.

	Percentage composition of various feeds		
Ingredient	Starter Feed	Rearing Feed	Layer Feed
Maize	20	20	20
Wheat	57.9	53.9	40.9
Fishmeal (64% crude protein)	10	2	2.5
Soya grit (47% crude protein)	8	9.8	12.3
Meat meal (50% crude protein)	0.9	4	5.7
Wheat bran	2.5	8.7	5
Food lime	–	0.3	5.3
Methionine premix (5% active ingredient)	–	0.5	0.5
Salt	0.2	0.3	0.2
Vitamin premix	0.5	0.5	0.5
Mineral premix	–	–	2.5
Wheat germ	–	–	1.5
Milled sunflower seed cake (oil extracted)	–	–	3.1
	100	100	100

General Management of Duck-Fish Farms

The main production component in integrated duck-fish farms is the fish and, therefore, the farm manager is a fish culture expert. Because ducks need special care, however, a duck-rearing technician is also engaged to attend to guarding, feeding and growing the ducks.

The farm manager is responsible for all fish culture operations. He also decides the stocking density and timetable of the duck raising and oversees all other aspects of duck farming.

If the farm maintains a duck breeding center, there is also need for a duck expert to manage the selection of the breeders, feeding, egg production and all activities concerning the breeding stock. He is responsible for the hatchery house, which is run by a technician. The duck expert is also responsible for the duck nursery and his responsibility is to hand over to the fish culture expert healthy, well-fed, well-habituated 10- to 14-d-old ducklings for stocking on the ponds. The market value of these ducklings is determined for bookkeeping purposes and calculation of production costs.

It is desirable, as well, that the runs and pens of the breeding stock be located on the side of a pond so that most of their manure can reach the water. A part of the pond can be fenced off for these ducks or their manure can be collected and distributed to the ponds after being dissolved and dispersed in water.

The manager is responsible for the purchase of feed ingredients or readymade duck feed. The composition of the duck feed is decided by an expert because the cost of feed is 60 to 65% of the total production costs and profitability is highly dependent on the price of feed and efficiency of feed utilization.

The manager is responsible for marketing in general, but the actual harvesting, weighing, packing in boxes and transportation of ducks to the processing plant is the responsibility of the technician. In Hungary, a contract is arranged with the processing plant for the collection and transportation of marketable ducks from the farm.

Economic Aspects

Since capital investment and production costs vary widely from country to country, it is not possible to present a general economic analysis with cost-benefit ratios to prove the profitability of duck-fish farming. Well-operated breeding and duckling distributing centers are basic prerequisites in all developing countries. These require high capital investment (suitable land, adequate water, pens and runs for the breeding stock, hatchery buildings, incubators, nurseries and installations for ducklings, transport facilities, stores, etc.). Furthermore, the production cost of eggs and young ducklings is a decisive factor in determining the profitability of duck raising on ponds. Although the beneficial effects of the ducks on fish yields is evident, the duck raising operation should also be profitable. The fish yield depends mainly on the species composition, stocking density and climate.

The production cost of ducks depends on many factors: the duck strain, length of the growing period, cost and availability of feeds, mortality rate, labor costs, transport, market characteristics, etc. Some of these costs are partly shared with the cost of fish culture. The market price and demand for ducks are decisive factors in deciding upon the establishment of integrated duck-fish farms.

Examples from Central Europe and the Far East show that integrated duck-fish farming greatly increases the animal protein production per unit area and can be highly profitable.

Bibliography

Balogh, L., L. Kozma and G. Mosonyi. 1975. Halastavi peosenyekacsa [Duck-fish culture] Mezőgazdasági Kiadó, Budapest. 210 p. (In Hungarian).

Blume, H. 1960. Entenmast in Verbinduing mit Karpfenzucht [Fattening ducks in connection with carp culture]. Deut. Fischereiztng, 7:196-204 (In German).

Bogre, J. 1968. A Kacsa-. lud-. pulyka- es gyöngytyuk-tenyésztés Kézikönyve [Manual of the rearing of duck, goose, turkey, and guinea-fowl]. Mezőgazdasági Kiadó, Budapest. 339 p. (In Hungarian).

FAO/UN. 1974. Report of the Government of Nepal on inland fishery biology. Based on the work of E. Woynarovich, FAO Inland Fishery Biologist. Rep. FAO/UNDP/TA/3287, 24 p.

Ling, S. W. 1971. Travel report. Visit to Taiwan and Hongkong. FAO, Rome. FID/71/R7. 11 p.

Nehring, K. and H. Knabe. 1961. Die Verdaulichkeit verschiedener Futterstoffe bei Enten [Digestibility of different feed stuffs by ducks]. Arch. Geflugelk., 25:263-75 (In German).

Probst, E. 1934. Teichwirtschaft und Geflügelzucht in ihren Wechselbeziehungen (Pond culture, duck raising and their interactions). Handbuch der Binnenfischerei Mitteleuropas. 4:408-82.

Renner, E. and W. Sarodnik. 1973. Jahresbericht 1972 über die Production des Wirtschaftzweiges Binnenfischerei der Deutschen Demokratischen Republik (report on the production in 1972 of the inland fishery sector in the German Democratic Republic). Binnenfisch. D.D.R., 20:134-53 (In German).

Woynarovich, E. 1956a. Das Carbondüngung Verfahren [The techniques of carbon-manuring]. Deut. Fischereiztg., 3:48-52 (In German).

Woynarovich, E. 1956b. Versuchsergenisse der Düngung von Fischteichen mit organischen Düngemitteln in Ungarn [Results of the manuring of fish ponds with organic manures in Hungary]. Deut. Fischereiztg., 3:17-19 (In German).

Woynarovich, E. 1956c. A halastavak szervestrágyázásának jelentősége [Importance of the manuring of fish ponds with organic manures]. Magy Tudom. Akad. Agrar. Osztaly Kozl., 10:308-19 (In Hungarian).

Woynarovich, E. 1979. The feasibility of combining animal husbandry with fish farming, with special reference to duck and pig production, p. 203-208. *In* T. V. R. Pillay and W.A. Dill (eds.) Advances in aquaculture. Fishing News Books Ltd., Farnham, Surrey, England.

Integrated Livestock-Fish Farming in India

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Abstract

The integration of fish culture with livestock rearing holds great promise and potential for augmenting production of animal protein, betterment of the economy, and generation of employment in rural India. Until recently, however, no worthwhile attempt was made in this direction even though 80% of the country's population live in villages, and are undernourished and in urgent need of gainful employment.

The work done on pig-fish farming and duck-fish farming in India is described and the results obtained, including the economics of integrated systems, are compared with those of modern semi-intensive fish culture. Integrated farming systems involving fish production have opened up new horizons of high animal protein production at very low cost. Fish yields of 7,300 kg/ha/yr and 4,323 kg/ha/yr were achieved for pig-fish and duck-fish farming, respectively. The pig and duck manure replaced fish feed and pond fertilizers. The costs/kg of fish produced were Rs1.07 (pig-fish) and Rs1.61 (duck-fish). The raising of ducks on a fish pond fits very well with the ecological niche concept of polyculture: the unutilized surface water niche in fish culture becomes occupied.

The possibilities of combining horticulture and fish culture by growing vegetables, fruit trees, and cattle fodder on the terraced embankments of ponds and using pond detritus as fertilizer are also discussed.

Introduction

About 80% of India's population live in rural areas at subsistence or near subsistence level. These rural folk are greatly undernourished and need not only a large supplement of animal protein to their diet but also new sources of gainful employment. Fish culture could contribute substantially towards solving these crucial problems, but no worthwhile impact in this direction has been made so far because of the various constraints against the adoption of existing high-yielding aquaculture technologies. One of the most serious constraints is the high cost of inputs, especially fish feed and pond fertilizers. This cost can be reduced considerably and fish production increased by combining fish culture with raising livestock. If livestock, such as pigs, ducks and poultry, are raised on pond embankments and the fish utilize the waste animal feeds and animal excreta, then fish production can be greatly enhanced by the increase in the biological productivity of the water. Supplemental feed and fertilizers are not needed in such a system and the cost of inputs is therefore reduced.

Integrating fish culture with livestock raising has been well-developed in China, Hungary, Germany, Malaysia and certain other countries (Hickling 1960; Wolny 1966; Ling 1971; Tapiador et al. 1977; Woynarovich 1979).

Little attention has been paid to the recycling of animal wastes through fish production in India, but cattle manure is used for fertilizing fish nursery, rearing and stock ponds (Alikunhi 1957; Sharma 1974; Jhingran 1974). Attempts have also been made in recent years to combine livestock raising with fish culture and to standardize the number of animals required per unit of water area for adequate manuring and high fish yields in the absence of fertilizers and supplemental feed. The integration of pig and duck farming with fish culture was attempted for the first time in India in District Nadia, West Bengal (Sharma et al. 1979a, 1979b).

The work done so far in India on the integration of livestock raising with fish culture is presented in this paper.

Pig-Fish Farming

POND MANAGEMENT AND HARVESTING

An experiment was conducted in a 0.1-ha pond, situated in a 5-ha agricultural farm owned by the Don Bosco Society, Krishnagar, District Nadia, West Bengal. The water remained static, with no circulation or aeration, and the average depth was 3 m. Existing pigsties, situated a little away from the pond, were used, but due to the lack of drainage channels, the urine and washings from the pigsties could not be added to the pond. The existing stock of fish in the pond was first removed by poisoning with Mahua *(Bassia latifolia)* oil cake at 250 ppm. Lime was also applied 15 d before poisoning at 200 kg/ha.

The pond was stocked in January 1977 with fingerlings of the Indian major carps, catla *(Catla catla)*, rohu *(Labeo rohita)*, mrigal *(Cirrhina mrigala)*; the Chinese carps–the silver carp *(Hypophthalmichthys molitrix)* and the grass carp *(Ctenopharyngodon idella)*–and the common carp *(Cyprinus carpio)* (Table 1).

Pig manure was collected from the pigsties, weighed and dumped in heaps at the four corners of the pond each morning. No supplemental fish feed or fertilizers were used other than chopped green cattle fodder, which was given to the grass carp. This was grown on the terraced embankments of the pond, together with lettuce and spinach, and other crops such as papaya, bananas and coconuts. No aquatic vegetation was provided for the grass carp. The pond bottom was raked once every week to release any gases. Lime was applied four times during the course of experiment at 200 kg/ha/application.

The dissolved oxygen (DO) and biochemical oxygen demand (BOD) of the pond water were monitored and the quantity of manure added regulated accordingly. The DO ranged from 3 to 6 ppm and the BOD from 4.08

Table 1. Yields of fish and pigs from an integrated farming experiment at the Don Bosco Agricultural Farm, Krishnagar, District Nadia, West Bengal, India, using a 0.1-ha fish pond stocked with a total of 850 fish and a culture period of 12 mo.

1. Fish

Species	Average weight at stocking (g)	Composition of stock (%)	Average weight at harvest (g)	Total weight harvested after 12 mo (kg)	Survival (%)	Contribution to total yield (%)
Catla	48	20	1,100	120.750	64.1	16.5
Rohu	28	20	1,000	95.600	55.8	13.1
Mrigal	23	20	809	77.740	56.4	10.6
Silver carp	9	15	2,100	219.000	80.4	30.0
Grass carp	5	20	1,300	191.800	85.2	26.2
Common carp	3	5	450	25.750	83.3	3.5
			Total yield	730.640 kg		

2. Pigs

No. of piglets for fattening	Average initial weight (kg)	Period of growth (mo)	Average finished live weight (kg)	Total weight (kg)
First group 8	22.5	8	95.4	763.200
Second group 5	25.0	4	66.5	332.500
			Total yield	1,095.700 kg

to 9.05 ppm.

The pond was harvested after 12 mo and yielded 730 kg of fish. All the species stocked showed good growth rates (Table 1).

PIG HUSBANDRY

Two groups of Landrace piglets were raised during the course of experiment: the first group (8 piglets) for 8 mo and the second group (5 piglets) for 4 mo. The pigs were confined to the pigsties and fed on pig mash concentrate at an average rate of 1 kg/pig/d. Green grass or green cattle fodder was also fed every day and sod (turf with soil) provided once a week to prevent mineral deficiency. This diet kept the pigs in a healthy condition and hygiene was of a high standard. Table 1 gives the initial and final weights of the pigs.

ECONOMICS

Details of the input costs and returns for fish culture and pig raising are given in Table 2. The fish were sold at the farmgate. The costs of production/kg were Rs1.07 for fish and Rs4.15 for pigs (US$1.00 = Rs8.00).

Table 2. Input costs and returns for a year's production of fish and pigs from an integrated farming experiment using a 0.1-ha pond at the Don Bosco Agricultural Farm, Krishnagar, District Nadia, West Bengal, India (US$1.00 = Rs 8.00).

	Quantity	Unit cost or value (Rs)	Total cost or value (Rs)
A. Fish			
1. Input costs			
Mahua cake *(Bassia latifolia)*	800 g	0.41/kg	331.20
Fingerlings	850 fish	8.25/kg	136.94
Lime	100 kg	0.24/kg	24.00
Potassium permanganate	1 kg	21.40/kg	21.40
Labor, netting, etc.	–	–	170.00
Pond rental	0.1 ha	1,000/ha/yr	100.00
		Total	783.54
2. Returns			
Fish sales	730.64 kg	7.62/kg	5,567.48
B. Pigs			
1. Input costs			
Piglets (first group)	8 (180 kg)	5.50/kg	990.00
Feed	1,976 kg	1.00/kg	1,976.00
Piglets (second group)	5 (125 kg)	5.50/kg	687.50
Feed	690 kg	1.00/kg	690.00
Green fodder, etc.	–	–	104.00
Depreciation cost of pigsties– construction cost, Rs 3,000; life expectancy, 30 yr	–		
		Total	4,547.50
2. Returns			
Sale of pig meat	1,095.70 kg	5.50/kg live weight	6,026.35
C. Summary			
Total operational costs	= Rs 5,331.04		
Interest on working capital at 10%	= Rs 533.10		
Total variable costs	= Rs 5,864.14		
Total returns	= Rs 11,593.83		
Net profit	= Rs 5,729.69		
Net profit as a % of total variable costs	= 98%		

Duck-Fish Farming

POND MANAGEMENT AND HARVESTING

A 1.48-ha rectangular pond was used with average depth of 1.5 m, but rising to 2.5 m during the rainy season. The pond was prepared for fish stocking as described above.

The pond was initially stocked in January 1977 (Table 3). After partial harvesting in October 1977, however, a second stock of catla fingerlings was added to the remaining stock and the percentage species composition became catla, 12%; rohu, 13%; mrigal, 27%; silver carp, 12%; grass carp, 11%, and common carp, 25%.

During the daytime the duck manure was spread on the pond by the ducks themselves. Manure produced at night was collected from the duck houses and added to the pond. No supplemental feed or fertilizer was used, but lime was applied twice during the course of the experiment at 250 kg/ha/application.

The pond was harvested twice during the one-year experiment: partial harvesting after 9 mo and final harvesting after 12 mo. The total yield was 6,397 kg, which corresponds to 4,323 kg/ha/yr. The details of growth, production, survival and contribution by various species are shown in Table 3.

DUCK HUSBANDRY

One hundred Khaki Campbell-Bengal runner cross ducklings were reared over the pond. They were allowed to range freely over the water by day and sheltered at night in a floating duck house made of bamboo matting over empty oil drums, positioned close to the pond bank. The ducks depended initially on the natural food available in the pond, but were fed 100 g/head/d of balanced poultry feed from August 1977, supplemented with chopped aquatic weeds (e.g., *Hydrilla* and *Potamogeton)* and occasionally with molluscs. In July 1977, some of the ducks died due to an unspecified disease, and were replaced by fresh ducklings.

After attaining maturity, the ducks laid 1,835 eggs. They attained an average weight of 2.5 kg after 12 mo. A total of 250 kg of ducks (live weight) for consumption was also produced (Table 3).

Table 3. Yields of fish and ducks (eggs and live weight for meat) from an integrated farming experiment at the Anjana fish farm, Krishnagar, West Bengal, India using a 1.48-ha pond stocked with a total of 9,400 fish (6,340/ha) harvested after 9 and 12-mo growth periods (for catla alone, a second stocking was made after the 9-mo harvest–see text).

1. Fish

Species	Average initial weight (g)	Composition of stock (%)	Growth period (mo)	Average weight at harvest (g)	Total weight at harvest (kg)	Survival (%)	Contribution to total yield (%)
Catla							
First stocking	43	10	9	904	801.150	96.3	19.2
Second stocking			3	498	429.300		
Rohu	28	18	9	413	346.500	90.6	13.1
			12	633	488.650		
Mrigal	23	28	9	495	305.800	72.6	15.4
			12	513	677.300		
Silver carp	5	15	9	1,643	632.000	94.2	30.2
			12	1,920	1,300.300		
Grass carp	5	10	12	1,720	1,092.000	76.8	17.1
Common carp	5	19	12	206	161.200	53.1	2.5
Miscellaneous	–	–	–	–	163.100	–	2.5
			Total yield		6,397.300 kg		

2. Ducks

No. of ducklings raised	Average initial weight (g)	Growth period (mo)	Average finished weight (kg)	Total finished weight (kg)	No. of eggs produced
100	250	12	2.500	250	1,835

Details of the input costs and returns for fish culture and duck raising are shown in Table 4. The cost of production for fish was Rs1.61/kg. The fish were sold at a fixed government price of Rs5.50/kg as against the prevailing farmgate price of Rs8.00/kg by deliberate policy to make them available to local consumers. The eggs were also sold at a very low price (Table 4). The ducks were not sold at the end of the experiment.

Chicken-Fish Farming

Integration of fish culture with chicken farming has only recently been initiated in India and few results are available. Research on the fertilizing efficiency of chicken manure in fish ponds, either alone or in combination with cattle manure, has been done by Banerjee et al. (1969), who observed that a combination of chicken and cattle manure worked better than the cattle manure alone in fertilizing nursery ponds. It has also been

Table 4. Input costs and returns for a year's production of fish, duck eggs and ducks sold for meat from an integrated farming experiment at the Anjana fish farm, Krishnagar, West Bengal, India using a 1.48-ha pond stocked at 6,340 fish/ha (US$1.00 = Rs 8.00).

A. Fish 1. Input costs	Rate/ha	Quantity	Unit cost or value (Rs)	Total cost or value (Rs)
Mahua cake *(Bassia latifolia)*	250 ppm	6,400 kg	0.38/kg	2,432.00
Lime	250 kg	372.5 kg	0.30/kg	111.75
Fingerlings	6,340	9,400	–	2,506.75
Insecticide (BHC)	1 kg	1.5 kg	7.50/kg	11.25
Netting and other miscellaneous costs	–	–	–	997.51
Labor (security and fish handling)	–			2,761.54
Pond rental	–	1.48 ha	1,000.00/ha/yr	1,500.00
			Total	10,320.80
2. Returns				
Fish sales		6,397 kg	5.50/kg*	35,183.00
B. Ducks 1. Input costs				
Ducklings		140	approx 9.00/head	1,272.00
Poultry feed		1,510 kg	1.00/kg	1,510.00
Medication		–	–	97.00
Depreciation cost of floating duck house–contribution cost, Rs 2,500; life expectancy, 5 yr				500,000
			Total	3,379.00
2. Returns				
Egg sales		1,835	0.40/egg*	734.00
Ducks for meat		250 kg (live weight)	10.00/kg	2,500.00
			Total	3,234.00

C. Summary

Total operational cost	= Rs 13,699.80
Interest on working capital at 10%	= Rs 1,369.98
Total variable costs	= Rs 15,069.78
Total returns	= Rs 38,417.00
Net profit	= Rs 23,347.72
Net profit as a % of total variable costs	= 155%

reported that poultry manure is a complete fertilizer, with the characteristics of both organic as well as inorganic fertilizers (Banerjee et al. 1979). Ray and David (1969) found that chicken manure produced a large population of rotifers quicker than cattle manure. A fish yield of 670 kg/ha/90 d has been reported by Banerjee et al. (1979), using poultry manure and no supplemental feeds.

Discussion

Experiments on integrated livestock-fish farming have opened up a new horizon of high animal protein production at very low cost. Besides providing cheap protein-rich food, integrated farming has proved to be an efficient means of waste disposal and has allowed savings on the use of inorganic fertilizers and supplemental feeds in fish production.

The yield of 7,300 kg/ha/yr from the pig-fish experiment, without the use of any supplemental feeds or inorganic fertilizers, is high compared to the average yields of 3,543 kg/ha/yr, achieved through polyculture with intensive feeding and fertilization in the Eastern region of India (Anon. 1977); 4,290 kg/ha/yr from Krishnagar, West Bengal (Sharma et al. 1978); 4,250 kg/ha/yr from District Nadia, West Bengal (Murshed et al. 1977) and 3,232 kg/ha/6 mo at Kalyani, West Bengal (Sinha et al. 1973). The yield from the present experiment is also significantly higher than the yields obtained from pig-fish rearing in other countries, e.g., in Illinois, U.S.A., 3,625 and 4,140 kg/ha/yr with polyculture of Chinese carps (Buck et al. 1979); 3,667 kg/ha/yr in Penang (Le Mare 1952) and 5,500 kg/ha/yr in France (Bard et al. 1976).

The fish, besides consuming the large amounts of natural food produced in the pond, were also observed to feed directly (especially the bottom feeders) on pig manure (Sharma et al. 1979a). Maar (1956) has reported that pig manure contains 70% digestible food for fish. Le Mare (1952) observed that the food, while passing through the alimentary canal of the pig, gets mixed with certain enzymes which continue to digest the manure even after voiding. Manure therefore has high food value for fish.

About 2,000 kg of pig manure was recycled in the 0.1-ha pond during the 12-mo experiment. One pig voids from 550 to 600 kg manure in one year and therefore about 35 to 40 pigs would be sufficient to fertilize 1 ha of water. These observations are in close agreement with pig-fish farming practice in China, where 35 to 45 pigs/ha are used (Tapiador et al. 1977).

In India, pig-fish farming has a special significance, as it can improve the socioeconomic status of many of the weaker rural communities, especially the tribal communities which traditionally rear pigs. Demonstrations of the technology, financial assistance and water areas must, however, be provided. According to a 1972 livestock census, the pig population in India was 6.5 million (Anon. 1976), which is sufficient to bring 0.16 million ha of water into pig-fish farming.

The fish yield of 4,323 kg/ha/yr from the duck-fish experiment, without the use of any supplemental feed or inorganic fertilizers, is also high compared to the yields of 4,290 kg/ha/yr, obtained from the same pond during 1973 to 1974 (Sinha and Sharma 1976; Jhingran and Sharma 1978; Sharma et al. 1978); 3,543 kg/ha/yr in Eastern India (Anon. 1977), and 4,258 kg/ha/yr from District Nadia, West Bengal (Murshed et al. 1977), which were achieved with heavy supplemental feeding and fertilization. The present yield is also higher than that from duck-fish farming in Taiwan: 3,500 kg/ha/yr (Ling 1971).

The raising of ducks on fish ponds fits very well with the ecological niche concept of polyculture. In conventional polyculture, the major niches are all occupied by various species of fish, except for the water surface niche which is unutilized. The ducks consume such organisms as tadpoles, mosquitos, larvae of dragon flies and other insects, molluscs and aquatic weeds, and thus do not compete significantly with the fish for any food items commonly found in conventional polyculture of carps. Their manure fertilizes the pond, and their disturbance of the substrate, while feeding, helps to release nutrients from the soil and further increases fish production. By day, the ducks distribute their manure over the whole pond area.

The polyculture ponds described here for integrated farming lack any aquatic vegetation and the ducks therefore depend mostly on feeding by man. The number of ducks should be kept to an easily manageable number, just adequate for pond fertilization. In the present experiment, 100 ducks provided approximately 10,000 kg of manure over 12 mo. The results and experience obtained suggest that 100 to 150 ducks can give adequate fertilization of 1 ha of water. This is comparable with the recommendation of Behrendt (1978): i.e., 300/ha average and 100/ha where natural food is limited.

The duck population in India has been estimated at 10 million (Anon. 1976). Ducks are mostly concentrated in Tamil Nadu, Kerala, Assam, Orissa, West Bengal and Bihar. They are mainly used to produce eggs. The surplus drakes and ducks which are too old for laying are used for meat. These states also have great potential for fish culture and could greatly increase their animal protein production by integrated duck-fish farming.

Ducks are likely to eat small fish and should be excluded from nursery ponds. Fingerlings of 10 cm or over are recommended for stocking in duck-fish systems.

The chicken population of India has recently been estimated at about 136 million (Anon. 1976) and the integration of chicken farming and fish culture, if developed on scientific lines, could also help solve the animal protein deficiency problem of the country and generate employment opportunities for the rural poor.

Integrated livestock-fish farming not only increases fish production but also cuts down the cost of fish culture operations considerably. The average cost of production in conventional polyculture with supplemental feeding and inorganic fertilization was Rs2.93/kg in Eastern India (Anon. 1976). Murshed et al. (1977) have also recorded Rs2.67/kg as the cost of fish production by conventional methods in District Nadia, West Bengal. The present costs of production of Rs1.07/kg (pig-fish) and Rs1.61/kg (duck-fish) are much lower.

The annual profits made from pig and duck farming are not very impressive, but the total income from an integrated farming system must be considered to assess economic viability. The waste materials, i.e., pig dung and duck droppings, act as a substitute for supplemental fish feed and fertilizers, which in conventional fish culture account for 58.6% of the total input cost (Anon. 1977). The expenditure incurred by raising ducks and pigs is largely offset by the sales value of pig meat, eggs and duck meat. The percentage returns on total variable costs of 98% (pig-fish) and 155% (duck-fish) would give enough income not only for the maintenance of the farmer's family but also some spare capital for enlarging his scale of operations.

The gap between the demand and supply of inorganic fertilizers is increasing every day due to intensive cropping of the high yielding varieties of cereals. The recycling of organic wastes, through integrated farming systems, can help solve this problem. The cattle fodder, vegetables, and fruit crops grown on the terraced embankments of the pond, which are not normally utilized in the fish culture operations, provided fodder for the grass carp and pigs and extra income to the farmer. The organic detritus removed from the pond bottom can also serve as an efficient fertilizer for growing land crops. This opens up possibilities of combining horticulture and fish culture.

While integration of livestock farming with fish culture gives high yields at low cost, the systems require effective management. One of the problems is the difficulty in combining and balancing the expertise needed in fish and animal husbandry. Overconcentration on one may work to the detriment of the other. Monitoring the DO and BOD of the pond water is absolutely essential as a thick organic sediment settles at the pond bottom, which hastens the depletion of oxygen and enhances the production of toxic gases, and can result in fish kills. The application of manure should be regulated according to the pond water DO. The pond should also be desilted when a significant amount of detritus has accumulated at the bottom.

Animal excreta are a potential source of infection for various parasites and diseases. Studies are being made to investigate the possible human health hazards from integrated livestock-fish farming systems. Obviously, the livestock should be maintained in good health and under hygienic conditions.

References

Alikunhi, K.H. 1957. Fish culture in India. Farmers Bull. (Indian Council of Agricultural Research) 20. 144 p.

Anon. 1976. Report, National Commission on Agriculture. Part VII. 531 p.

Anon. 1977. First 138 case studies of composite fish culture in India. Bull. Cent. Inland Fish. Res. Inst., Barrackpore 23. 152 p.

Banerjee, R.K., G.S. Singit and P. Ray. 1969. Some observations on the use of poultry manure as fertilizer in rearing major carp fry. Indian J. Fish. 16:29-34.

Banerjee, R.K., P. Ray, G.S. Singit and B.R. Dutta. 1979. Poultry droppings–its manurial potentiality in aquaculture. J. Inland Fish. Soc. India 2(1):94-108.

Bard, J., P. de Kimpe, J. Lazard, J. Lemasson and P. Lessent. 1976. Hand Book of Tropical Fish Culture. Centre Technique Forestier Tropical, Nogent Sur Marne–France.

Behrendt, A. 1978. Profit at all levels of the carp pond. Fish Farmer, 1(4):42.

Buck, D.H., R.J. Baur and C.R. Rose. 1979. Experiments in recycling swine manure in fish ponds, p. 489-492. *In* T.V.R. Pillay and W.A. Dill (eds.) Advances in aquaculture. Fishing News Books Ltd., Farnham, Surrey, England.

Hickling, C.F. 1960. Fish culture. Faber and Faber, London.

Jhingran, V.G. 1974. Fish and Fisheries of India. Hindustan Publishing Corporation, New Delhi, India.

Jhingran, V.G. and B.K. Sharma. 1978. Operational Research Project on Aquaculture in West Bengal. Bull. Cent. Inland Fish Res. Inst., Barrackpore, 27. 6 p.

Le Mare, D.W. 1952. Pig rearing, fish-farming and vegetable growing. Malayan Agric. J. 35(3): 156-166.

Ling, S.W. 1971. Travel report, visits to Taiwan and Hong Kong, FID/71/87, FAO, Rome. 11 p.

Maar, A. 1956. Tilapia culture in farm dams of Southern Rhodesia. Rhodesia Agric. J. 53(5):667-687.

Murshed, S.M., S.M. Roy, D. Chakraborty, M. Ranadhir and V.G. Jhingran. 1977. Potentials and problems of composite fish culture technology in West Bengal, Bull. Cent. Inland Fish. Res. Inst. 25. 11 p.

Ray, P. and A. David. 1969. Poultry manure as potential plankton producer in fish nurseries. Labdev. J. Sci. 7B(3): 229-231.

Sharma, B.K. 1974. On the survival and growth of major carp spawn in nurseries manured with organic fertilizers. J. Zool. Soc. India 4: 156-159.

Sharma, B.K., A. Mukherjee, J. Chander, D. Kumar, M.K. Das and S.R. Das. 1978. Operational Research Project on Composite Fish Culture, Krishnagar, Nadia, West Bengal (Report). First Annual Workshop on Operational Research Projects of the Indian Council of Agricultural Research, held at Karnal, India. 17 p.

Sharma, B.K., Dilip Kumar, M.K. Das, S.R. Das and D.P. Chakraborty. 1979a. Observations on swine dung recvcling in composite fish culture, p. 99. *In* Symposium on Inland Aquaculture (February 12-14, 1979), Central Inland Fisheries Research Institute, Barrackpore, India. (Abstract only)

Sharma, B.K., Dilip Kumar, M.K. Das, S.R. Das and S.K. Neogi. 1979b. Observations on fish-cum-duck rearing, p. 95. *In* Symposium on Inland Aquaculture (February 12-14, 1979), Central Inalnd Fisheries Research Institute, Barrackpore, India. (Abstract only)

Sinha, V.R.P., M.V. Gupta, M.K. Banerjee and D. Kumar. 1973. Composite fish culture at Kalyani, West Bengal. J. Inland Fish. Soc. India 5:201-207.

Sinha, V.R.P. and B.K. Sharma. 1976. Composite fish culture in large sheets of water. Indian Farming 26(2): 30-31.

Tapiador, D.D., H.F. Henderson, M.N. Delmendo and H. Tsutsui. 1977. Freshwater fisheries and aquaculture in China, FAO Fish. Tech. Pap. 168. 86 p.

Wolny, P. 1966. Fertilization of warm-water fish ponds in Europe. Paper presented in the FAO World Symposium on Warm Water Pond Fish Culture, Rome, May 18-25, 1966. FR:11/R-7. 18 p.

Woynarovich, E. 1979. The feasibility of combining animal husbandry with fish farming, with special reference to duck and pig production, p. 203-208. *In* T.V.R. Pillay and W.A. Dill (eds.) Advances in aquaculture. Fishing News Books Ltd., Farnham, Surrey, England.

Freshwater Aquaculture in Indonesia with Special Reference to Small-Scale Agriculture-Aquaculture Integrated Farming Systems in West Java

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Abstract

This paper presents a brief review of the status of freshwater aquaculture in Indonesia, with special reference to integrated agriculture-aquaculture farming systems. Results and discussion of case studies undertaken in West Java are reported separately including technical and socioeconomic analyses. In this area, integrated systems are found combining fish, rice, aquatic vegetables, chicken, duck and sheep raising, etc. Rice-fish culture is found in almost all provinces throughout the country. Cattle-fish farming comes next in importance, followed by other integrated farming systems. These farming systems have obviously given a number of advantages to rural farmers with small landholdings.

Introduction

Integration of aquaculture with crop and livestock farming is receiving worldwide attention but has only recently been documented in Indonesia. It is a relatively new type of farming, apart from rice-fish culture which has been practiced for over a century.

Historically, integrated systems were called mixed-farming in which two or more commodities were produced separately in the same farm, to use land efficiently and to increase the farmer's income. Aquaculture is an attractive additional component as water can be utilized for three purposes: irrigation, domestic use and fish production. Livestock raising has been an essential component of many integrated systems, supplying urine and manure as land and water fertilizers. The main component of such systems has normally been agriculture, however, with aquaculture and livestock raising being subsidiary activities.

The systems described here differ from these in placing the greater emphasis on aquaculture, and are performed entirely in such aquatic environments as ponds and rice fields. The main component, however, may still be either fish, crops or livestock. In West Java, four types of crop-fish farming, four types of animal-fish farming and three types of fish culture combined with home industry were found. The farmers' aim is to make the fullest use of their land at the lowest cost to increase their income. This type of farming is still in its infancy but is already wisely practiced in many parts of the country.

Freshwater fish culture is a well established rural activity and an important source of protein supply. The present annual production is 74,014 t: 18% of the total production from inland fisheries. There are vast areas available for expansion but there are technological gaps which must be filled to make increased production possible.

The National Fisheries Development Program emphasizes the importance of the development of fish culture in the rural areas and lists four major goals:

1. To increase fish production and the productivity of fishery resources, to contribute to satisfying the demand for food and to improve human nutrition.
2. To raise the living standards and general welfare of fish farmers and fishermen, through increasing income and social status.
3. To provide employment opportunities for the rural people.
4. To promote the conservation of fishery resources.

Integrated farming is relevant to all these objectives and deserves further attention and encouragement. This paper reviews the status of freshwater aquaculture in Indonesia, and presents the results of a case study in West Java.

The Present Status of Freshwater Aquaculture in Indonesia

Freshwater aquaculture in Indonesia includes pond culture, irrigation pond farming, rice-fish culture, raceway and running water pond culture, net enclosure culture in rivers and canals and submerged and floating cage culture.

Pond culture and rice-fish culture are by far the most widely practiced aquaculture operations. They are performed along traditional lines with low production input levels. Others, especially raceway, running water and net enclosure culture, are new operations which need high level commercial inputs for construction cost, fish seed and feeds, etc. Investment in such commercial operations has recently increased, e.g., the culture of high value fishes such as the common carp *(Cyprinus carpio)*, giant goramy *(Osphronemus goramy)*, leptobarbus *(Leptobarbus hoeveni)*, snake heads *(Ophicephalus spp.)*, etc. the culture of high value crustaceans, such as penaeid shrimps in brackishwater ponds, and *Macrobrachium* culture.

Pond culture, rice-fish culture and similar operations use low, as well as high value species, including *Puntius* spp., *Osteochilus* sp., *Helostoma temmincki* (kissing goramy), tilapias, *Trichogaster pectoralis* (sepat siam), *Clarias batrachus*, *Cyprinus carpio* and *Osphronemus goramy*. The National Fisheries Development Program encourages both the traditional and the commercial culture operations, the former being important for the domestic market and to supply cheap and nutritious food for the rural people and the latter to provide luxury and exportable products.

The yields from pond culture differ widely from place to place, e.g., Sumatra 576 and Java 2,135 kg/ha/yr, with a country average of 1,537 kg/ha/yr. The location and yields for fish culture areas are given in Table 1.

Cage culture in city drainage ditches has been practiced for about 40 yr and, although restricted to 2,655 units in West Java, contributes to an annual production of 403 t. This type of culture, constrained by public service and sanitary considerations, should be maintained and developed due to its economical importance for the local population. It is basically waste recycling and, being suitable for family or community management, could easily be adopted in all parts of the country, wherever there is suitable water.

Commercial raceway, running water and net enclosure culture, which started in late 1971, have increased to a total of approximately 175 farms in West Java, and are occasionally found in other provinces. These high yielding culture systems are appropriate for markets which demand continuous and large quantities of fish. They supply local and export demands.

Rice-Fish Culture

Rice-fish culture is still widely practiced in Indonesia (Table 1). Examples of annual yields are: West Java, 777 kg/ha; South Sulawesi, 174 kg/ha; Bali, 62 kg/ha, and the national average 353 kg/ha. The complete range of yields is even wider, from 23 kg/ha in Bengkulu to 1,202 kg/ha in East Java.

Rice-fish culture (called sawah tambak) expanded from 1950 in East Java to involve 11,589 ha by 1978. There are two types of sawah tambak, coastal and purely freshwater, the latter being found in the Solo and Brantas river basins. The coastal rice fields were originally brackishwater fish ponds, as indicated by the layout and construction of their dikes, canals and irrigation systems. They were originally rainfed ponds and rice-fish culture is still possible only during the wet season. The ponds were converted into rice fields because of silt deposits in the canals, rivers and coastline which prevented tidal waters from reaching the tambak areas. The sawah tambaks give high yields. Productive examples give an annual production of 1.5 to 2.0 t of rice and 1.1 to 1.6 t of fish/ha, which requires the application of 175 kg urea and 300 kg triple super phosphate (TSP)/ha. A mixture of milkfish *(Chanos chanos)* and Java carp *(Puntius gonionotus)* is used. The sawah tambak method of rice-fish culture is spreading from East Java to other areas.

There are several other methods of rice-fish culture in Indonesia: fish culture along with the rice crop (bersama

Table 1. The areas used for aquaculture in the provinces of Indonesia and their total production in 1976 (Source: Directorate General of Fisheries 1976).

Province	Pond culture Area (ha)	Pond culture Production (t)	Brackishwater culture Area (ha)	Brackishwater culture Production (t)	Rice-fish culture Area (ha)	Rice-fish culture Production (t)	Total Area (ha)	Total Production (t)
Aceh	–	45	14,958	10,378	–	23	14,958	10,446
North Sumatra	1,005	1,159	227	203	4,875	883	6,107	2,245
West Sumatra	2,969	2,553	5	–	70	42	3,044	2,595
Riau	–	21	–	–	–	–	–	21
Jambi	498	146	–	–	–	–	498	146
South Sumatra	1,477	671	–	–	1,052	192	2,529	863
Bengkulu	263	49	–	–	1,561	36	1,824	85
Lampung	379	230	116	35	77	62	572	327
Jakarta	900	539	1,430	373	550	64	2,880	976
West Java	16,946	41,294	32,570	13,800	19,250	14,962	68,766	70,056
Central Java	1,516	2,086	25,243	7,693	4,654	192	31,143	9,971
Yogyakarta	210	207	–	–	1,376	88	1,586	295
East Java	2,079	2,100	44,500	22,908	1,010	1,214	47,589	26,222
Bali	70	81	180	35	7,886	491	8,136	607
Nusa Tenggara Barat	644	294	1,834	923	2,468	202	4,946	1,419
Nusa Tenggara Timur	78	81	49	25	97	24	224	130
West Kalimantan	327	6	–	–	1	–	328	6
Central Kalimantan	–	–	–	–	–	–	–	–
South Kalimantan	122	6	50	7	–	–	172	13
East Kalimantan	67	1	465	12	–	–	532	13
North Sulawesi	1,266	427	132	37	2,358	618	3,756	1,082
Central Sulawesi	1,534	51	898	95	334	27	2,766	173
South Sulawesi	1,260	330	41,646	23,546	12,950	2,254	55,856	26,130
Southeast Sulawesi	443	108	274	73	38	9	755	190
Maluku	65	21	16	12	–	–	81	33
Irian Jaya	117	125	1	3	–	–	118	128
	34,235	52,631	164,594	80,158	60,607	21,383	259,436	154,172

padi), fish culture in between two rice crops (panyelang) and fish culture as a secondary crop (palawija).*

Documentation of Rice-Fish Culture and Other Integrated Farming Systems

In an attempt to document integrated farming systems in Indonesia, a questionnaire was circulated to the Provincial Fisheries Services. The information derived from this relates almost entirely to rice-fish culture with few details on other systems. Table 2 gives the location and size of respondent families practicing integrated farming. Figure 1 shows the location of the case study area.

*Palawija is a rotating crop system in which usually dry crops like maize, ipomoea, cassava, etc. are cultivated in rice fields where there is not enough water for rice cultivation. Where there is enough water, fish is cultured instead.

Rice-fish culture, which is found in 10 out of the 15 provinces studied, accounts for 66.6% of the integrated farms by number. Integration with cattle (53.3%), duck (26.6%) and vegetables, sheep and pig raising (3% each) come next in descending order of importance. In West Java, the following systems are found: rice-fish, kangkung *(Ipomoea reptans)*-fish, genjer *(Limnocharis flava)*-fish, mendong *(Fimbristylis globusa)*-fish, duck-fish, sheep-fish and buffalo-fish. The last one is excluded from this paper. It is worthwhile noting that brackishwater ponds also use an integrated farming system, i.e., fish and firewood (from mangroves). Mangroves are planted on a 200-m coastal strip to protect the coast area from erosion and to create shelter for coastal fishes. This regulation, issued by ministerial decree, includes also an obligation to plant mangrove plants inside the brackishwater ponds: along the foot of the dikes and in the pond proper. This gives the farmer income from both fish and firewood.

Production of algae *(Gracilaria* sp.) in fish ponds is limited to small-scale activities in the vicinity of Jakarta.

Integration of aquaculture with other sectors of production has the following advantages:

1. Maximum yield and diversified products from a minimum area.
2. Efficient utilization of resources in terms of space and time.
3. Increased and beneficial spread of income throughout the year.
4. Better employment for the farm family and community.
5. Self-sufficiency in food supply for the farm family and community.

Disposal and Marketing of Products

Freshwater fish is generally sold in well-established special live fish markets which are found in many important fish culture centers. West Java has the most developed market facilities with cement raceways and tanks, fiberglass containers, oxygen cylinders and permanent offices. Surface water and ground water are supplied to keep the fish in good health. Fry, as well as fish for consumption, are marketed here; these are bought by fish dealers, middlemen or by the farmers themselves. A well-known fish market in Cisaat, Sukabumi, can accommodate about 100 pairs of fish baskets a day. Each pair holds one pikul (about 60.5 kg). The volume of fish sold in 1978 amounted to 18,841,000 fingerlings, 85,653 bowls of fry (1,000 to 3,000 of 1 to 3-cm fry/bowl) and 494 t of food fish.

Freshwater Pond Farms

The total number of workers engaged in freshwater pond culture is estimated at 489,153 distributed over the country as follows: West Java (43%), West Sumatra (18%), Central Java (17%), East Java (10%) and Yogyakarta (3%). The number of farming establishments in these provinces are 43%, 18%, 17%, 11% and 3%, respectively, with a total of 287,737. Table 3 lists the average farm and pond sizes.

Case Study

OBJECTIVES AND SCOPE

The objectives of the case study were to document the types, techniques and socioeconomic structure of the integrated farming sustems being developed in the country, to use this information as baseline data for experimentation to improve methods and technology and to spread this to other parts of the country.

The study was conducted in West Java, centralized mainly in the most important aquaculture centers of Cianjur, Garut and Tasikmalaya (Figure 1). The study was carried out in two phases: June 1 to 10, 1978 and March 1 to 10, 1979 as a followup.

The scope of the study included collection of first hand data and information on:

1. Methods and techniques of fish farming, such as pond type and construction, water supply, fish

Table 2. Location and family size of respondents to a questionnaire on integrated farming in West Java.

District	Sub-district	Village	Respondent	Family size	Comments
Tasikmalaya	Singaparna	Singaparna	Iin Karim	4	
		Singaparna	Suhada	6	
		Singaparna	Abdul Jalil	7	
		Singaparna	Eha	3	
	Indihiang		Syarif	–	Has additional activities
		Indihiang	Entong	11	
	Cibeureum	Cibeureum	Endang	4	
		Cibeureum	Bohar	11	
		Purbaratu	Holis	6	
		Manenjaya	Abdullah Junaedi	2	Unmarried
Garut	Karang Pawitan	Karang mulya	Adang	7	
			Suhada	5	The total labor force is 14 as some married sons live nearby
	Leles	Cangkuang	Konceng	4	Includes three grandchildren
Cianjur	Ciranjang	Cibanteng	Nandang	8	
	Karang Tengah	Bojong	Rachmat	–	Has additional activities
	Warungkondang	Bangbayang	Abdulah	11	
Bogor	Parung	Babakan	Abdurahman	6	

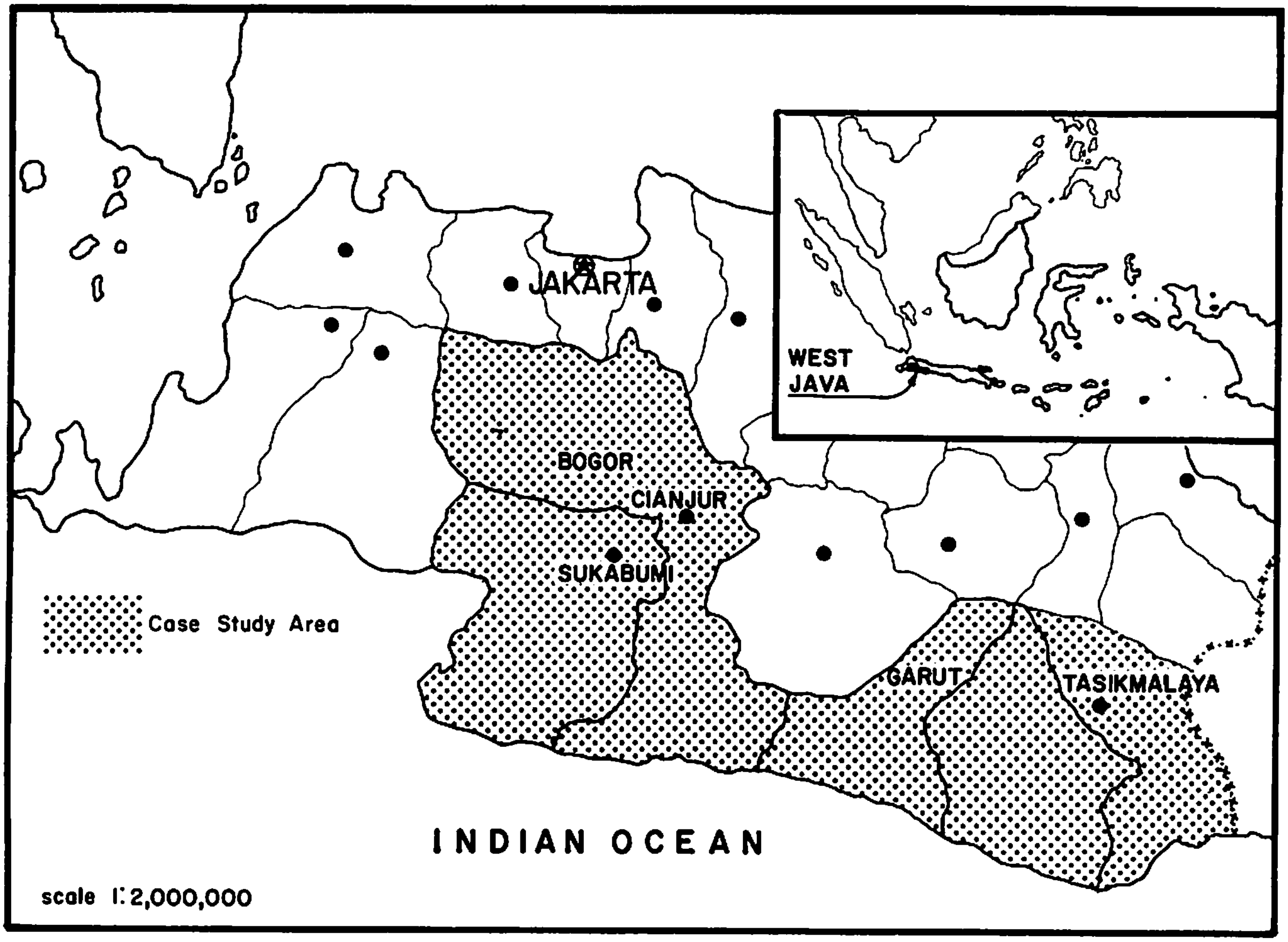

Figure 1. Map showing the area in West Java, Indonesia used for the case studies on integrated farming.

species and stocking sources, pond management, etc.;

2. Methods and techniques of crop and livestock farming, including species cultivated, rotations and cropping techniques, livestock husbandry and management, etc. and
3. Social status of the farmers and the farming community, production economics and marketing, etc.

STUDY METHODS

A team of four research staff members of the socio-economic and aquaculture section of the central Inland Fisheries Research Institute, Bogor, was assisted by local technicians of the Provincial Fisheries Service of West Java. In the first phase of the study, one or two members of the team were sent simultaneously to Sukabumi, Cianjur and Tasikmalaya. The main study method was interviewing, using a prepared questionnaire previously drawn up by the full team. In the second phase, this was repeated by further pairs of the study team supported by a FAO consultant.

At least three respondents were interviewed to represent each type of the integrated farm. Small-scale farmers with less than one hectare and with more than 5 yr experience were chosen, either farm owners or farm caretakers. Each interview took from 1.5 to 2.0 hr. Tables 4 and 5 summarize the data.

RESULTS

Fish Ponds and Rice Paddies

Ponds are located in or in near the centers of population; they are an integral part of the owners' land. Some typical integrated farm layouts are shown in Figure 2.

Integrated farm ponds are similar to conventional ponds: rectangular in shape, 100 to 5,600 m^2 (Table 5) in area and 0.5 to 0.8 m deep. The crop-fish ponds are subject to certain modifications, especially in their depth and soil preparation, to make them suitable for crop growing. They are 0.3 to 0.6 m deep and the bottom is traversed by canals. The rice-fish sites studied are all within the villages where the farmers live. Kangkung and genjer can be cultivated either in rice fields or fish ponds, but mendong is always cultivated in rice fields.

There are some differences between a rice-fish farm and an ordinary rice farm. The dikes are made higher and broader and the bottom deeper (traversed by diagonal or peripheral canals), often with a small deep basin near the water inlet. The canals give shelter to the fish and aid harvesting. The basin acts as a fish shelter and as a storage pond when draining for harvest, or for any other purposes, such as weeding, pesticides spraying, etc.

Water Supply

All the ponds and rice fields studied derive their water supply from irrigation canals. Each pond or field compartment has a separate inlet and outlet. The system is arranged to prevent effluent flowing into another pond or rice field. The water pipes and screens are all made of bamboo. Some ponds use nutrient-rich water from village or city run-off.

Table 3. The average size of farming establishments and individual freshwater ponds in certain Indonesian provinces.

	Farm area (ha)	Average pond area (ha)
Sumatra	0.11	0.06
Java	0.10	0.06
Bali and Nusa Tenggara	0.14	0.08
Kalimantan	0.37	0.22
Sulawesi	1.03	0.61
Maluku and West Irian	2.02	1.19
Indonesia	0.12	0.07

Farm Management

From interviews with 17 respondents in three areas, it appeared that fish culture is divided into the following operations: rearing of fish for direct human consumption (54%), raising fingerlings from fry (36%) and breeding and fry production (10%). Some of the respondents run polyculture systems, using two to seven species, while others are engaged in conventional monoculture of common carp or java carp. Common carp appears the most suitable species in all integrated farming systems, followed by java carp and tilapias.

Crop-fish Intregration

Most of the rice-fish farms are involved in fingerling production (54%), followed by those raising fish for consumption (46%). Monoculture seems to be more popular than polyculture, and was found in 82% of cases studied. Common carp is the main species used; tilapias, kissing goramy, nilem carp *(Osteochilus hasselti)* and Java carp are minor species. Generally, the fish are stocked 5 d after transplanting the rice seedlings to allow the seedlings to root properly. The rate of stocking varies from 3 to 48 kg of fry or fingerlings for fields of 1,400 to

Table 4. Occurrence of integrated agriculture-aquaculture in Indonesian provinces, based on a case study questionnaire in 1979.

Province	Crops and livestock integrated with fish culture						
	Rice	Vegetables	Chicken	Duck	Goat	Pig	Cattle
North Sumatra	+	–	+	–	–	–	–
West Sumatra	+	–	+	–	–	–	+
Jambi	+	+	+	–	–	–	+
Lampung	+	–	+	–	–	–	+
Jakarta	–	+	+	–	–	–	–
West Java	+	+	+	+	+	–	+
Central Java	+	–	–	–	–	–	–
East Java	+	–	+	+	+	–	+
Bali	+	–	+	–	–	+	–
South Kalimantan	+	–	–	–	–	–	–
West Kalimantan	+	–	+	+	+	+	+
Central Kalimantan	+	–	–	–	–	+	+
South Sulawesi	+	–	–	–	–	–	–
Central Sulawesi	+	–	+	+	–	–	–
Maluku/Nusa Tenggara Barat (NTB)	+	–	–	–	–	–	+

Table 5. Summary of the areas used by small-scale integrated farms in Indonesia responding to a case study questionnaire in 1979.

Crops and livestock integrated with fish culture	Area of farm components (m^2) Fishpond	Paddy field	Dryland	Total	Farmer	Comments
Rice	–	2,800	700	3,500	Suhada	Located in Garut
Rice, kangkung	–	3,780	100	3,880	Eha	
Rice, kangkung	560	4,200	420	5,180	Konceng	
Rice, kangkung	280	2,940	280	3,500	Holis	
Rice, tempe*	1,680	1,890	70	3,640	Suhada	Located in Tasikmalaya; the tempe operation is separately owned
Rice, tahu*	5,600	6,300	100	12,000	Entong	The tahu operation is separately owned
Rice, duck, buffalo	1,120	4,200	100	5,420	Iin Kar	
Genjer	–	812	350	1,162	Adang	
Genjer	2,100	2,000	1,000	5,100	Abdulla	
Mendong	–	1,680	100	1,780	Endang	
Mendong	–	1,050	100	1,150	Bohar	
Mendong	–	420	100	520	Abdulah	
Tahu and chicken; sheep	2,492	–	98	2,590	Abdul	The tahu operation is separately owned
Chicken	400	–	100	500	Rahmat	
Chicken	8,000	–	116	8,116	Abdurahman	The chickens are raised over an 800 m^2 pond
Duck	4,200	–	1,000	5,200	Sarif	
Duck	2,800	8,400	2,800	14,000	Nandang	

*Tempe, tahu–products made from soyabean.

6,300 m^2 and the total yield after 1- to 4-mo culture is 12 to 126 kg (Table 6).

In spite of mass campaigns launched by the government to encourage the use of high yielding IR varieties, some respondents are still farming local traditional varieties, such as C_4. Unlike IR varieties which take about 4 mo to grow, the local varieties require 5 to 6 mo. The local varieties are possibly retained for their better taste and market price. Records from 7 respondents show that an average of 32.6 kg of paddy seed is needed per hectare. Weeding is done twice a season: a month after planting and again a month later. Combined fertilizer urea (70%) and TSP (30%) are commonly used, usually at a rate of 243 kg/ha/season.

The kankung-fish farms are adopting the polyculture system. Here the pond has peripheral and partitioning canals (Figure 2) and a depth of 0.5 m. The fish are stocked 7 d after kangkung planting and are fed with ricebran (3% body weight per day). The stocking rate for 560 to 980 m^2 ponds varies from 5.4 kg (9 bowls) to 50 kg, and the total yield varies from 15 to 170 kg (Table 7).

The kangkung slips are usually planted 25 cm apart after first tilling the pond bottom. Planting is done with the water about 2 cm deep. Urea is given after every harvest. The leaves are harvested every 15 to 25 d and the whole plantation has to be totally renewed every year.

The ponds used for genjer-fish farming also have peripheral and partitioning canals and are 0.5 m deep. The fish are stocked 7 d after genjer planting, and fed with rice bran (2% body weight per day). Examples of the stocking data and yields for common carp monoculture and polyculture with tilapia are given in Table 8.

The genjer is also planted in rows, with the plants 25 cm apart on the raised pond beds. Planting times vary according to the crop rotation practiced. In the Garut area, green manure, such as aquatic vegetation, is sometimes applied and in many other cases, such as in the Cianjur area, other fertilizers, such as urea and chicken manure, are used. The young sprouts and flowers are harvested at intervals of 3 to 4 d.

The ponds used for mendong-fish culture are prepared in the same way as paddies for rice-fish culture. The depth of water in the pond proper is only 5 to 10 cm and 30 to 50 cm in the canals. Polyculture is used and the fish are fed with rice bran (4% body weight per day). Examples of stocking data and yields are given in Table 9. The operations include fry production from introduced broodstock.

Mendong seedlings are planted 40 cm apart, so that for a 1,050-m^2 pond 12,600 seedlings are needed. Urea is applied at a rate of 6 to 50 kg (average 35 kg)/season. Weeding is done twice a season: 1.5 mo after planting and again 1.5 mo later. The first harvest is taken after 6 mo. The plantation may produce 7 harvests taken every 4 mo from the second up to the seventh. The whole crop has to be removed and new plants brought in after the seventh harvest (2.5 yr).

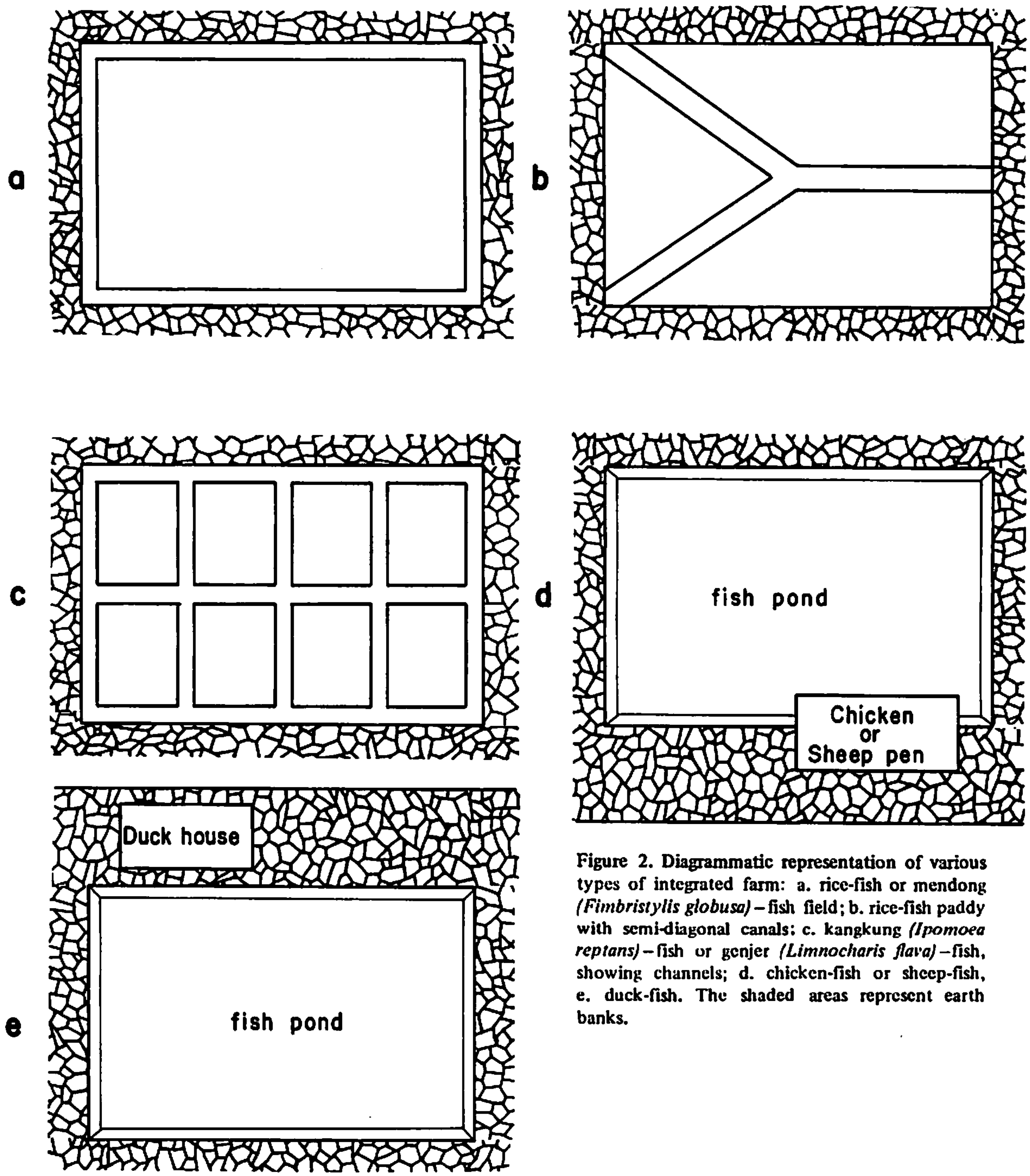

Figure 2. Diagrammatic representation of various types of integrated farm: a. rice-fish or mendong *(Fimbristylis globusa)* – fish field; b. rice-fish paddy with semi-diagonal canals; c. kangkung *(Ipomoea reptans)* – fish or genjer *(Limnocharis flava)* – fish, showing channels; d. chicken-fish or sheep-fish, e. duck-fish. The shaded areas represent earth banks.

Livestock-Fish Integrated Farms

The chicken-fish farms usually practice monoculture of common carp or java carp stocking with 1 to 3 cm fry and 10 g fingerlings. The alternative is polyculture of common carp, tilapia, nilem carp and kissing goramy. No supplemental feeds are given. Table 10 gives examples of inputs and yields for chickens and fish.

The chickens are kept in battery-houses, erected on elevated parts of the land or the pond bank, with a part of the chicken house protruding over the pond. Generally, the houses are raised on wooden poles with split bamboo walls and are supported by some cement foundations. This allows waste feed and excreta to fall into the pond. Plate 1 shows a chicken house over pond water in Babakah Parung. It is estimated that 20% of the feed and almost all excreta of the chickens drop into the water. The lifetime of layer chickens is 2 yr, and each chicken produces about 40 g of excreta per day.

The duck-fish farms culture common carp, nilem carp, giant goramy and java carp. In one farm using panyelang rice-fish culture, advanced fingerlings of common carp were stocked whereas in a 4,200-m^2 pond system, common carp and Java carp were stocked together. Another farmer keeps ducks on his 1,050-m^2 java carp broodstock pond. Supplemental feed (3% body weight per day) is given apart from the panyelang-based system, where no feed is applied. Table 11 gives examples of inputs and yields. The duck house is located at a suitable place on the pond bank and has a simple bamboo-tiled roof and earthern floor. The ducks swim on the pond during the day and spend the night in the duck house.

One farmer in Tasikmalaya keeps 120 ducks, together with others owned by another farmer, on his 4,200-m^2 paddy field in which he practices panyelang fish culture. The total number of ducks is not known. Another farmer, with a 4,200-m^2 pond, has fenced off a 900-m^2 duck enclosure using bamboo where he runs 50 ducks, whereas a farmer with a 1,050-m^2 pond allows his 60 ducks to range freely over all the pond (Table 11). All the farmers use a high egg-yielding duck variety: Alabio, originally found in South Kalimantan. The duck feed is a mixture of rice bran, maize, soybean and some minerals. About 80% of the ducks lay one egg each day and their productive lifetime is about 2.5 yr. The duck farms can produce ducklings as well as eggs.

In a sheep-fish integrated farm in Tasikmalaya (Plate 2), monoculture of the giant goramy is practiced in an 84-m^2 pond, with 2,500 fingerlings (25 kg) stocked and occasionally given tahu waste products as supplemental feed. The total yield from a 1-yr culture period is 200 kg and the mortality rate varies from 10% to 20%. The farmer keeps a total of 4 sheep in two sheds on the pond bank which overhang the pond. The floors allow faeces, waste feed and urine to drop into the water. The sheep were brought in when 8 mo old (about 8 kg each) and, within 10 mo, were grown to about 20 kg each; two lambs were also produced. Their daily feed was about 40 kg of grasses and 15 kg of soybean cake wastes.

SOCIOECONOMICS

Social Status of Farmers

In the study area, the community consisted of 50% farmers, 20% merchants and 30% officials and others (Djajadiredja et al. 1979). The respondents had an elementary education background and 67% of them had more than 10 yr farming experience: the remainder had less. In general, the farmers use labor from outside the family and not all of them use their children to help on the farm; they prefer to send their children to school and some succeed in sending them for higher education.

Almost all farmers are Islamic, enjoy good social status, and are prominent in village community affairs. The families of the respondents usually consisted of the farmer, his wife and children, but, in certain cases, grandchildren stay with the family. The size of the respondents' families varied from 2 to 11 people (Table 2). Their daily household expenditure varies from Rp* 800 to Rp 2,500, with an average of Rp 267 per head.

ECONOMIC ANALYSES

Rice-Fish Farming

Table 12 summarizes the inputs and outputs for seven respondents. The major input costs were, on average, as a % of the total: construction, 35%; labor, 34% and fish seed, 18%. The other components, such as fish feed, fertilizer, taxes and pesticides, each account for less than 6%.

Kangkung-Fish Farming

Table 13 summarizes the inputs and outputs for three respondents. The major input costs were, on average, as a % of the total: labor, 38% and fish seed, 33%. The minor components were fish feed, 10%; pond construction, 8% and fertilizer, 8%, etc.

*US$1.00 = Rp 627.

Genjer-Fish Farming

Table 14 summarizes the inputs and outputs for two respondents. Labor can account for as much as 73% of the total input cost: other inputs were relatively minor, e.g., pond construction, 10% and fish seed, 13%.

Mendong-Fish Farming

Table 15 summarizes the inputs and outputs for three respondents. The major input costs were, on average, as a % of the total: labor, 28%; construction costs, 27%; fish feed, 18% and fish seed, 16%. Other input costs were relatively minor: less than 6%.

Chicken-Fish Farming

Table 16 summarizes the inputs and outputs for three respondents. The major input costs were, on average, as a % of the total: chicken feed, 57%; labor, 12% and fish seed, 10%.

Duck-Fish Farming

Table 17 summarizes the inputs and outputs for two respondents. The major input costs were, on average, as a % of the total: labor for duck raising, 31%; fish fingerlings, 17%; pond construction, 16% and duck feeds, 14%.

Sheep-Fish Farming

Table 18 summarizes the inputs and outputs for the single respondent. The major input costs, as a % of the total, were fish seed, 34%; labor, 22%; purchase of sheep, 20% and sheep feed, 18%.

MARKETING

Fish

The fish dealers usually buy at the farms and even take part in the harvest. The fish are taken to the local market or to other markets located outside the producing area. In Singapura (Tasikmalaya), the fish dealers have united into the Fish Dealers Association (I.P.I.S.). Here, as well as in some other important fish culture centers (e.g., Sukabumi and Bandung), there are special, well-established live fish markets. Live fish markets are also found in other cities attached to general markets. Live fish are still transported in traditional bamboo baskets, but for long distances, oxygenated plastic bags are now in common use.

Crops

Rice and other crops from the integrated crop-fish farms are sold using the ordinary market channels. The farmers mill their own rice and sell it in small quantities according to their financial needs. Rural Cooperative Units also exist in the study area, which provide credit for the purchase of seed, fertilizer and pesticides, etc. and to which the farmers may sell their produce.

As kangkung and genjer can be cropped daily, the farmers usually have established customers who manage both harvesting and marketing. The price by weight or number of bunches and the method of payment are usually negotiated beforehand. The produce is sold to the local market, delivered to restaurants, or distributed door to door.

The harvested mendong are usually cleaned, steamed or boiled, colored and further processed, either by the farmers themselves or by small-scale home industries. This produce is traded extensively, often reaching places outside the producing area.

Livestock

Marketing of livestock follows normal channels, as in the case of other agricultural produce. Poultry and eggs are often sold to established customers (restaurants or eggtraders). The eggs are usually delivered by the farmers who also take any excess to the local market. Ducks and sheep, when available for occasional sale, are also usually taken to the market by the farmers. Sheep of the "Garut types" are widely farmed and traded in the study area.

Discussion

The study considers small-scale integrated farms with landholdings ranging from 500 to 14,000 m^2. The ratio between water surface area and dry land is about 9:1 and, as the tables show, almost all the respondents used areas which exceeded the average fish pond holding for Java, which is about 0.06 ha.

The rice fields used for rice-fish culture varied from 1,400 to 6,300 m^2 and the integrated farm ponds from 400 to 1,408 m^2. Integrated farming systems appear to have advantages and to be suitable for further adoption by farmers. An average sized rice field of 3,370 m^2, which produces 3,322 kg rice per year (2 crops, worth Rp 247,979), can get an additional income of Rp 129,000 from 290 kg of fish produced. Similar advantages are derived from integrating fish ponds with other crops, chicken, ducks and cattle. The fish yields per hectare from kangkung-fish, genjer-fish, mendong-fish, chicken-fish and duck-fish operations are 3.40, 0.91, 1.50, 8.10 and 3.60 t, respectively. The average net fish yield per hectare from rice fields is 623 kg/yr: almost the same as the average production level found in West Java. Farmers believe that fish culture benefits rice production to a certain extent and fisheries workers confirm this. This might happen also with mixed culture of fish and vegetables. The interrelationships between the various products must be studied further.

Increased production of fish in poultry and livestock integrated farms is predictable since waste feed and excreta fertilize the ponds. This recycling system is certainly very economical for the rural farmers. Poultry manure is known to be the most powerful fertilizer for fish ponds whereas sheep manure is usually regarded as less effective and cow manure intermediate between these. The health of chickens kept in houses built over ponds has been questioned and their susceptibility to diseases should be studied. Some farmers, however, stress that diseases may often occur in conventional chicken houses as well.

As Table 5 shows, there may be up to three to four components in the integrated farm, e.g., rice/tempe-fish, rice/tahu-fish, rice/duck/buffalo-fish and tahu/chicken/sheep-fish. Some components, such as the ducks, buffalo and the tempe or tahu mills, may not belong to the main farmer. He allows others to raise animals and invest capital in his farm in return for free animal manure, feed wastes or waste products. Integrated farming, combining fish, crops, livestock and home industries, and even using human and domestic wastes (Djajadiredja et al. 1979), appears to be the most economical and productive system for small-scale rural farmers. It must be pointed out, however, that health, sanitation and aesthetic aspects require further study.

In crop-fish systems, kangkung has wide market preferences, whereas genjer enjoys this only in certain areas. Mendong is also marketable only in certain areas but its products are widely distributed throughout the country. It is interesting to note here that other vegetables are commonly planted on pond banks, e.g., the climbing plant (*Cucurbita moschata* Duck), which is supported by a bamboo framework partly or totally overhanging the pond.

The use of pesticides by farmers is being limited and their importation, use, storage, handling and distribution are subject to strict regulations under a recent law. Only pesticides of low or moderate toxicity are normally allowed in rice fields. High toxicity pesticides may be allowed with certain restrictions. The farmers have themselves encouraged proper methods and techniques to overcome this problem. They use short period fish nursery or rearing schemes in which fry or advanced fry are raised for 21 to 30 d during the intervals between spraying of approximately 30 d. When more than 30 d culture is needed, e.g., up to 90 d for growing fish for consumption, the fish are confined in special small compartments from just before spraying until toxicity has decreased. Ideally, all pesticides should be of low toxicity to fish but still effective for crop pest eradication.

Conclusion

Integrated agriculture-aquaculture farming systems make efficient use of resources and maximize the yields of a wide diversity of food products from limited water surface areas, thereby increasing the farmers' income. They also improve the protein supply and nutrition of the farm families and generate employment.

Integrated systems should combine fish, crop and livestock components. Further combination with home industries and domestic waste recycling is in line with the National Development Program, but increased attention must be paid to research and pilot projects, training and extension and availability of credit and supplies.

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Table 6. Annual fish and rice yields from integrated rice-fish farming systems in Indonesia (TSP, triple superphosphate; DAP, diammonium phosphate).

Paddy area (m^2)	Species: quantity stocked	With or between rice crops	Culture period (mo)	Fish yield	Yield in g/m^2	Rice seedlings planted (kg)	Crops/ yr	Fertilizers (kg)			Rice yield (kg)
								Urea	TSP	DAP	
1,400	Nilem carp: 20 cups (12 kg)	Between	1	60 cups (36 kg)	26	2	2	25	2	–	500
	Java carp: 5 cups (3 kg)	With	2	25 cups (15 kg)	11						
1,890	Common carp: 12 cups + 6 bowls (11 kg)	With	2 × 1	132 bowls (79 kg)	42	5	2	15	10	–	867
	and Tilapia: 20 kg			120 kg	63						
2,800	Common carp: 14 cups (8.4 kg)	With	2 × 1	44 bowls (26.4 kg)	9	18	2	60	30	–	1,330
2,800	Common carp: 8 cups (4.8 kg)	Between	1	12 kg	4	3.5	1.5	25	–	–	500
	Common carp: 5 kg	With	4	12 kg	4						
4,200	Common carp: 17 kg	Between	1	85 kg	20	15	2	80	25	–	2,600
	Common carp: 10 cups + 8 bowls (12 kg) – Total 23 kg	With	2 × 1	126 kg	30						
4,200	Common carp: 50 kg	Between	1	135 kg	32	10	2	125	–	–	2,333
	Common carp: 3,000 fish (15 kg)	With	2.5	50 kg	12						
6,300	Common carp: 3 kg Kissing gouramy: 42 kg and Nilem carp: 5 bowls (3 kg)	With	2.5	Total for all species –117 kg	19	25	2	54	–	120	3,500

Table 7. Stocking/fertilizing data and yields from integrated farm ponds combining kangkung *(Ipomoea reptans)* and fish culture in Indonesia (for an assessment of fish weights when only a volume figure in 'bowls' is given, compare with Table 6 and text; for kangkung, 1 bundle weighs about 200 g).

	Pond area (m^2)		
	560 (140 planted with kangkung)	840	980
Fish			
1. Stocking data			
Common carp	10 kg	400 fingerlings: 4 kg	3 bowls
Java carp	–	7 cups	–
Tilapia	10 kg	–	6 bowls
Nilem carp	15 kg	–	–
Kissing goramy	7.5 kg	–	–
Sepat siam	7.5 kg	–	–
Total	50 kg	8 kg	9 bowls
2. Culture period	3 mo	21 d	2 mo
3. Number of harvests/yr	3	10	4
4. Yield (kg)/culture period	170	25	15
Kangkung			
1. Cropping paterrn (bundles/cropping interval)	175/2 wk	3,900/25 d	2,000/2 wk
2. Annual yield (bundles)	4,200	43,200	40,000
Fertilizer input (kg urea/time interval)	3/2 wk	20/25 d	10/2 wk

Table 8. Stocking/fertilizing data and yields from integrated farm ponds combining genjer *(Limnocharis flava)* and fish culture in Indonesia (1 bunch contains 20 stalks, approximately 200 g).

	Pond area (m^2)	
	812	2,000
Fish		
1. Stocking data/culture period		
Common carp	5 kg	4,000 fry: 6 kg
Tilapia	–	1 kg
Total	5 kg	7 kg
2. Culture period	105 d	90 d
3. Yield/culture period		
Common carp	20 kg	28 kg
Tilapia	–	20 kg
Total	20 kg	48 kg
Genjer		
1. Cropping frequency	110 bunches/4 d	450 bunches/3 d
2. Annual yield	8,140 bunches	54,000 bunches
Fertilizer inputs	aquatic vegetation	20 kg urea + 30 kg chicken manure/3 mo

Table 9. Stocking/fertilizing data and yields from integrated farm ponds combining Mendong *(Fimbristylis globusa)* and fish culture in Indonesia (for an assessment of fish weights when only a volume figure in 'bowls' or 'cups' is given, compare with Table 6 and text).

	Pond area (m^2)		
	420	1,680	1,050
Fish			
1. Stocking data/culture period			
Java carp	4 kg	4 cups	Broodstock (8 pairs)
Kissing goramy	–	2 cups	Broodstock (2 pairs)
Common carp	3 kg	–	–
Tilapia	2 kg	–	–
Total	9 kg	6 cups	10 pairs
2. Culture period	2.5 mo	2 mo	2 mo
3. Yield/culture period	27 kg	45 kg	20 bowls java carp + 20 bowls kissing goramy
Mendong			
1. Yield/crop (kg)	300	800	736
2. Annual yield (kg)	750	2,100	1,840
Fertilizer inputs			
1. Kg urea/crop	6	50	50
2. Kg urea/yr	15	125	125

Table 10. Inputs and yields for integrated chicken-fish farms in Indonesia.

	Pond area (m^2)		
	400	2,408	800
Fish			
1. Stocking data	–	70 kg	–
Nilem carp	–	40 kg	–
Common carp	–	60 kg	6,000 1 to 3-cm fry: 12 kg
Kissing goramy	–	40 kg	–
Java carp	5 kg (fingerlings)	–	–
Total	5 kg	210 kg	12 kg
2. Culture period	3 mo	3 mo	3 mo
3. Yield	50 kg	650 kg	30 kg
Chicken			
1. Stocking data			
Number	240	29	300
Type	layers	–	layers
2. Daily feed (ricebran)	27 kg	2.5 kg	30 kg
Layers feed	–	0.2 kg	–
3. Yield	150 eggs/d	55 kg/2 mo	240 eggs/d

Table 11. Inputs and yields for integrated duck-fish farms in Indonesia.

	Pond area (m^2)		
	4,200 (actual duck enclosure = 900 m^2)	1,050	4,200 (paddy)
Fish			
1. Stocking data			
Common carp	20 kg	–	17 kg
Nilem carp	40 cups + 20 kg	–	–
Giant goramy	8,000 fingerlings	–	–
Java carp	–	Broodstock: ♂♂20 kg + ♀♀ kg	–
Total	84 kg	50 kg	17 kg
2. Culture period	2 mo	3 mo	1 mo
3. Daily supplemental feed (ricebran)	3.3 kg	3.0 kg	–
4. Yields			
Common carp	50 kg	–	85 kg
Nilem carp	230 kg	–	–
Giant goramy	1,500 kg	–	–
Java carp	–	200 cups	–
Total	345 kg	120 kg	85 kg or 20 g/m^2
Ducks			
1. Number stocked	50	60	
2. Daily feed	3 kg	4 kg	
3. Yield (eggs/d)	25	48	

Table 12. Annual inputs and returns from 7 rice-fish farms in Indonesia, excluding any depreciation costs (unit of currency–Rupiah (Rp): US$1.00 = Rp 627).

	Paddy areas (m^2)						
	1,400	1,890	2,800	2,800	4,200	4,200	6,300
Fish							
1. Inputs							
labor	12,000	12,400	4,800	8,400	21,800	22,400	23,200
fingerlings/fry	38,000	20,800	8,850	11,200	52,400	86,000	41,000
fertilizers	–	–	–	–	–	–	–
feed	20,000	10,000	–	–	–	–	15,000
Total (A)	70,000	43,200	13,650	19,600	74,200	108,400	79,200
2. Output (B)	170,000	84,000	25,200	44,000	168,800	296,000	115,000
Net return (B – A)	100,000	40,800	11,550	24,400	94,600	187,600	35,800
Rate of return as a % of A	143	94	85	124	127	173	45
Rice							
1. Inputs							
field construction	40,333	34,100	40,000	50,500	75,768	150,000	113,666
buildings and equipment	2,200	2,200	2,200	2,200	2,200	2,200	2,200
labor	16,000	34,500	39,450	52,600	68,990	107,161	75,200
seedlings	800	2,500	1,050	3,600	4,500	2,000	7,500
fertilizers	4,320	7,000	5,250	12,600	14,700	17,500	24,360
pesticides	500	–	–	–	–	1,400	–
taxes	1,400	1,900	2,800	2,800	4,200	4,200	6,300
Total (C)	65,553	82,200	90,750	124,300	170,358	284,461	229,226
2. Output (D)	110,000	143,922	150,000	164,920	322,400	396,610	448,000
Net return (D – C)	44,447	61,722	59,250	40,620	151,042	112,149	218,774
Rate of return as a % of C	68	75	65	33	89	39	95
Fish + Rice							
1. Total costs (A + C)	135,553	125,400	104,400	143,900	244,558	392,861	308,426
2. Total returns (B + D)	280,000	227,922	175,200	208,920	491,200	692,610	563,000
3. Total net return	144,447	102,522	70,800	65,020	246,642	299,749	254,574
4. Total rate of return as a % of total costs	107	82	68	45	101	76	83

Table 13. Annual inputs and returns from 3 integrated kangkung *(Ipomoea reptans)*-fish farms in Indonesia, excluding depreciation costs, other than the figure given for the 560 m^2 pond for which construction costs were depreciated at 10% over 15 yr (unit of currency, Rupiah (Rp): US$ 1.00 = Rp 627).

	Pond area (m^2)		
	560 (only 140 planted)	840	980
Fish			
1. Inputs			
pond construction	8,214	–	–
labor	24,000	15,000	8,800
fingerlings	75,000	85,900	12,000
feed	–	55,000	–
taxes	560	–	–
Total (A)	107,774	155,900	20,800
2. Output (B)	204,000	305,000	24,000
3. Net return (B – A)	96,226	149,100	3,200
4. Rate of return as a % of A	89	96	15
Kangkung			
1. Inputs			
field construction	–	22,000	17,680
labor	4,000	99,000	50,350
seedlings	–	–	1,000
fertilizers	8,400	19,200	14,000
pesticides	–	6,000	–
taxes	–	840	1,000
Total (C)	12,400	147,040	84,030
2. Output (D)	20,160	237,600	160,000
3. Net return (D – C)	7,760	90,560	75,970
4. Rate of return as a % of C	63	62	90
Fish + Kangkung			
1. Total costs (A + C)	120,174	302,940	104,830
2. Total return (B + D)	224,160	542,600	184,000
3. Total net returns	103,986	239,660	79,170
4. Total rate of return as a % of total costs	87	79	76

Table 14. Annual inputs and returns from 2 integrated genjer *(Limnocharis flava)*-fish farms in Indonesia, excluding depreciation costs (unit of currency, Rupiah (Rp): US$ 1.00 = Rp 627).

	Pond area (m^2)	
	812	2,000
Fish		
1. Inputs		
labor	12,800	25,000
fish	8,000	18,000
fertilizer	–	–
feed	–	4,560
Total (A)	20,800	47,560
2. Output (B)	32,000	94,000
3. Net return (B – A)	11,200	46,440
4. Rate of return as a % of A	54	98
Genjer		
1. Inputs		
field construction	–	14,700
field preparation	5,600	–
equipment	–	–
labor	15,600	95,300
seedlings	1,000	–
fertilizer	–	1,200
pesticides	–	–
taxes	812	200
Total (C)	23,012	111,400
2. Output (D)	56,320	379,200
3. Net return (D – C)	33,308	267,800
4. Rate of return as a % of C	145	240
Fish + Genjer		
1. Total costs (A + C)	43,812	158,960
2. Total returns (B+D)	88,320	473,200
3. Total net returns	44,508	314,240
4. Total rate of return as a % of total costs	102	198

Table 15. Annual inputs and returns for 3 integrated mendong *(Fimbristylis globusa)*-fish farms in Indonesia, excluding depreciation costs (unit of currency, Rupiah (Rp): US$ 1.00 = Rp 627).

	Water surface area (m²)		
	420	1,050	1,680
Fish			
1. Inputs			
labor	6,000	10,000	18,600
fish seed	20,000	15,000	12,000
feed	15,000	30,000	7,500
Total (A)	41,000	55,000	38,100
2. Output (B)	57,240	90,000	90,000
3. Net return (B − A)	16,240	35,000	51,900
4. Rate of return as a % of A	40	64	136
Mendong			
1. Inputs			
field construction	11,000	26,000	43,000
equipment	2,750	3,500	3,000
labor	11,700	21,000	16,800
seedlings	800	2,000	3,200
fertilizer	1,050	8,750	8,750
pesticides	–	–	375
taxes	420	1,050	1,680
Total (C)	27,720	62,300	76,805
2. Output (D)	60,000	117,750	134,400
3. Net return (D − C)	32,280	55,450	57,595
4. Rate of return as a % of C	116	89	75
Fish + Mendong			
1. Total costs (A + C)	68,720	117,300	114,905
2. Total returns (B + D)	117,240	207,750	224,400
3. Total net returns	48,520	90,450	109,495
4. Total rate of return as a % of total costs	71	77	95

Table 16. Annual inputs and returns for 3 integrated chicken-fish farms in Indonesia, excluding depreciation costs (unit of currency, Rupiah (Rp): US$ 1.00 = Rp 627).

	Pond area (m²)		
	400	800	2,408
Fish			
1. Inputs			
pond construction	880	22,000	44,000
labor	7,200	168,000	30,000
fingerlings	17,000	240,000	189,000
feed	21,900	–	–
fertilizer	10,600	1,800	8,100
taxes	400	800	2,400
Total (A)	57,980	432,600	273,500
2. Output (B)	130,600	1,201,800	610,350
3. Net return (B − A)	72,620	769,200	336,850
4. Rate of return as a % of A	125	178	123
Chickens			
1. Inputs			
chicken house	38,280	110,000	11,000
labor	150,000	127,400	36,000
stocking	48,000	525,000	82,500
feed	985,500	1,521,450	40,590
medication	–	19,200	–
Total (C)	1,221,780	2,303,050	170,090
2. Output (D)	1,773,000	3,585,000	247,500
3. Net return (D − C)	551,220	1,281,950	77,410
4. Rate of return as a % of C	45	56	46
Fish + Chickens			
1. Total costs (A + C)	1,279,760	2,735,650	443,590
2. Total returns (B + D)	1,903,600	4,786,800	857,850
3. Total net returns	623,840	2,051,150	414,260
4. Total rate of return as a % of total costs	49	75	93

Table 17. Annual inputs and returns for 2 integrated duck-fish farms in Indonesia, excluding depreciation costs (unit of currency, Rupiah (Rp): US $1.00 = Rp 627).

	Pond area (m^2)	
	4,200 (ducks kept on 900 m^2 only)	1,050
Fish		
1. Inputs		
pond construction	180,000	5,500
labor	61,000	36,500
fingerlings	162,000	–
broodstock	–	40,000
feed	20,000	8,100
fertilizer	10,950	8,640
taxes	4,200	1,050
extra labor	60,000	–
Total (A)	498,150	99,790
2. Output (B)	940,950	248,640
3. Net return (B – A)	442,800	148,850
4. Rate of return as a % of A	89	149
Ducks		
1. Inputs		
duck house	4,400	1,000
labor	182,500	182,500
ducklings	50,000	6,000
feed	116,800	43,200
Total (C)	353,700	232,800
2. Output (D)	447,500	610,000
3. Net return (D – C)	93,800	377,200
4. Rate of return as a % of C	27	162
Fish + Ducks		
1. Total costs (A + C)	851,850	332,590
2. Total returns (B + D)	1,388,450	858,640
3. Total net returns	536,600	526,050
4. Total rate of return as a % of total costs	63	158

Table 18. Annual inputs and outputs for an integrated sheep-fish farm, also producing tahu waste products, in Indonesia (unit of currency, Rupiah (Rp): US$ 1.00 = Rp 627).

	Pond area (m^2)
	84
Fish	
1. Inputs	
pond construction (depreciated at 10% over 15 yr)	2,000
labor	8,000
fingerlings (giant goramy)	87,500
taxes	100
Total (A)	97,600
2. Output (B)	120,000
3. Net return (B – A)	22,400
4. Rate of return as a % of A	23
Sheep	
1. Inputs	
shed construction (depreciated at 10% over 5 yr)	5,500
purchase of sheep	52,000
labor: permanent	10,000
labor: for feeding	45,000
feed	45,000
Total (C)	157,500
2. Output	
sheep	192,000
tahu waste products	45,000
Total (D)	237,000
3. Net return (D – C)	79,500
4. Rate of return as a % of C	50
Fish + Sheep	
1. Total costs (A + C)	255,100
2. Total returns (B + D)	357,000
3. Total net returns	101,900
4. Total rate of return as a % of total costs	40

Plate 1. Chicken-fish integrated farming at Babakak Parung.

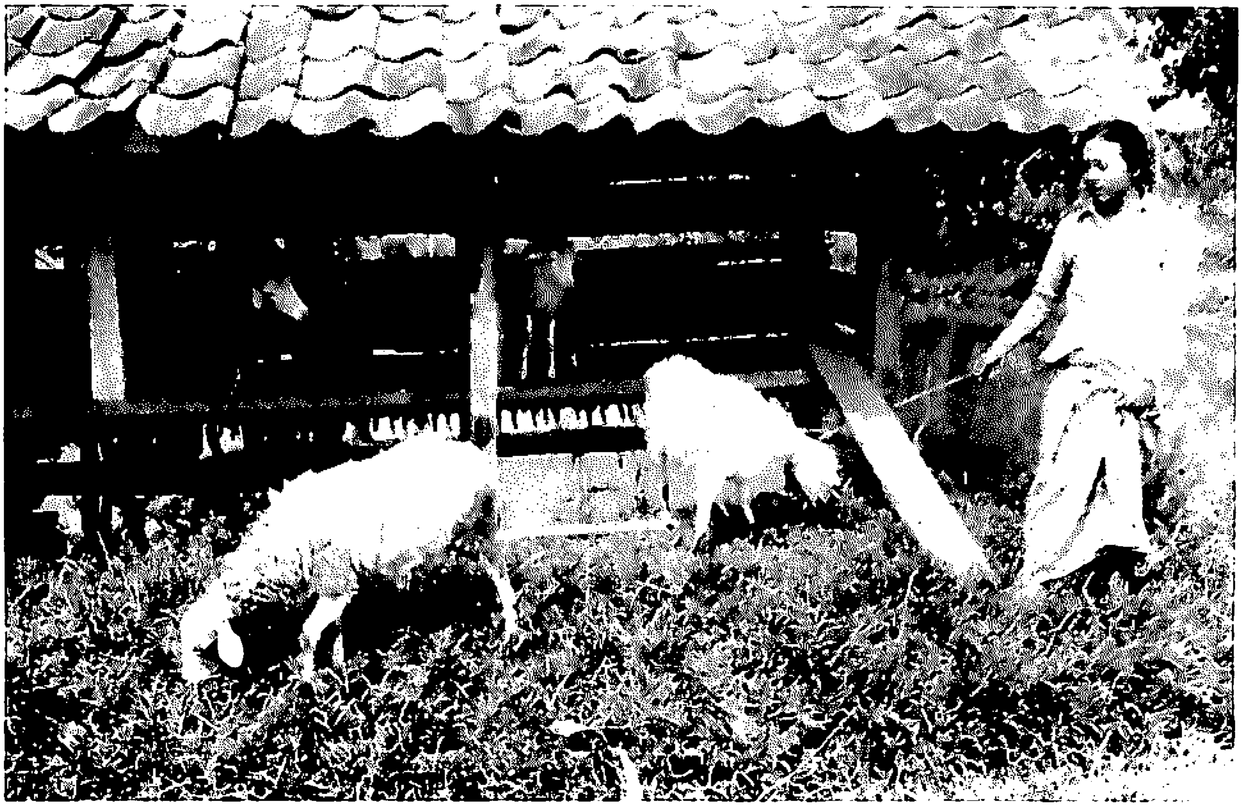

Plate 2. Integrated sheep-fish farming at Tasikmalaya.

Reference

Djajadiredja Rustami, Koesoemadinata Santosa, Zulkifli Jangkaru, Salman Kodijat and Oman Kertaman. 1979. The role of nightsoil and household waste in freshwater fish culture. A case study in West Java, Indonesia. Paper presented at International Development Research Centre (IDRC) Nightsoil Survey Leader's Meeting, 4-6 June 1979, Singapore. 56 p.

Additional bibliography

Ardiwinata, O. 1953. Common carp culture in rice fields. Vorhink Van Hoeve Vol. V. Bandung–'s Gravenhage, Vorkink, Bandung. 116 p. (In Indonesian with English summary).

Satari, Gunawan. 1962. Budidaya padi-sawah dengan ikan. Penelitian tentang beberapa aspeck agronomi. (Wet rice cultivation with fish culture: a study on some agronomical aspects). Bogor Agricultural University (IPB), Bogor, Indonesia. 126 p.

Directorate General of Fisheries. 1974. Estimated potency of Fisheries in Indonesia, Jakarta. 18 p. (In Indonesian).

Directorate General of Fisheries. 1976. Fisheries statistics of Indonesia, No. 6, 1976. Department of Agriculture, Jakarta. 91 p.

Djajadiredja Rustami and Zulkifli Jangkaru. 1977. A note on newly-developed fish culture methods in Indonesia. Proceeding of the ASEAN meeting of Experts on Aquaculture, Indonesia, ASEAN 77/FA. Eg A/Doc. W. 4. Inland Fisheries Research Institute, Bogor. 8 p.

Djajadiredja Rustami and Zulkifli Jangkaru. 1978. Small scale fish/crop/livestock/home industry integration: a preliminary study in West Java, Indonesia. Report No. 7. Inland Fisheries Research Institute, Bogor. (A report submitted to FAO Regional Office, Bangkok). 55 p.

Carp Culture in Japanese Rice Fields

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Edited and condensed by Roger S.V. Pullin, ICLARM, from the author's original work, "Carp culture in rice fields as a side work of Japanese farmers," Ministry of Agriculture and Forestry, Japanese Government, 1954, with kind permission of the author and the Ministry of Agriculture and Forestry.

Abstract

Traditional carp culture methods in Japanese rice fields are described in detail with production statistics for the years 1949 to 1952. The techniques described include field preparation, spawning and fry collection, fingerling culture, further growout, overwintering and harvest. An economic analysis is included from the 1952 census of Nozawa town, Nagano Prefecture

Introduction

Fish culture in Japanese rice fields has been practiced for over a century. Its origin is poorly documented but was probably the discovery that escapees from a carp pond into a rice field showed improved growth. The deliberate combination of rice and carp culture was successfully developed around 1855 in the Saku Plain, Nagano Prefecture and spread to other regions from the 1870s, with encouragement from central and local administration.

The fish are kept in rice field water and are regarded as a by-product of secondary importance to the rice crop. Fish culture, like pig or poultry husbandry, is a part-time activity for the farmers. It is important, however, not only as a source of protein for farmers heavily dependent on a rice diet but also as a supplementary source of income. The relative importance of these benefits has been investigated and the majority of the farmers use their fish as a saleable crop rather than for home consumption.

This paper describes the techniques used for fish culture in rice fields without any attempt to investigate its scientific basis. The information available from experiments and the farmers' experiences is scattered and unreliable. Most of the techniques described here are from observations made on the Saku Plain and are fairly typical of rice and fish culture practices throughout Japan, although there are regional variations. The main species used is the common carp, *Cyprinus carpio* (Koi, Japanese common name).

The Suitability of Rice Fields for Carp Culture

Carp will adapt to a wide range of freshwater habitats, including most rice fields, but less than 1% of a total Japanese field area of 3 million ha was used for carp culture in 1954. Production in the early 1950s remained around 1,000 t (Table 1) following a peak of 3,400 t in 1943, encouraged by war-time food production subsidies. Production will increase only if the farmers can be persuaded to establish the necessary techniques and markets and to overcome their resistance to new ideas. This will probably be a slow process as farming practices are traditionally passed from father to son.

Fish culture in rice fields requires careful management of water levels by irrigation and drainage, avoiding flooding and drying. Terraced or slightly sloping fields with plentiful supplies of warm water are the most suitable. A compacted soil type is preferred to avoid water seepage and to minimize the depth of the mud substrate. Supervision of the fish is best organized on a community basis. The fields should be within easy reach to allow frequent visits and also close to any accessory ponds and to reliable sources of fish food. Marketing should be organized by experienced fish merchants as the rice farmers lack the necessary expertise.

Rice Field Construction and Operation

Rice fields of conventional construction are usable for fish culture, but it is preferable to use fields specifically designed for the purpose. Individual fields vary in

Table 1. Japanese fish production from rice field culture, pond culture and natural waters taken from Ministry of Agriculture and Forestry statistics, 1949 to 1952. The differences between the figures for carp and all fish result from small numbers of wild and domesticated goldfish (*Carassius auratus*), other cyprinids, loach (*Misgurnus anguillicaudatus*) and ayu (*Plecoglossus altivelis*). The areas of rice fields and rice production figures are given for comparison.

	1949	1950	1951	1952
Total area of rice fields (ha)	2,847,000	2,847,000	2,999,600	2,999,600
Rice crop (m^3)	11,091,060	11,295,000	10,665,360	11,611,080
Area of rice fields used for carp culture (ha)	9,533	9,565	9,552	8,465
Area of rice fields used for all fish culture (ha)	9,628	9,615	9,568	8,517
Fish production from				
1. Rice field culture				
(a) Carp (kg)	918,375	1,238,250	1,547,625	1,169,625
(b) All fish (kg)	938,625	1,248,375	1,552,875	1,176,000
(c) Seed fish (000)	80,216	149,038	73,016	22,802
2. Pond culture				
(a) Carp (t)	1,981.9	2,902.9	3,071.6	4,834.1
(b) Seed fish (000)	148,557	93,033	122,595	249,018
3. Natural waters				
(a) River carp (t)	390.4	1,201.9	721.9	695.6
(b) Carp from lakes, etc. (t)	673.9	841.1	839.6	960.4

area from 3.3 m^2 to 0.3 ha, and in shape according to land levels, irrigation and drainage systems. The dikes separating the fields and bordering the irrigation canals are rigid structures, 30 cm wide and 40 to 45 cm high, reinforced with straw on their inside walls when yearlings or 2-yr-old fish are stocked. Soybeans are planted on top of the dikes for home consumption in the fall.

Each rice field receives water from an irrigation canal or adjacent field via an intake, usually at a corner. This may be a temporary breach in the dike or a wooden duct set through the dike at the field bed level. The duct, 1.8 to 3.6 m long, 21 to 30 cm wide and 12 cm deep, has a sliding inlet sluice and discharges into the field through an upwelling screen with 1-cm gaps. The area around the intake is further screened with split bamboo, mulberry or other local wood to a height of 45 to 60 cm, to keep out debris and small fish. The field drain, usually diagonally across from the intake, has an identical screen (Plate 1) and is a simple breach in the dike plugged with rubble, which can be adjusted to control the depth and flow of water. Each field has a catch basin of area about 3.3 m^2 and depth 45 to 60 cm below the field bed, with wooden boards or rocks reinforcing its walls. This connects with a shallow trench in the field bed about 30 cm wide, which runs either between the intake and drainage areas or around the field periphery. This trench is not planted to rice; it directs the fish to the catch basin on draining. The number and arrangement of intakes, drains and catch basin vary with the field area and availability of water.

The depth of water is varied according to the temperature, the size and feeding activity of the fish, the strain of rice planted and the amount of pesticides used, but is normally maintained at 12 to 15 cm in spring and summer and 18 cm in the fall up to the fish harvest, with daily or more frequent inspections. The water is kept stagnant during the day and supplemented at night from the intake if necessary.

The ploughing and fertilization of the soil are done as in conventional rice field preparation. The use of inorganic fertilizers has increased greatly in recent years but organic manures are still very important and combinations of both types are customary. Table 2 gives examples of fertilizers and amounts applied. Fertilizers are applied just after ploughing and rarely during the growing season. Their effects on the yields of fish and rice are not well understood. Natural feeding for fry is increased by fertilization, particularly by organic manures, but this high productivity in the water column may adversely affect the rice yield. Apart from lime, none of the fertilizers used is harmful to fish at the suggested rates of application.

Rice fields are usually weeded by hand two or three times during the growing season. This causes no harm to the fish, which may even benefit from the temporary agitation and aeration of the water. It is also possible that the fish reduce weed growth, but there are no data to support this. Herbicides, such as 2,4-dichlorophenoxyacetic acid (2,4-D), are being increasingly used in rice farming and are considered harmful to fish. Other pesticides, such as the Bordeaux mixtures, derris, dichlorodiphenyl trichloroethane (DDT), benzene hexachloride (BHC), tetraethyl phosphate (TEP) and Folidol, have become almost essential in rice farming. The

Table 2. The amounts of fertilizers applied (kg/0.1 ha) to rice fields on the Saku Plain, Nagano Prefecture for (1) a standard combination, (2) organic fertilizers alone, and (3) inorganic fertilizers alone.

Fertilizer	1 Standard application	2 Organic application	3 Inorganic application
Cow manure	1,125.0	1,125.0	
Soybean cake	7.5		
Ammonium sulphate	11.25	30.0	41.63
Calcium cyanamide	11.25		
Thomas phosphate manure[1]	3.75		
Calcium superphosphate	11.25		26.30
Silkworm pupae meal	7.50	22.5	
Fish meal	7.50	22.5	
Potassium chloride			15.00
Total	1,185.0	1,200.0	82.93

[1]A local fertilizer brand available in the 1950s.

farmers rely on the advice of agricultural and fisheries scientists on methods of application, such as treating seedlings before transplantation, to minimize their harmful effects on fish.

Spawning Techniques and Fry Collection

Many farmers purchase their fry from professional suppliers or from the Prefectural Fisheries Station, who both use specialized equipment and techniques for mass rearing. The price and availability of fry depend mainly on the weather conditions at the time of spawning. Examples of 1954 prices for a range of fry sizes are given in Table 3. The techniques described here, however, are used by nonspecialist farmers to become self-sufficient in spawn and fry production.

The carp gonads ripen with the spring rise in temperature (April to May) and the spawning pond must be prepared in advance. The pond, area 3.3 to 16.0 m^2 and depth 0.7 to 1.5 m, is often located in the corner of a rice field. It is a temporary structure, enclosed by a mud dike, screens or wooden boards, with simple intake and outlet holes, and is destroyed after spawning. Nesting material, such as willow roots, hemp palm fiber, grass roots, and bundles of such aquatic plants as *Ranunculus* and *Myriophyllum* from local streams, is spread at random in the pond to encourage oviposition and facilitate egg collection. The farmer chooses the time for transfer of the broodstock from their holding ponds to the spawning pond very carefully, assessing the appearance of the fish and the weather conditions. The broodstock are usually over 10 yr old and weigh up to 3.8 kg, with the females the largest and oldest fish. The stocking densities and sex ratios used for the spawning ponds vary, e.g., six males with two females for a 3.3-m^2 pond; 17 males with 17 females for a 9 m^2 pond, 60 cm deep.

Table 3. 1954 prices for carp fry: the grading system is used to describe size ranges (US$1.00 = about 360 Yen (¥)).

Grade	Size (mm)	Price per 100 (Yen)
1	12-14	6
2	15-20	10
3	21-26	18
4	27-29	30
5	30-38	45
Special	39 and over	65

A nursery field is prepared to receive the nesting material and eggs. This field is less than 0.1 ha in area but is otherwise identical to other rice fields and can be planted to rice after the nursery operations. It is filled with water, to a depth of 15 to 18 cm, 1 or 2 wk before the commencement of spawning and a very slight flow is maintained. This allows the buildup of plankton (mainly *Daphnia* and other crustaceans) which are then immediately available as larval foods. The nesting material is transferred to the nursery field when the millions of eggs have eyed and is either scattered evenly over the surface or held at one side, for which bamboo stakes and string are necessary as it tends to float. The fry are moved from the nursery field to the rice fields for grow-out either by collection in baskets at the field outlet or by flushing them through with water into adjacent fields.

There are no reliable data on the numbers of eggs and fry produced by this method. The likely survival from eggs to advanced fry up to first-feeding is between 10 and 50%, with the farmers considering 10% a realistic figure.

The First Growing Season: Fry and Fingerling Culture

The fields are usually stocked with 15- to 30-mm fry commencing early June to early July. The stocking densities vary with the expected natural productivity of the water and the planned amount of supplemental feeding. For example, a 990-m^2 field area is normally stocked with 300 fry when relying on natural feeding alone, and 1,000 to 1,500 fry when planning substantial supplemental feeding. The time of stocking and the time of transplanting the rice seedlings from their nursery beds can affect each other. Some farmers believe that the fry can disturb the rooting of early seedlings, whereas others disregard this possibility in favor of stocking as early as possible for rapid acclimatization of the fish and maximizing the length of the growing season, believing that even a few days delay significantly retards fry growth. Practices vary therefore from stocking directly after filling and conditioning the field to delaying stocking until 10 d after planting. There is no data to support either practice but all the farmers accept that a longer delay of 20 d beyond planting reduces fry growth. The growing season can vary from 60 to 120 d.

The yields of fish are higher when the fry receive supplemental food in addition to cropping the natural plankton. Feeding is started about 10 d after stocking when the plankton is depleted. The food used for both fry and fingerlings is meal from silkworm pupae with or without added cereal bran. The feeding frequency and amounts fed are adjusted according to the appetite of the fish, which falls when temperatures exceed 27 to 28°C. This is common during the day in midsummer and feeding is often suspended until the late afternoon. Feeding is discontinued at temperatures above 32°C and when the production of plankton, particularly *Daphnia*, is visibly increased or when food is left uneaten. Table 4a describes a typically flexible feeding schedule.

Table 4. Supplemental feeding schedules for carp in rice field culture.

A. Fry and fingerlings

Days after stocking	Amount of meal (1)	Feeding frequency
10	2	Daily
30	4	Daily
50	10	Daily
70	14	2 or 3 times/d

B. Yearlings

Period	Daily amount for 400 fish (kg)	Feeding frequency
First month	0.75 - 1.20	Daily
Second month	2.20 - 3.00	Daily
Thereafter (increasing)	3.50 - 5.50	2 or 3 times/d

First Season Harvesting and Disposal

Rice is harvested from mid-September to late October with complete draining of the fields. This may shorten the fish growing season, but the rice crop always takes precedence. Fish feeding is stopped 5 to 6 d before draining so that their guts are empty during harvest or transfer. Drainage from the outlet is started at a slow rate very early in the morning gradually increasing the flow. A little water is allowed in from the intake to create a flow pattern that concentrates the fish in the catch basin. This is essential for a rapid and efficient fish harvest, which can be completed by 9:00 A.M. on the day of draining by experienced operators. If, however, the flow pattern and catch basin fail to concentrate the fish, it is better to postpone the operation until the following day and start afresh, rather than attempt to collect widely dispersed fish. The outlet water is directed through a bamboo basket to trap any small flushed-out fish.

The fish yield obtained depends on many factors, including the quantity and quality of the stocked fry, the amount of feeding, the weather conditions (especially water temperature), the amount of fertilizers applied, and the design of the field. Yields are generally in the range 70 to 100 kg for a field of 0.1 ha stocked with 1,000 fry given adequate supplemental feeding. Table 5 shows the advantages of supplemental feeding, although all the yields here are below average. The best farmer from the Saku Plain, Nagano Prefecture harvested 112 kg of 0-group fingerlings and 660 l of rice from a 990-m^2 field in 1943. The corresponding average figures for 23 farmers were 96 kg and 649 l. The harvested fish weigh from 15 to 300 g (mean weight about 30 g). Losses of 30 to 50% are expected from stocking to harvest. The 30-g fingerlings, length about 12 cm, are too small for eating. They are sold to fish culturists for fattening in ponds and irrigation reservoirs and to fisheries cooperatives for stocking natural waters, or are retained by the rice farmers for further rice field culture. If retained, they are first transferred to a stocking pond, area 7 to 16 m^2, depth 1.0 to 1.5 m, at a density of 100 to 130 fish/m^2. Here, they are kept in running water and fed using the same methods described above until late November, when the temperature falls to 15°C and they are moved to overwintering ponds.

Overwintering of fingerlings or runts from older age categories (see below) is necessary from November to April in cold localities. The overwintering ponds require a reliable, non-stagnant water source, preferably a warm spring, and are often sited adjacent to the farmer's house or in his garden (Plate 2). Each pond has a maximum area of 15 m^2 and a minimum depth of 1 m. In very cold areas, a deeper hold is sometimes dug in the pond center and covered with wooden boards. Additional covering, such as straw-matting, wooden boards and bamboo brush, is placed over the pond surface. The fish are not fed below 10°C, but small amounts of food are given above 10 to 12°C. They suffer an unavoidable weight loss of 20 to 30% during overwintering.

Culture of Older Fish

Yearlings or 2-yr-old fish of 30 to 60 g (10 to 16

Table 5. Carp and rice yields obtained in 1942 over 90-d grow-out from triplicate 300 m^2 fields, with and without supplemental feeding on 94:4 silkworm pupae meal: bran (by weight). A control field (7) with no fish culture is included for comparison (S, O and I refer to Standard, Organic and Inorganic combinations of fertilizers; see Table 2).

Field Number	Number of fish stocked	Wt of fish stocked (g)	Supplemental feed (kg)	Fertilizer applied (kg)	Fish yield Number	Wt (kg)	Mean Wt (g)	Food conversion ratio[1]	Mean Ht (cm)	Rice yield Mean Branch-out	Wt (kg)
1	1,000	94	13	397.5 (S)	633	13.9	22.5	1.09	65	18.8	302.3
2	1,000	94	13	397.5 (S)	580	13.9	24.0	1.07	62	21.0	300.0
3	1,000	94	13	397.5 (S)	610	13.2	21.0	1.02	68	22.0	304.0
Av.	–	–	–	–	607	13.6	22.5	1.06	65	–	303.1
4	1,000	94	0	401.3 (O)	535	8.2	18.8	–	55	18.2	300.0
5	1,000	94	0	397.5 (S)	420	6.3	18.8	–	53	17.5	337.8
6	1,000	94	0	26.3 (I)	320	6.8	18.8	–	60	20.0	277.9
Av.	–	–	–	–	427	7.6	18.8	–	56	–	305.2
7	0	–	–	–	0	–	–	–	–	15.0	169.5

[1]Food conversion ratio is here defined as weight of supplemental food per unit weight of fish harvested; it takes no account of natural food obtained from the ponds.

Plate 1. A field drain screened with mulberry stakes and plugged with rubble to control the depth and flow.

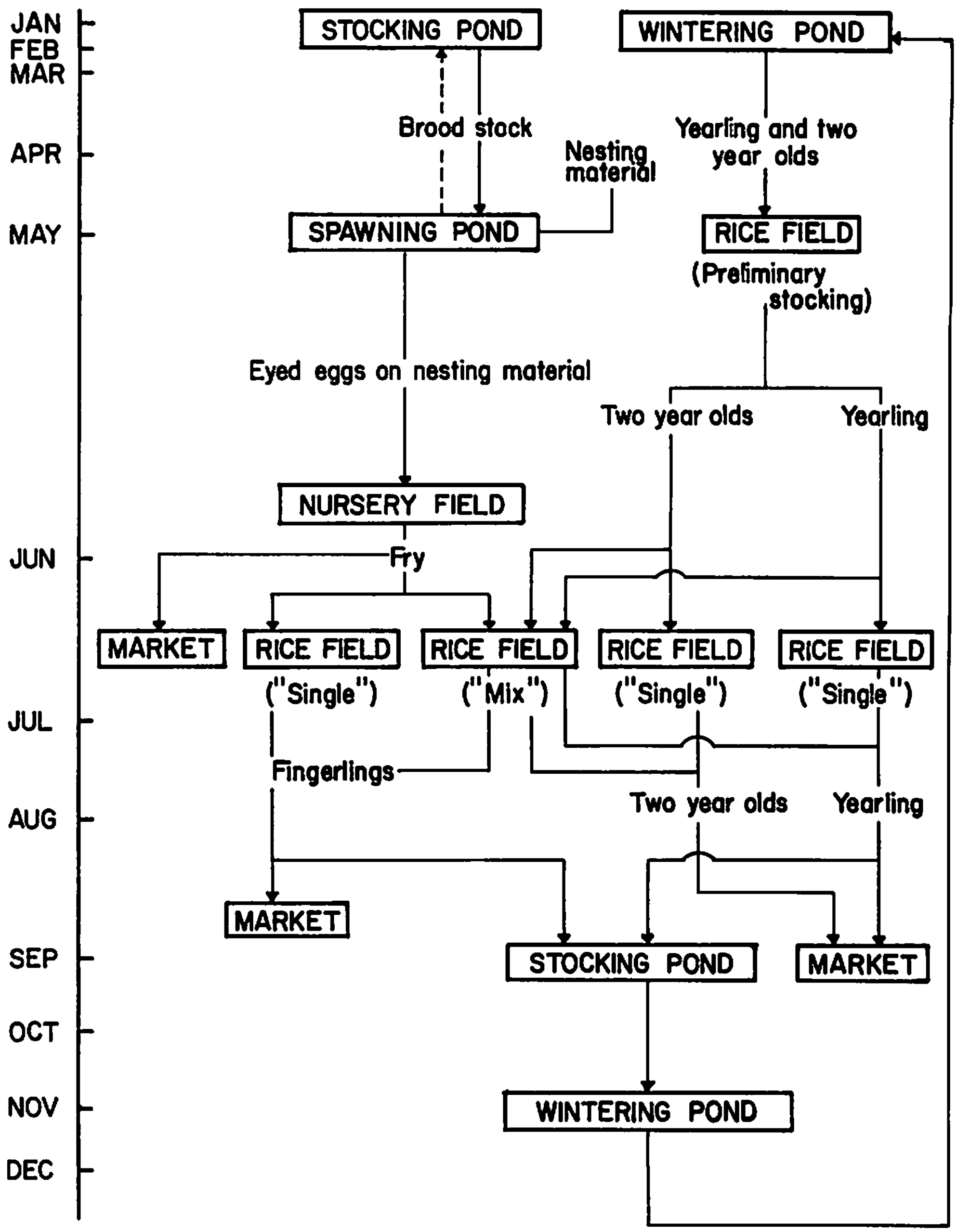

Fig. 1. Flow diagram of the various options open for mixed- and single-age fish culture in Japanese rice fields.

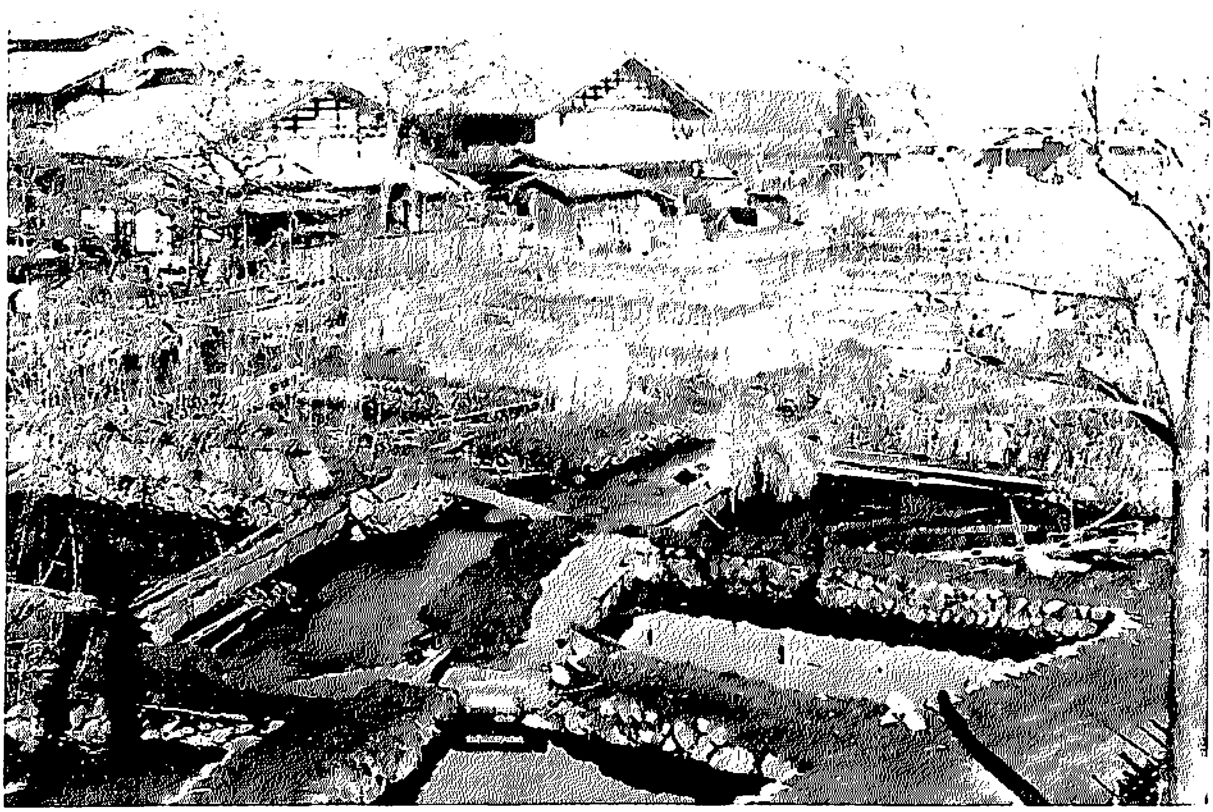

Plate 2. A group of overwintering ponds close to the farmers' houses supplied from a central watercourse.

cm) are taken from the overwintering ponds or purchased from fish culturists for continued grow-out. They are often stocked as mixed-age groups, sometimes including 0-group fish and fry, which gives rise to the term "mixed-age" as opposed to "single-age" culture. The following description applies to single-age and mixed-age culture of yearlings and 2-yr-olds, but variation in feeding is necessary for different combinations of ages, especially when fry are included, e.g., 200 to 600 fry stocked with 400 yearlings.

Fish from the overwintering ponds are transferred to a preliminary stocking field of area 0.1 to 0.2 ha, previously well ploughed and fertilized, at a density of 4,000 to 5,000 fish/ha. They are fed at low rates on well-boiled wheat and dried mysids or other small shrimps, but not on silkworm pupae. This preliminary stocking promotes recovery from winter conditions, including the cessation of feeding, and entrains the fish to supplementary feeding.

The fish are then stocked in the rice fields as described above, with a similar variation in the relationship between stocking and planting dates. Many farmers stock about one week after planting, but some prefer to stock after ploughing and conditioning the field and before planting, in which case special measures are necessary to prevent root disturbance. On the day before or early on the day of planting, the fish are concentrated in the catch basin by vigorous flushing from the intake. The seedlings are then planted and the water level is kept low, confining the fish to the catch basin until after rooting, when the level is raised to 15 to 20 cm, with some variation according to the size of the fish. The flow-through of water is kept slightly higher than for fry culture.

Supplemental feeding is practiced by nearly all the farmers, although low yields are possible from natural feeding alone. The foods used include silkworm pupae (fresh, dried, fat-extracted, or prepared as meal), dried mysids and other small shrimps, and cereal bran. The silkworm pupae are thought to have the highest nutritive value, either chopped into small pieces for early feeding or given whole after 70 d. Food is broadcast by hand from the dikes while the rice is low, and by wading when it grows too high. Food presentation is designed to encourage an even distribution of fish throughout the field, taking note of the presence of fish and their food-searching activity which shows as disturbances in the water. Table 4b gives a typical feeding schedule.

Harvesting is carried out as described for fingerlings. With supplemental feeding, the yields vary from 0.75 to 1.12 t/ha for yearlings and 1.12 to 1.80 t/ha for 2-yr-olds, the weights of individuals varying from 100 to 220 g (23 to 26 cm) and 375 to 750 g, respectively. Any runts smaller than the lower figure for yearlings are considered unsaleable and are overwintered for an additional growing season. Figure 1 summarizes the options open to the farmer for varying his culture practices.

In addition to mixing ages, the wild goldfish (*Carassius auratus;* funa, Japanese common name) is sometimes mixed with carp, particularly in Nagano Prefecture. This species, although less valuable than carp, is much hardier and is a good table fish. Two-year-olds are added to culture fields containing yearling or two-year-old carp (but not carp fry), at a density of 100 (70 males:30 females)/ha. They are summer spawners and produce 6 to 10 cm fingerlings for harvest in the fall, yielding about 750 kg/ha.

Environmental and Economic Aspects

The only data available are from the 1952 town census of Nozawa town (Plate 1), close to the center of Honshu, and probably represent higher standards of farming than the national average. Nozawa town is a typical farming community 680 m above sea level, with two streams to the north and south supplying ample water for irrigation through canals and natural water courses. The mean air temperature in 1952 was 13.5°C (range 13.5 to 34.5°C) and the following temperatures were recorded for rice field water during the growing season: late May 16 to 18°C; late July to early August, 35 to 40°C; mid-September, 16 to 17°C. The annual precipitation was 1,300 mm and the snow fall 25 to 35 cm. Table 6 describes the scale of the farming effort and the yields obtained and Table 7 the inputs and income in more detail. The total fish harvest of about 90 t may be an underestimate as the 1943 figure was 198 t, and there may be other inaccuracies.

Table 6. Fish, rice and silkwork culture data for Nozawa town, Saku Plain, Nagano Prefecture in 1952.

Total area	648 ha
Population	8,201
Number of families	1,690
Number of farming families	658
Number of farmers	3,818
Total area of rice fields	342 ha
Area of rice fields used for fish culture	250 ha
Area of fish ponds	62 ha
Rice crop	1,685,880 l
Fish harvest in rice fields	66,947 kg
Fish harvest in ponds	23,062 kg
Silkworm cocoons	22,488 kg

Table 7. Analysis of inputs and income per 0.1-ha unit for rice and fish culture, as compiled by the Nozawa town Farmers Cooperative and Fisheries Station, Saku Plain, Nagano Prefecture 1952 (US$1.00 = about 360 Yen (¥)).

Inputs	Quantity	Cost (Yen)
Rice seed	3.6 l	140
Fertilizers:		3,600 (total)
Manure	75.0 kg	
Ammonium sulphate	7.5 kg	
Calcium cyanamide	37.5 kg	
Potassium chloride	9.4 kg	
Lime	37.5 kg	
Phosphate	30 kg	
Fish seed:		1,838 (total)
Carp fry	7,000	
Carp fingerlings	150	
Wild goldfish	5	
Fish food:		2,277 (total)
Silkworm pupae	56.2 kg	
Wheat bran	19 kg	
Labor		1,900
Repayment of loans		1,420
Interest on loans		1,930
Tax		1,660
Equipment (tools)		300
Miscellaneous		1,170
	Total	16,235
Yield	**Quantity**	**Income (Yen)**
Rice	648 l	28,330
Straw	–	1,500
Fish	61 kg	8,617
	Total	38,447
	Net total profit	22,212

Acknowledgments

The author is indebted to Mr. Kazuo Okada and Mr. Kazuo Nakamura for supplying data and opportunities to view fish culture practices, to Mr. Motoyoshi Yokote for photography, and to the Saku Fish Culturist Cooperative for assistance during field work.

The Integration of Fish Farming with Agriculture in Malaysia

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Abstract

The status of freshwater aquaculture in Malaysia is reviewed with special reference to integrated farming. Case studies of pig-fruit-vegetable-fish, pig-fish and pig-poultry-fish farms are described in detail and the kampung style integrated farms (smallholdings involving rice, fruit, vegetable, livestock and fish production) are discussed. The main problems associated with integrated farming in Malaysia are identified as lack of technical information, lack of accurate farm records and insecurity of land tenure.

Introduction

In Malaysia, the most important source of animal protein for the population is fish. In 1971, the per caput consumption of fish was 26.6 kg/yr compared with 14.4 kg/yr for other sources of animal protein (Labon 1974). With the increasing prices of food fish associated with limited supply and increased demand, malnutrition especially among the poor, may increase. This potential problem requires urgent attention.

In the Second and Third Malaysia Plans (1970 to 1975 and 1976 to 1980), the eradication of poverty and malnutrition was the primary objective. Recognizing that 74% of the poor earned their livelihood from agriculture and the processing of agriculture products and that the agricultural sector provided employment to about 1.9 million people and contributed 45.5% of the country's foreign exchange earnings (29.8% of the Gross National Product in 1975), the Malaysian Government allocated *M$4.7 billion for agricultural development during the Third Malaysia Plan. This was an increase of 95.8% over the Second Malaysia Plan allocation of M$2.4 billion and included funds required for development of fisheries, including aquaculture. The availability of funds and subsidy schemes for aquaculture implemented by the Fisheries Division and the Fisheries Development Authority (MAJUIKAN), the latter primarily responsible for the commercialization of fish-related activities, were intended to encourage the rural sector, in particular, to initiate aquaculture activities.

In Malaysia, agricultural activities dominate the life of the rural population. If aquaculture is to be introduced to the rural areas, it follows that some form of integration of aquaculture with agriculture is essential, at least during the early phases of development, so that the potential value of aquaculture, not only as a reliable source of food protein but also regular income, is gradually realized by the rural population. Such a strategy would enable financial assistance to be channelled to the rural poor directly. As these communities are located away from the sea, freshwater aquaculture using both fish and crustaceans is appropriate.

The objectives of this paper are to outline the status of freshwater aquaculture in Malaysia, the forms of integration of such practices with other farming activities and to describe the results of specific case studies of integrated farming systems involving fish culture.

*US$1.00 = M$2.06.

The Status of Freshwater Fish Culture in Malaysia

The development of aquaculture in Malaysia began with the farming of freshwater fishes, such as the Chinese carp and common carp *(Cyprinus carpio)*, in ponds and the production of fish in Malaysian paddy fields (Heath 1934). In a survey of fish culture in Selangor, Tan, C.E. (1973) reported that some of the fish ponds have been in operation for over 30 years. The culture of freshwater fish using traditional methods introduced by the Chinese has therefore dominated aquaculture activities in Malaysia for decades. In recent years, however, the culture of blood cockles, *Anadara granosa*, in brackish water has gained prominence in view of its high yields. In 1976, the yield of blood cockles from 923 ha of mud flats in Malaysia, excluding Sarawak was 31,642 t, compared with 1,603 t from freshwater fish culture (Anon. 1978a). In 1977, fish culture in floating cages in coastal waters and reservoirs was introduced via a subsidy scheme operated by the Fisheries Department. The preliminary results are encouraging and show promise for its future expansion in order to exploit suitable water space.

The production from aquaculture operations in Malaysia is relatively small compared to the capture fisheries. In 1976, a total of 33,245 t produced from aquaculture was only equivalent to 6.43% of the total fish landings. Table 1 shows the production and value of various types of aquaculture operations in Malaysia, excluding Sarawak, in 1976. Low (1976), however, estimated that in 1974 the total production from freshwater fish culture in Malaysia was 9,614 t from a total pond area of 5,969 ha.

The statistics on yields of freshwater fish production reflect its significance in the total fish yield in Malaysia. They are, however, estimated values which are less than the actual production figures for the following reasons:

a) they do not include many of the small subsistence fish farms which produce fish mainly for domestic consumption;
b) in some rural areas, the fish are removed at unspecified intervals for food and no records of these catches are maintained by the fish farmers (especially in the case of small integrated agriculture/fish farm systems) and
c) the shortage of field data collectors in the Freshwater Extension division of the Fisheries Department.

Therefore, the socioeconomic importance of freshwater fishes, especially to the rural communities, tends to be underemphasized in statistics.

With the increasing prices of food fishes and the availability of subsidy schemes, there is growing interest in fish farming as reflected in Table 2. The concurrent increase in the number of fish pond operators, mainly in the rural areas, provides additional employment. The two states most active in freshwater fish culture in Peninsular Malaysia are Perak and Selangor where the total areas of ponds used for fish culture in 1977 were 3,265 and 387 ha, respectively. In these states (Figure 1), numerous disused mining pools have been converted for fish farming in combination with pig and other livestock rearing. In 1968, a total of 1,135 mining pools with a total area of about 1,266 ha were used by 445 farmers for fish culture in 7 districts in Perak and Selangor (Jothy 1968). These ponds, resulting from dredged excavations, gravel extraction and hydraulic mining, range in size from 0.2 to 35 ha and in depth from 3 to 15 m. Most of them cannot be drained completely although some have outlets draining into streams and ponds. Ponds constructed for fish culture, however, vary in depth from 1 to 2 m and in size from 0.1 to 1.0 ha.

Polyculture of carps is the prevalent practice in freshwater culture ponds and disused mining pools. These fish farms are often part of an integrated farming system together with the rearing of livestock and/or plant crops. The major carp species currently being cultured are the big head carp, *Aristichthys nobilis;* grass carp, *Ctenopharyngodon idella;* the lampam java or tawes, *Puntius gonionotus;* the common carp, *Cyprinus carpio;* the silver carp, *Hypophthalmichthys molitrix* and the mud carp, *Cirrhina molitorella.* The stocking rates of selected carp species in polyculture systems in Malaysia recommended by the Fisheries Department are shown in

Table 1. Yield and value of various types of aquaculture operations in Malaysia, excluding Sarawak, in 1976 (Anon. 1978a).

	Aquaculture		
	Marine culture	Brackishwater culture	Freshwater culture
Production (tons)	–	31,642	1,603
Value (US$1000s)	–	3,766	1,622

Table 2. The number and total area of fish ponds in operation in Peninsular Malaysia from 1973 to 1977. (Source: Annual Fisheries Statistics, Malaysia).

Year	Number of ponds	Area (ha)	Number of operators
1973	8717	4195	?
1974	9344	4403	6355
1975	9674	4581	?
1976	10313	4558	6977
1977	11531	4797	7649

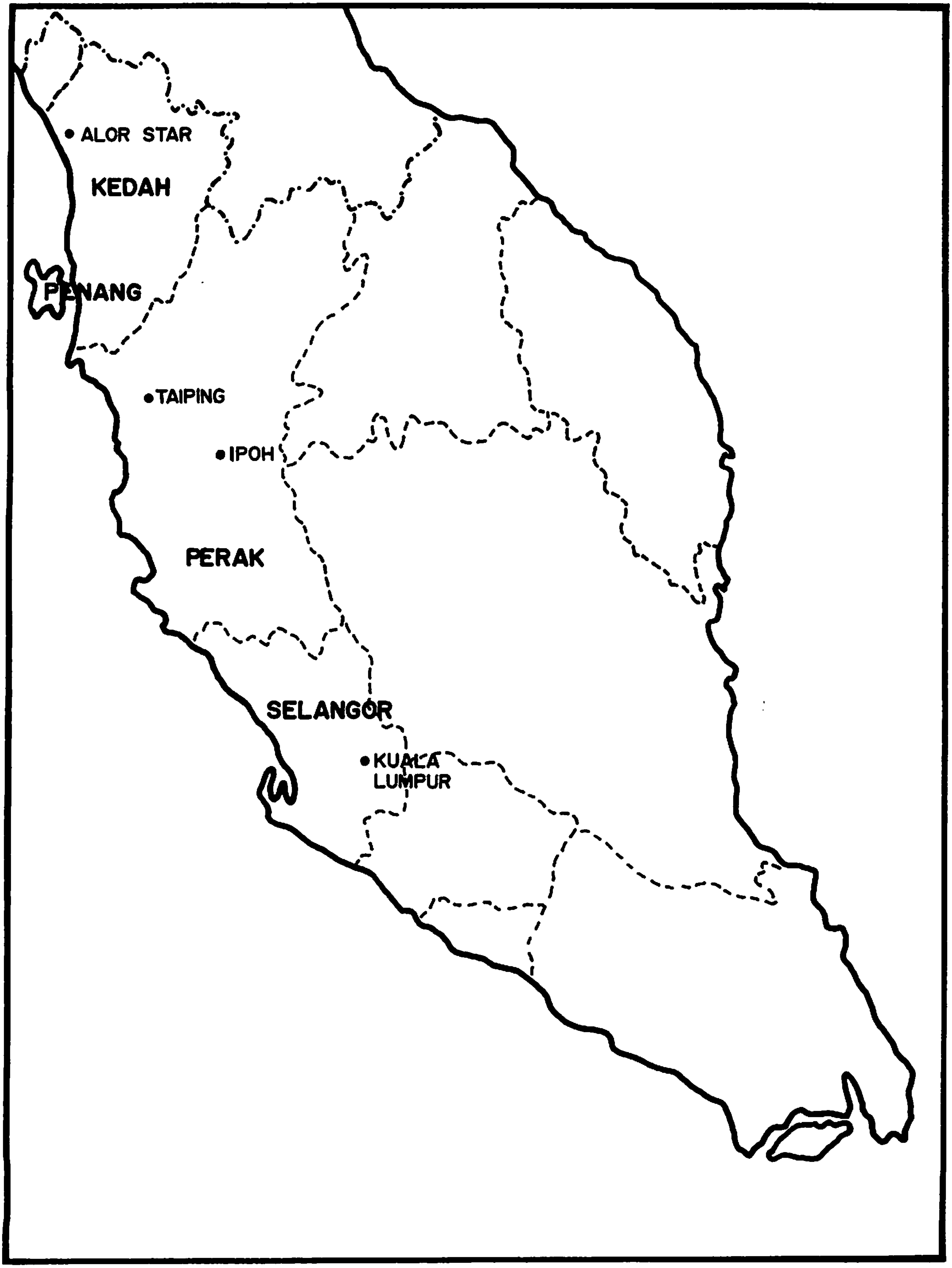

Figure 1. Map showing Perak and Selangor states in Peninsular Malaysia: the major areas of freshwater fish culture.

Table 3 (Anon. 1978b). In 1977, the culture of a riverine carp, *Leptobarbus hoeveni*, was started in a fish farm near Kuala Lumpur, but data on yields are not yet available. The production of fish in paddy fields involves 3 main species: the snakeskin gourami, *Trichogaster pectoralis* and the catfish, *Clarias macrocephalus* and *Clarias batrachus* (Tan 1978).

Table 3. Recommended stocking rates of selected carp species for fish culture in Malaysia (Anon. 1978b).

Species	Stocking rate/ha (1)	Stocking rate/ha (2)
Big head carp	250	379
Grass carp	500	250
Common carp	250	1240
Lampam java	–	2470

Fry of Chinese carps are imported from Hong Kong and Taiwan, but because of the recent successes in induced spawning of Chinese carps at the Malacca fish breeding station, fry for culture operations should soon be available from within Malaysia. There are six fish breeding stations run by the Fisheries Division which produce mainly fry of *P. gonionotus*, *C. carpio* and *T. pectoralis* for free distribution to fish farmers and for restocking programs in public waters. In 1977, 2.82 million fish fry were produced in these stations (Anon. 1978c).

There is little accurate information on yields from Malaysian fish ponds. The average annual yield in 1974 was 1.61 t/ha (Low 1967). Hickling (1948), however, reported yields of up to 3.9 t/ha/yr. In mining pools managed by farmers, yields ranging from 303 kg/ha to 1,796 kg/ha within 8 to 9 months have been recorded (Jothy 1968, see Table 4).

Table 4. The production of fish from mining-pools in Peninsular Malaysia (after Jothy 1968).

Pool no.	Area (ha)	Stocking: Species	Stocking: Number	Period of rearing (mo)	Harvest: Number recovered	Harvest: % recovery	Harvest: Total weight (kg)	Fish production (kg/ha)
1	0.81	Lampam java	1000	9.5			242	1795
		Common carp	500				61	
		Grass carp	450		400	89	909	
		Big head carp	100		100	100	242	
		Lampam java	1500	9.5	1000	67	363	1644
		Grass carp	550		450	82	969	
2	0.61	Lampam java	1000	24.0	400	40	121	677
		Common carp	500		100	20	18	
		Grass carp	120		80	67	212	
		Big head carp	20		20	100	50	
		Giant gorami	50		30	60	12	
3	1.21	Lampam java	2000	9.0	1000	50	303	851
		Grass carp	300		200	67	606	
		Big head carp	50		40	80	121	
4	0.81	Lampam java	3500	9.0			363	784
		Grass carp	200		100	50	242	
		Big head carp	50		35	70	30	
5	1.21	Lampam java	1200	8.0			303	1302
		Common carp	300				60	
		Grass carp	500		300	60	909	
		Big head carp	200		100	50	303	
6	0.04	Lampam java	600	8.0	400	67	121	3025
		Grass carp	700	17.5	342	63	733	
				21.5	98		263	
7	1.01	Big head carp	200	17.5	130	80	428	
				21.5	39		115	

The big head carp is the most suitable species for culture in mining pools. As plankton feeders, they are less susceptible to poaching and can grow to 3 kg in 8 months. Jothy (1968) stocked different species in 3 mining pools which were left unmanaged. The results (Table 5) showed that big head carp weighed 3.89 to 5.41 kg each after a growth period of 9 to 10 months with high recovery rates of 70 to 100%. For comparison, *Catla catla* and *Labeo rohita* grew to 15.77 to 21.23 kg and 0.45 to 4.03 kg, respectively, after a period of 5.5 years. Variations in fish yields depend on the species and stocking densities, the primary production of the ponds and management practices.

Fish production from Malaysian paddy fields is important for providing additional income, as well as food protein, in some rural communities, especially in the North-western paddy areas of Peninsular Malaysia (Low 1976; Tan 1978). In the mid-1960s, paddy field fish constituted the most important source of freshwater fish even though no deliberate stocking of fish was practiced (Merican & Soong 1966). The production of paddy field fish in Malaysia involves little or no management, and is solely dependent on natural production of fish fry. Heath (1934) reported that an irrigation canal about 110 m long, 2.5 m wide and 2 m deep produced about 10,000 kg of fish *(T. pectoralis, Ophicephalus striatus* and *Clarias macrocephalus)* while production of fish from sump-ponds in paddy fields, commonly referred to as telagas (see Tan, S.P. 1973), varied from 200 to 1,700 kg/telaga. With the introduction of rice double cropping and the increased use of pesticides, a number of problems have arisen for the cultivation of fish in paddy fields, but these can possibly be overcome if remedial measures are implemented soon (Tan 1978). Tan et al. (1973) estimated that paddy field fish production in the Krian Irrigation Scheme in 1971 was about 10 times less than that in the 1940s.

Beside the distribution of free fish fry to farmers, the Fisheries Department, in an attempt to promote freshwater fish culture, has been allocated funds to subsidize the construction of new fish ponds and floating fish-cages during the Third Malaysia Plan. In Peninsular Malaysia, the cash subsidy available for pond construction is dependent on the pond size: 0.1 to 0.2 ha, M$1,250; 0.2 to 0.4 ha, M$2,500; and 0.4 to 1.2 ha, M$2,500 per 0.4 ha. The proposed site for pond construction requires inspection and approval by the Fisheries Department and subsidies are given only after the fish pond has been constructed according to their specifications, to avoid malpractice. For each fish pond approved for construction, further assistance in the form of 50 kg of cement and piping for the water inlet and outlet are provided.

Table 5. Results of experimental fish stocking in mining-pools in Peninsular Malaysia (after Jothy 1968).

Pool no.	Area (ha)	Stocking: Species	Stocking: Number	Stocking: Mean total length (cm)	Period of rearing (mo)	Harvest: Number recovered	Harvest: % recovery	Harvest: Mean total length (cm)	Harvest: Mean weight (kg)	Harvest: Total weight (kg)
		Lampam java	1580	7.21	6	22	1.4	17.55	0.09	1.98
		Common carp	780	6.20	5	14	1.8	13.69		
		Big head carp	51	16.31	9	51	100.0	76.05	4.22	215.22
1	0.96	Lampam java	800	5.08	17	7	0.9	35.00	0.91	6.37
		Common carp	400	7.62	17	4	1.0	40.00	1.25	5.00
		Grass carp	110	11.85	13	2	1.8	52.00	1.08	2.16
		Big head carp	30	15.24	10	21	70.0	81.00	5.41	113.61
		Silver carp	50	9.65	16	Nil	Nil	Nil	Nil	Nil
2	0.29	Lampam java	480	7.24	25	Nil	Nil	Nil	Nil	Nil
		Common carp	240	4.45	25	1	0.2	41.00	1.36	1.36
		Grass carp	105	10.16	10	Nil	Nil	Nil	Nil	Nil
		Big head carp	7	10.16	10	6	85.7	73.00	3.89	23.34
6	2.30	Lampam java	3200	–	72	30	0.9	25.50	0.24	7.20
		Common carp	100	–	72	6	6.0	42.00	1.25	7.50
		Catla)	1500	–	66	5)	11.2	97.79	18.83	94.15
		Rohu)				163)		50.20	1.50	244.50
		Lampam java	3780	4.86	10	24	0.6	13.33	0.03	0.72
		Common carp	1900	4.01		53	2.8	18.15	0.12	6.36

For approved floating cages, the Fisheries Department provides technical advice and all the construction materials required (Anon. 1977). In 1979, a total of 14 floating cage units were set up in both Chenderoh Lake and Bukit Merah Reservoir to encourage fish culture and other agricultural activities among 'kampung'* residents as part of an Applied Nutrition Programme. Preliminary observations of the growth of *P. gonionotus* and *Ctenopharyngodon idella* in floating cages at Kampung Kelantan, Chenderoh Lake are encouraging. These fishes are fed with tapioca leaves and aquatic weeds.

On the other hand, little official encouragement is given for paddy field fish culture as the main emphasis is on maximizing rice production. More attention should be given to improve this method of fish production, particularly in deep-water paddy areas, and research is needed in specific areas to show the feasibility of such integrated schemes.

Integrated Fish Farming with Agriculture

In Malaysia, fish farming is commonly integrated with agricultural activities, such as livestock rearing, vegetable farming, paddy cultivation and fruit farming. The form of integration being practiced takes only a small portion of the farmers' time for fish stock maintenance. With pig or poultry raising, fecal wastes are deposited into the fish ponds for disposal and recycling and fish culture is usually a secondary activity with little management involved. For Chinese farmers, the fish crop provides additional income to buffer the fluctuating costs of pig and poultry production. In kampung areas, fish farming is usually operated at the subsistence or artisanal level.

In 1973, C.E. Tan published a report on the economics of fish culture in Selangor using disused mining pools. Their total area (about 312 ha) constitutes 78% of the total water area used for fish culture in Selangor. Out of the total of 350 operators, 326 managed the fish ponds themselves or with the help of family labor. Only 15 establishments employed assistants to look after their ponds. The survey showed that in Selangor, only 26.6% of the total households relied on fish culture as their sole activity. The remainder practiced integration of fish culture with other agricultural activities. Integration with fruit growing and pig raising was practiced by 15.7% and 11.2%, respectively (Table 6). The majority of the larger farms maintained one or more types of livestock and used their fecal wastes as free feed and fertilizer for fish production.

According to Tan, C.E. (1973), fish constituted the main source of income in 127 (36% of the total households involved in fish culture. In the remaining 223, fish culture was only a secondary or supplementary source of income. Of these, 89 derived their main income from agricultural activities or off-farm occupations, such as operating provision shops or food stalls, manual work and teaching, while for 50 residing in land settlement schemes, rubber cultivation was the main source of income. Any fish they raised was for home consumption only.

In Selangor, the larger ponds are normally stocked only with grass carp and big head carp. Other ponds are stocked with either lampam java and common carp, or a combination of grass carp, big head carp, lampam java and common carp. Tan, C.E. (1973) did not provide information on the stocking rates practiced. Only 11 out of 99 farmers interviewed had had formal training in fish culture from the Inland Fisheries Extension Branch of the Fisheries Division. Of the remainder, 50 had learned fish culture from their neighbors and 31 others by techniques passed from father to son.

The fish ponds were often a considerable distance from the farmers' houses, which presented problems for supervision and in the time spent on daily travelling: 58% of the surveyed ponds were more than 0.5 km away from the farmers' residence. Many of the farms (35%) were illegal holdings and few improvements had been made to the ponds (mostly mining pools) due to insecurity of tenure. Moreover, the farmers, without legal

Table 6. Integrated farming in Selangor, Peninsular Malaysia (from Tan, C.E. 1973): F = fish, Fr = fruit, V = vegetables, Pa= paddy, Po = poultry, Pi = pigs, R = rubber.

Type of farming	No. of farms surveyed	% by number
F only	93	26.6
F + Fr	55	15.7
F + Pi	39	11.2
F + Po	26	7.4
F + V + Pi	22	6.6
F + Pi + Po	20	5.7
F + Po + Fr	18	5.1
F + V + Fr	14	4.0
F + V + Pi + Po + Fr	13	3.7
F + V	12	3.4
F + R	11	3.1
F + Pi + V + Fr	9	2.6
F + Pi + Fr	7	2.0
F + Po + V	5	1.4
F + Po + V + Pa	3	0.9
F + Po + R	1	0.3
F + Po + Fr + R	1	0.3
F + Po + V + Fr	1	0.3
Total	350	100.0

*A rural Malay village.

rights, were unable to prevent poaching which was a serious problem, especially in distant ponds.

Many farmers were unaware of the services and aids offered by the Fisheries Department for improving fish culture techniques. Almost 50% of those interviewed were not aware of any services other than the provision of free fish fry. Only 10% had actually received other services including the poisoning of ponds and material aids such as cement, pipes and fertilizer. With regard to the free supply of fry, the general complaint was that a prolonged delay occurred between the time of a request and the time that the fry were delivered. Also, the fry provided were often too small.

Findings on the economics of fish culture by Tan, C.E. (1973) showed that the fish were harvested once annually by most fish farmers (88%), while 11% obtained 2 crops annually. Tan, C.E. (1973) did not provide details on the actual fish yields from these operations but gave the value of average income from various types and sizes of ponds. The data in Table 7 include the income derived from sales and the value of fish for home consumption and gifts. Excavated fish ponds of 0.1 to 0.2 ha yielded maximum average earnings of M$3,709/ha.

It was also found that in these fish culture operations, the major costs incurred were for labor charges, purchase of fish fry, maintenance of equipment and rent (Table 8). The average cost of production was the lowest for mining pools (M$613/ha) and highest for excavated ponds less than 0.1 ha (M$4,105/ha). Tan, C.E. (1973) indicated that the costs of labor and fertilizer, rather than feed, were unusually high especially for small ponds. This is partly due to the large estimates for the time spent on fish culture operations by the farmers. In the case of large mining pools, minimal care is provided once the fish have been stocked. If comparisons of income and production costs are made as in Tables 7 and 8, it is apparent that fish culture in mining pools is the most profitable, but fish culture in excavated ponds relying only on family labor is also attractive especially with financial assistance from the Fisheries Department. In summary, fish culture in mining pools yields a net return of about 45% on capital invested: partly due to the low capital investment involved. Excavated ponds of 0.1 to 0.2 ha give a net return of about 17% while those over 0.2 ha or below 0.1 ha show losses. It is clear that methods for fish culture in ponds must be better documented to compare the profits obtained.

In contrast, paddy field fish culture requires little management. Yields vary from year to year depending on prevailing natural conditions. It was estimated that in 1969, 1,400 t of catfish, *Clarias* spp. were produced from 9 major paddy areas on the west coast of Peninsular Malaysia, of which 972 t were from the Krian District in Perak. Here, catfish constituted only 10 to 20% of the total harvest of paddy field fishes, which also included *T. pectoralis* and *O. striatus* (Tan 1978). In one particular 1.2-ha paddy field in the Krian District in 1970, S.P. Tan (1973) found that the farmer derived M$452 from fish and M$1,200 from rice. This shows the importance of these fish as a source of income. In a more systematic survey of the importance of paddy field fishes in the Krian District, Tan et al. (1973) estimated that the farmers' income from fish constituted 22 to 60% of the income from rice in the single-cropping areas and 4 to 19% in the double-cropping areas. They concluded that fish formed a significant part of the total income of at least 60% of the tenant farmers interviewed. There is therefore an urgent need to improve this method of fish production.

Table 7. Income derived from various types and sizes of fish ponds in Selangor, Peninsular Malaysia (from Tan, C.E. 1973): US$1.00 = M$2.06.

Type of pond	Size (ha)	Income M$/ha
Mining	All sizes	1791
Excavated	Above 0.2 ha	1013
Excavated	0.1-0.2 ha	3709
Excavated	Less than 0.1 ha	3393

Table 8. Average costs of fish production (M$/ha) for different types and sizes of ponds in Selangor, Peninsular Malaysia (from Tan, C.E. 1973): US$1.00 = M$2.06.

Items	Mining pools (all sizes)	Excavated ponds Above 0.2 ha	0.1-0.2 ha	Less than 0.1 ha
Fish fry	287	427	383	163
Feed	7	35	74	121
Fertilizers	30	47	207	497
Rent	178	163	175	158
Repairs and maintenance	27	62	516	334
Labor	79	306	833	2800
Others	5	2	5	32
Total	613	1042	2193	4105

Case Studies of Integrated Fish Farms

The methods and economics of integrated fish farming in Malaysia warrant further studies to provide useful guidelines for future planning. To this end, 5 owners of integrated farms were interviewed: two operating at subsistence level at a Malay kampung 30 km from Taiping, Perak; two commercial ventures in fish, poultry and pig production sited near disused mining pools at Taiping; and the fifth a farm at Bayan Lepas, Penang.

A. THE FARM AT BAYAN LEPAS, PENANG

This 14-acre (5.7 ha) integrated farm combined fish production, pig and poultry raising and the cultivation of fruit trees and vegetables. It was established in 1950 and was widely used as a model integrated farm for training courses conducted by the Fisheries Division in the fifties. A detailed description was published by Le Mare (1952), at which time the farm was still being developed and no data on the income from newly planted fruit trees and poultry husbandry were available. Le Mare concentrated on the methods and economics of pig-fish culture.

The farm is located on what was formerly 5 acres of coconut plantation and 9 acres of paddy land. A stream running across the farm provides water for the fish ponds and other farming activities. In 1952, the farm was organized into three main sections: 1) pig breeding, 2) pig fattening and fish culture and 3) vegetable and fruit growing.

The pig nursery consisted of a building for farrowing and the maintenance of two stud boars, a house for the pig keeper and a store and cook-house for pig-food. The breeding stock consisted of two Middle-White stud boars and 50 local or local x Middle-White cross sows. The 5 acres of old coconut plantation were fenced to allow free ranging of the breeding sows and their litters. This section was maintained by one worker.

The section for pig fattening consisted of three sets of buildings: the pigsties with 20 compartments, the laborers' accommodation and fodder store and two cooking stores with two cauldrons–a total area of 3 acres maintained by one supervisor and two laborers. The pig-sties were washed daily and the fecal wastes carried along a concrete drain system to the fish ponds. At any one time about 220 pigs were kept for fattening.

There were eight fish ponds with a total water surface of 2.65 acres and an average depth of 1 m. Water was derived from the nearby stream via concrete channels. Rambutan and mango trees were planted along the bunds between the ponds. Two workers were engaged to look after the fish ponds. Six ponds were stocked with 16,500 fry of *Sarotherodon mossambicus* and the other two ponds were stocked with grass carp, big head carp, silver carp and common carp. The actual numbers of carps released was not stated by Le Mare (1952). Accurate data on annual fish production in these ponds could not be ascertained due to predation of fish by otters and undocumented harvest of young fish for pig food and for consumption by the laborers. Le Mare (1952) estimated that a total annual production of 3.25 t was obtained from these ponds.

The economics of pig-fish culture are summarized in Table 9. The net annual income of M$4,563 represented 14.2% of capital investment of M$32,200 or 6.2% of the total annual running costs. It should be mentioned that since piglets and fattened pigs were sold every 6 mo, the actual working capital for running these two sections at any one time was only $38,668.

To evaluate the subsequent development of this integrated farm at Bayan Lepas, visits were made to this farm in 1979. It was found that the farm changed hands in 1964 due to outstanding debts incurred in the purchase of pig rations and financial losses in operating the farm. This arose from a decline in price of pigs and increased costs of feed. Further, water supply to the fish ponds became inadequate due to diversion of the water supply in the stream via an irrigation canal constructed in 1963 for paddy cultivation. In 1967, the existing eight fish ponds and two additional 0.6-ha ponds were renovated for fish culture. Attempts to culture lampam java and common carp supplied by the Fisheries Department failed due to high mortalities resulting from a shortage of water supply. As a result, fish culture was stopped and the ponds left unused. The farm, renamed Ladang Kim Chong in 1976, has since been involved mainly with the production of pigs and chickens. Fecal wastes of pigs are channelled into the two large 1.5-acre ponds and another sump pond excavated near the breeding pens but these are not utilized for fish culture.

To accommodate increased activities in pig and egg production, additional buildings have been constructed in the farm since the description of Le Mare (1952). The breeding sows are no longer allowed to free range in the nursery section and are now maintained in an additional

Table 9. The economics of pig-fish farming for the Bayan Lepas farm Penang, Malaysia, 1951, excluding depreciation and maintenance costs (modified from Le Mare, 1952): US$1.00 = M$2.06.

Activity	Expenditure (M$)		Income (M$)	
	Capital costs	Running costs (A)	Gross (B)	Net (B-A)
Pig breeding	12,000	17,028	18,200[a]	1,172
Pig fattening	8,600	51,268	53,240[b]	1,972
Fish culture	11,600	4,520	5,939	1,419
Total	32,200	72,816	77,379	4,563

[a]Based on sales of 700 piglets.
[b]Based on sales of 440 fattened pigs.

breeding shed consisting of 60 pens. A further 32 sow pens have been added to the original building for farrowing. In the pig fattening section, another building with 18 pens has been built. Brood hens are housed in battery cages in a shed constructed in the pig nursery section. The owner-manager resides with his family in a newly-built house located in the pig nursery section of the farm.

The pig farm has approximately 1,000 animals at any one time, including 100 to 110 breeding sows (Landrace Large White cross and 7 boars (Duroc). With improved breeding techniques, 1,739 piglets were produced in 1978 and raised to 85 to 90 kg for marketing in 5.5 mo. All the pigs are now fed with dry rations of various quality at different phases of growth. In April 1978, the cost of feed alone was M$21,027. The pigs were washed prior to feeding twice daily. A supervisor and three assistants were engaged in maintaining the pigs at a monthly labor cost of M$1,200.

Egg production from layer hens is supervised by the farmer's wife who is assisted by two workers. The brood hens totalling 1,295 are maintained in battery cages and produce on the average about 1,050 eggs daily. Each layer (strain: Hisex or Babcock) can produce about 220 eggs annually. The layer hens consume 1 t of mash (M$600/t) every 9 days.

Table 10 shows the estimated annual income and operating costs of the farm in 1978, exclusive of depreciation of buildings and equipment. It does not include the sale of chicken manure since most of this was given away or sold at M$1/30 kg, provided that the buyers collected and packed it themselves. Since the pigs are sold monthly, the actual working capital for operating the pig farm in any one month is about M$30,000 of which 70% is used for purchase of pig food. For egg production, the estimated working capital for maintaining the brood hens per month is about M$4,000. For fruit production, the 100-odd rambutan trees were contracted to fruit-collectors as the harvest involved additional labor. Similarly, the 8,000 coconuts that were sold at M$0.20 each were harvested and sorted by the buyer at the farm.

In 1978, the farm made a profit of M$101,145 due to good prices available for pigs (M$140/*pikul) and eggs (M$0.13 each). Production costs of pigs and eggs were calculated to be M$113.50/pikul and M$10.30 per 100 eggs, respectively. It must be emphasized that with increasing costs of animal feed and the unpredictable fluctuation of prices of eggs and pigs, profit margins in such farming systems are becoming narrower and efficient management practices are essential to maintain the viability of small farms.

*1 pikul = 60.5 kg.

Table 10. The economics of the integrated farm at Bayan Lepas, Penang, Malaysia for the year 1978 excluding depreciation of buildings and equipment: US$1.00 = M$2.06.

Items	Value (M$)
Production costs	
1. Pig farming	
Food	252,444
Labor	11,400
Electricity	1,800
Maintenance of equipment	700
Subtotal (A)	266,344
2. Egg production	
Food for layers	24,344
Labor	14,400
Electricity	360
Maintenance of facilities	500
Subtotal (B)	39,604
Total operating costs M$305,948	
Gross income	
Sale of 1,739 fattened pigs at M$200/pig (C)	347,800
Sale of 382,250 eggs at $13/100 eggs (D)	49,693
Sale of rambutans (E)	8,000
Sale of coconuts (F)	1,600
Total	407,093
Net income	
Pig farming (C-A)	81,456
Egg production (D-B)	10,089
Fruit production (E+F/assuming no costs)	9,600
Total (see text)	101,145

The owner of the farm has shown interest in restarting fish culture at the farm following discussions with us. The major constraint remains the inadequate water supply, but this could be overcomed by tapping water from the irrigation canal, subject to approval of the Irrigation Department. Such approval is likely since paddy cultivation has virtually ceased in this area with the recent expansion of the Penang airport. Assistance from the Fisheries Department is being sought to redevelop the fish ponds which have become overgrown.

B. A PIG-FISH FARM AT TAIPING, PERAK

This farm was established illegally near an 8-ha disused mining pool and has been in operation for 5 yr. It consists of a wooden building housing 300 pigs (including 30 breeding sows) accommodation for three laborers and space for storing food and cooking the pig food.

In 1976, 5,000 big head carp, 20,000 mud carp, 500 grass carp and 4,000 common carp were introduced into the mining pool. Difficulties were experienced in harvesting and in preventing illegal angling of the species other than big head carp and therefore only big head carp have been stocked in subsequent years. No supplemental feeding is provided besides the discharge of pig manure into the pond.

The pigs are fed with a wet ration consisting of pig mash, trash fish and tapioca. It costs M$20/day to maintain 300 pigs. Every month 40 pigs each weighing about 100 kg are sold. The economics of this system are shown in Table 11. The fish harvest consisted of only big head carp, average weight 1.5 to 2.0 kg, after a culture period of 8 months. These were sold at M$1,360/t. The gross income of three fish harvests in 2 years amounted to M$30,000. The annual net income from fish is equivalent to 43% of the total. Other fish species caught are given away or used for home consumption.

In this illegal farm, no rental of land was incurred but capital investment was kept to a minimum due to the insecurity of tenure. The operator was keen to obtain a temporary occupation license but had encountered problems in his repeated attempts, as has been the case for virtually all similar farming units 'squatting' on disused mining land.

C. A PIG-FISH AND POULTRY FARM UNIT IN TAIPING, PERAK

This farm, belonging to Mr. P. Y. Tai, was established illegally on a 4 ha of disused mining land next to a 3.3-ha disused mining pool near Taiping, Perak. The farm cost M$10,000 to establish and consists of seven chicken coops (one of which is sited over the pond) a duck pen, a pigsty for 60 pigs, a store shed and a hut for the farm workers. It is managed by three workers, each responsible for one type of livestock.

In early 1978, the mining ponds with depths up to 10 m were stocked with 2,500 big head carp, 200 grass carp and 300 common carp. Besides animal wastes, vegetable remnants and tapioca leaves were occasionally thrown into the pond. Little effort was entailed in fish culture operations.

Production of table chickens follows a rotation method. Every month, 1,500 chicks (Harper strain) are purchased at M$0.80 each. In 60 days, the chicks reach market size (1.8 kg) and are sold at M$1.48/kg. The production cost of each chicken is about M$3.30. Following such a scheme, it is possible to produce 17,100 chickens for sale annually with mortality rate at 5%.

Table ducks are produced on a smaller scale. The ducks are allowed to roam freely in the farm and are penned only at night. Four batches of 250 ducks are raised each year: they can reach marketable size in 75 days. This method of production has a mortality rate of about 20%.

A stock of 60 pigs is maintained in pens in the pigsty. The owner pays more for the same pig feed than the farm at Bayan Lepas as he has to pay market rather than wholesale prices.

The operating costs and income of this farm for 1978 are shown in Table 12. It is evident that with the utilization of animal wastes, the net income of M$7,675 from fish culture was very high in relation to production costs compared to chicken production. Losses were incurred in pig and duck production. Thus, fish culture provides an important source of additional income to help defray the cost of production of other livestock, especially in small pig farms. In the present case, income from fish is derived only from the harvest of big head carp. The other species harvested are used for home consumption or given away.

D. KAMPUNG STYLE INTEGRATED FARMS INVOLVING FISH CULTURE

In the kampungs, each family owns a small plot of land. Various crops, such as paddy, fruit trees and vegetables, are grown in these smallholdings, mainly for domestic consumption but also for additional income

Table 11. The annual operating costs and income for a pig-fish farm on disused mining land at Taiping, Perak, Malaysia from 1977 to 1978: US$1.00 = M$2.06.

Items	Value (M$)
Operating costs	
Pig food	61,000
Labor	3,600
Maintenance and operation of equipment	1,800
Subtotal for pigs (A)	66,400
Purchase of fish (B)	3,650
Total	70,050
Gross income	
Sale of 480 pigs at M$170/pig (C)	81,600
Sale of big head carp at M$1,360/ton (D)	15,000
Total	96,600
Net income	
Pig production (C-A)	15,200
Fish production (D-B)	11,350
Total	26,550

for the purchase of essential household needs. Often, a small number of livestock, such as goats, cows, buffaloes and chickens, are raised near the family homes as additional sources of food. The Malays, being Muslims, are not allowed to rear pigs. The majority of rural Malays are subsistence farmers and often suffer from malnutrition.

Fish culture has been introduced into smallholdings to provide additional animal protein. Incentives, such as subsidies for pond construction, free distribution of fish fry and availability of technical supervision provided by the Fisheries Department, have attracted the owners of smallholdings to freshwater fish culture. Such a scheme was initiated at Kampung Pantai Besar, Batu Kurau, which is about 30 km north of Taiping, Perak. A study of two small integrated farms with newly constructed fish ponds was conducted from February to March, 1979.

Table 12. The operating costs and income of a pig-fish and poultry farm at Taiping, Perak, Malaysia for the year 1978: US$1.00 = M$2.06.

Items	Value (M$)
Operating costs	
1. Pig production	
Labor	3,600
Maintenance	400
Food	19,400
Subtotal (A)	23,400
2. Chicken production	
Labor	4,200
Maintenance	400
Purchase of 18,000 chicks	14,400
Food	48,000
Subtotal (B)	67,000
3. Duck production	
Labor	1,600
Maintenance	400
Purchase of 1,000 ducklings	450
Food	2,160
Subtotal (C)	4,610
4. Fish production	
Purchase of fish fry (D)	825
Total	95,835
Gross income	
Sale of 96 pigs (E)	18,240
Sale of 17,100 chickens (F)	76,950
Sale of 800 ducks (G)	3,600
Sale of big head carp (H)	8,500
Total	107,290
Net income	
Pig production (E-A)	−5,160
Chicken production (F-B)	9,950
Duck production (G-C)	−1,010
Fish production (H-D)	7,675
Total	11,455

The first farm of 1.5 ha belongs to Mr. Haji Abdul Wahab, the headman of the kampung. It consists of a 0.8-ha paddy field; a wooden house surrounded by fruit trees including durian, rambutan, and bananas; a vegetable plot measuring 5 x 10 m and a small animal enclosure. Two ponds of 0.10 and 0.05 ha were constructed in 1977 with a cash subsidy provided by the Fisheries Division. The labor required in running the farm is largely provided by the farmer and his family.

All crops other than durians are for home consumption. The paddy field produces 4,350 kg of rice annually which is shared equally with another person who assists with paddy operations. The livestock, 4 goats and 20 chickens, are allowed to roam freely in the farm and provide meat for special occasions as well as a supply of eggs. The only cash income (M$2,400/yr) is obtained from the sale of fruit from eight durian trees.

The two fish ponds which were stocked with 585 lampam java and 195 grass carp by the Fisheries Department provide a reliable supply of fish for home consumption. Animal wastes and inorganic fertilizers are added to the pond, together with tapioca leaves, leftover rice from meals, grass and aquatic weed. Despite the removal of a few fish periodically for home consumption, a harvest of 120 kg of fish was obtained after a culture period of 10 mo in 1978.

The constant availability of fresh fish from these ponds, which were the first to be constructed in the kampung, proved attractive to many other smallholders especially with the various incentives available from the Fisheries Department. An interest in fish culture has therefore developed in this kampung. The initial fish yields are expected to be low due to lack of experience, but the availability of fresh fish is a significant contribution to the families' diet.

The other farm of 0.8 ha examined belongs to Mr. Ahmad B. Sulong and consists of a 0.3-ha paddy field, a wooden house, a plot of durian and other fruit trees and a 0.05-ha pond which the owner constructed manually without any aid from the Fisheries Department. Members of the farmer's family assist in operating the farm.

Double-cropping is practiced in the paddy field to meet the rice requirements of the family. Chillies, gourd, beans and other vegetables are grown around the house and along the bunds of the pond for home consumption. Fruit from nine durian trees provide annual income of M$2,600 and is the only cash crop. The farmer also maintains about 20 hens which are allowed to wander freely searching for food. Supplemental feed such as leftover rice and rice bran are given to the hens, which produce eggs for daily consumption. Besides operating his small farm, the owner earns an additional annual income of M$600 by working as a rubber tapper in a nearby estate.

The fish pond is adjacent to the house and forms part of garden containing flowers and vegetables. An ample supply of water for the pond is obtained from an irrigation canal. In view of the good water supply and security of the pond, the Fisheries Department stocked 5,000 juveniles of the giant freshwater prawn, *Macrobrachium rosenbergii*, on January 23, 1978 and 140 lampam java on May 28, 1978.

Rice bran, roasted coconut kernel, rice, tapioca leaves and grass were used to feed the fish and prawns but amount and frequency of feeding were not recorded. The prawns weighed about 94 g each after 12 mo of culture. The fish showed poor growth and were only about 100 g each after nearly 10 mo. The yield from this pond has yet to be determined since the fish and prawns have not yet been harvested, but a few fish have been caught for home consumption.

Discussion

Integrated farming systems aim to optimize food production from limited land and water space. In practice, they maximize utilization of the farmer's time, with or without the efficient recycling of wastes. The recycling of animal wastes in fish production, as observed in pig-fish farms, is important in providing additional income for the farm.

The utilization of disused mining pools for fish farming in Malaysia requires minimal capital costs. As a commercial enterprise, it is very profitable provided that adequate fertilizers, both inorganic and organic, are used. This provision can be met by channelling animal wastes, especially pig manure, into the pools. There is, however, little control of the quantity of wastes being drained into these pools and excessive quantities can cause mass mortality of fish by eutrophication and oxygen depletion. Further studies are required to determine the appropriate amount of various animal wastes required for a defined water space and the recommended stocking densities of fish so as to maximize production.

In comparison with yields of 9.5 t/ha/yr in polyculture systems in Israel (Yashouv & Halery 1972), fish yields in ponds in Malaysia are low and could be improved by better management techniques. Intensive fish farming techniques (e.g., Tal & Ziv 1978) have yet to be practiced commercially in Malaysia, though their potential should be investigated in view of the increasing competition for the utilization of land (Low 1976).

Unlike the commercially-operated integrated farms which are profit-oriented, fish culture in small ponds operated by smallholders at the kampung level is relatively recent. As an additional activity for small subsistence integrated farms, it involves minimal operating costs yet provides a valuable source of animal protein. It also provides practical experience in fish culture which offsets the rather poor initial yields and offers a way of directly assisting the rural inhabitants. With proper training, farmers should be able to increase the yields which would generate further interest in aquaculture at the kampung level. Ultimately, improved methods for fish culture must be formulated to make it more commercially viable.

Conclusions

1. In Malaysia, freshwater fish culture is often integrated with the production of other agricultural crops in an effort to maximize food production within a limited space. It makes efficient use of the farmer's time, as in the case of kampung style integrated farms, and produces an additional cash crop via the recycling of wastes, as in pig-fish farms.
2. Various problems are faced by these integrated farms. In the small kampung farms operating at subsistence level, the lack of technical knowledge and experience in fish culture have depressed the initial yields of fish: the concept of fish culture has only recently been introduced.
3. In commercial farms, culturing fish by adding animal wastes to disused mining pools, the farmers employ little or no management. The relatively low yields could be increased by improved management techniques which should be a topic for urgent investigation. The insecurity of tenure in many of these farms located illegally on disused mining lands poses an additional constraint to improving the methods of production and discourages investment.
4. The lack of accurate records on production of fish and other crops in integrated farms often made it difficult to assess their profitablity and to recommend improvements. Efficient management is of utmost importance in increasing profit margins.

Acknowledgments

I am greatly indebted to the owners of the various farms visited and the Fisheries Department, Perak, for the cooperation and assistance given during the field study. Thanks are also due to Messr. A. A. Jothy and C. E. Tan for allowing the use of their published data and to Ms. Hajar Abd. Rani for typing the manuscript.

References

Anon. 1977. Programme to encourage and develop fish-farming among farmers and fishermen. Ministry of Agriculture, Kuala Lumpur, Malaysia. 9 p. (In Malay)

Anon. 1978a. Fishery statistical bulletin for the South China Sea area, 1976. Southeast Asian Fisheries Development Center, Samutprakarn, Thailand. 172 p.

Anon. 1978b. Cutting freshwater fishes. Ministry of Agriculture, Kuala Lumpur, Malaysia. Fish. Bull. No. 14. 59 p. (In Malay).

Anon. 1978c. Annual Fisheries Statistics 1977. Fisheries Division, Ministry of Agriculture, Kuala Lumpur, Malaysia. 154 p.

Heath, R.G. 1934. Fish production in the Krian Irrigation Area. Malayan Agric. J. 22(4):186-189.

Hickling, C.F. 1948. Fish farming in the Middle and Far East. Nature (Lond.) 1601(4098):748-751.

Jothy, A.A. 1968. Preliminary observations of disused tin-mining pools in Malaysia and their potentials for fish production. Paper presented at the 13th Session, Indo-Pacific Fisheries Council, Brisbane, Australia, October 1968. IPFC/C68/ Tech. 25. 21 p.

Labon, A. 1974. Malaysian long-term fisheries development plan until 1995. South China Sea Fisheries Development and Coordinating Programme, Rome, Italy. FAO/SCS/DEV/73/10. 91 p.

Le Mare, D.W. 1952. Pig-rearing, fish-farming and vegetable growing. Malayan Agric. J. 25:156-166.

Low, S.J. 1976. Present status and potential for development of inland fisheries in Malaysia. Paper presented at the 17th Session, Indo-Pacific Fisheries Council, Colombo, Sri Lanka, November 1976. 29 p.

Merican, A.B.O. and M.K. Soong. 1966. The present status of freshwater fish-culture in Malaysia. Paper presented at FAO World Symposium on Warm-water Pond Fish Culture, Rome, Italy, 18-25 May 1966. 12 p.

Tal, S. and I. Ziv. 1978. Culture of exotic species in Israel. Bamidgeh 30(1):3-11.

Tan, C.E. 1973. Report on a survey of the economics of fish culture in Selangor, West Malaysia. Fisheries Development Authority Malaysia, Kuala Lumpur. 19 p.

Tan, C.E., B.J. Chong, H.K. Sier and T. Moulton. 1973. A report of paddy and paddy-field fish production in Krian, Perak. Ministry of Agriculture and Fisheries, Kuala Lumpur, Malaysia. Bulletin No. 128. 57 p.

Tan, E.S.P. 1978. Problems influencing padifield fish culture in Malaysia, p. 275-281. *In* H.F. Chin, I.C. Enoch and Wan Mohamad. Othman (eds.) Food and Agriculture Malaysia 2000, Faculty of Agriculture, Universiti Pertanian Malaysia, Kuala Lumpur, Malaysia.

Tan, S.P. 1973. The significance of sump ponds in harvesting paddy-field fishes in North Krian, Perak. Malayan Nat. J. 26:26-31.

Yashouv, A. and A. Halery. 1972. Experimental studies of polyculture in 1971. Bamidgeh 24(2):31-39.

Integrated Farming Systems: A Case Study under the Federal Land Development Scheme

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Abstract

The Malaysian government is committed to develop aquaculture as a means of protein production. This paper describes a case study in the Belara Land Development Scheme, Trengganu State, under the supervision of the Federal Land Development Authority. The scheme involves about 30 fish farmers. Fixed costs (land acquisition and pond construction) and variable costs (seed, fertilizers, pesticides, labor, etc.) are tabulated for 0.25-acre ponds stocked with grass carp, common carp, bighead carp and *Puntius gonionotus*. The costs and returns are summarized as follows, per 0.25 acre pond: fixed costs, M$2,200 (M$800 for land acquisition); total variable costs for a 9-month production period, M$847; total revenue, M$1,906; gross profit, M$1,059. The use of freshwater aquaculture as a supplementary occupation in land development schemes is discussed.

Introduction

The prime objective of encouraging integrated farming systems is to increase the income and upgrade the standard of living of small-scale farmers. If systematically implemented, they would maximize the utilization of land and labor resources.

As in most third world countries, a large proportion of Malaysian small-scale farmers are characterized by low income which is defined as income below that required for minimum subsistence, otherwise known as the poverty line. In 1975 this ranged between 47 and 79% in the agricultural sector compared to 23 to 29% in the nonagricultural sector (Government of Malaysia 1976). The high incidence of poverty in the agricultural sector results from many interacting socioeconomic variables. It is impossible to ascertain which variables exert the strongest effects, but the general consensus among economists and policy makers is that the low productivity of farms resulting from low investment, weak organization and uneconomic size is the predominant factor. For example, 45% of smallholders growing rubber hold less than 5 acres and 90% less than 10 acres. Similarly, 55% of paddy farmers hold less than 3 acres and 80% less than 5 acres (Government of Malaysia 1976). The conservative tradition of passing farming methods from generation to generation also accentuates the problem to some extent.

Another factor in agricultural poverty is the underutilization of labor. For example, rubber tappers have a considerable amount of spare time after the 4 to 5 hr morning period of tapping and subsequent collection and paddy farmers employing single-cropping have spare time particularly leading up to harvest. Rural underemployment was estimated at around 11.6% in October 1974 (Government of Malaysia 1976). This is partly due to the seasonal nature of agriculture. Population growth at 2.5 to 3% per annum and the slow absorption of excess labor into the nonagricultural sector also aggravates the problem.

It is not feasible in the long term to raise farm income solely by increasing farm acreage as there are limited areas of cultivable land available. There is also strong evidence that many producers are reluctant to expand and involve themselves in a considerable amount of investment. High rates of inflation have discouraged investment by small-scale farmers.

Given these circumstances, integrated farming systems have a high potential by combining, for example, animal husbandry with plantation crops and cattle with rubber or oil palm (Abraham 1978). Freshwater aquaculture can also be integrated with other farming practices, e.g., with paddy farming, vegetable or fruit growing, pig or poultry rearing, and rubber plantations.

This study focuses on the integration of aquaculture and rubber planting and examines the role of freshwater aquaculture as a supplementary source of income to rubber smallholders, particularly the settlers in the Federal Land Development Schemes. It attempts to construct cost profiles and expected payoffs in establishing freshwater fish farms, based on the data obtained from a recent study. The paper concludes with a discussion on the feasibility of similar projects in land development schemes.

The Malaysian government is committed to develop aquaculture to supplement the animal protein needs of the population and has provided financial subsidies and training facilities for potential fish farmers. This support for aquaculture results initially from the deteriorating state of marine fisheries which have been depleted by overfishing (Khoo Khay Huat 1976).

THE CASE STUDY

1. Study Area

This study was conducted in the Belara Land Development Scheme (Belara Scheme), one of the many land schemes under the supervision of the Federal Land Development Authority (FELDA), located in the state of Trengganu, West Malaysia, about 25 m from Kuala Trengganu. There were about 30 fish farm operators actively involved in this scheme. Aquaculture was introduced here only recently which was the main reason for choosing the area as the actual cost and investment involved in aquaculture would still be fresh in the memory of fish farmers, many of whom do not keep any records.

In 1976, there were about 172 settlers in the Belara Scheme, each of whom was given 8 acres of land for the main crop (rubber) and an additional 0.25 acres for building their dwellings and for home gardening. Their average income was then about M$333/mo, compared to only M$111/mo in 1975. This indicates that the scheme has been very successful in approaching the FELDA target level of M$350/mo. Table 1 shows the distribution of monthly income groups. In the Belara Scheme 84% of the settlers belong to families with 6 to 10 persons (Table 2), indicating large numbers of young people. A large number of family dependents means additional labor for agriculture and related activities but also brings additional pressures in providing their basic necessities. This may force the family to seek additional sources of income to that derived from rubber.

Table 1. Average monthly income of settlers in the Belara Scheme in 1976. (Source: FELDA Institute of Land Development and Department of Data Processing, FELDA Settler Census 1976).

Income class	No. of settlers
M$*100 and less	2
101-200	20
201-300	82
301-400	44
401-500	19
501 and above	3
No response	2
Total	172

*M$1 = US$0.46.

Table 2. Family size of settlers in the Belara Scheme in 1976. (Source: FELDA Institute of Land Development and Department of Data Processing, FELDA Settler Census, 1976).

Family size	No. of households	%
2	1	0.6
3	3	1.7
4	12	7.0
5	17	9.9
6	31	18.0
7	34	19.8
8	25	14.5
9	23	13.4
10	14	8.1
11	6	3.5
12	2	7.0
13	1	0.6
14	1	0.6
15	1	0.6
16	1	0.6
Total	172	

2. Costs and Returns Analysis of the Aquaculture Project

Cost and revenue data were collected through personal interviews with the fish farmers in the Belara Scheme. The average pond size is about 0.25 acre, which is representative of small fish farms at present. It is also safe to assume that few farmers would be willing to sacrifice much of their cultivated land, such as paddy fields or rubber plantations for aquaculture. This view will change, however, if aquaculture is seen to be profitable.

In determining the profitability of aquaculture we concentrated on short-term analyses, assuming two categories of costs: fixed and variable costs. Fixed costs are those which will be incurred even if there is no output, i.e., they do not vary with the production level. Variable costs are a function of output in the production period and are not incurred if nothing is produced. Our full definitions were:

a. Fixed costs: Fixed costs, sometimes referred to as development costs, included the cost of acquiring land and the necessary equipment for the preparation of ponds (especially for land clearance and levelling, bund construction, etc.). They also included the cost of labor and machinery employed for pond preparation. In this case the construction of the ponds was completely assigned to a contractor and the amount paid was taken as fixed costs.

b. Variable costs: The variable costs included the cost of inputs such as seed or fish fry, fertilizers, insecticides, pesticides and materials and other items such as labor, both family and hired. Items like repairs and maintenance were minimal and were excluded from the calculations.

Table 3a shows the fixed costs incurred for a 0.25-acre pond: a total of M$2,200 with an average of M$800 (36%) for land acquisition. In the Belara Scheme, fish farmers acquired cheap swampland which was unsuitable for agriculture. The remaining 64% of the fixed costs were construction charges paid to contractors. It is important to note that for each individual farm, the actual amount for construction jobs varied with the size and location of ponds, depth of excavation and the topography of the land.

The variable costs varied with many factors, such as stocking rate, quantity and frequency of feeding, etc. For an average 9-mo production period, the estimated variable costs for a 0.25-acre pond were M$847. Table 3b shows that about 35% of the total variable costs comprised seed or fry purchase, despite the fact that fry were usually obtained free of charge from the Fisheries Department under a subsidy scheme. The value of the fry has been estimated here to reflect their real cost.

Table 3. Fixed and variable costs of a 0.25-acre fish farm in the Belara Scheme in 1979.

a. Fixed costs:			%
Land acquisition			
(0.25 acre of swampland)	M$*	800	36
Construction cost		1,400	64
Total	M$	2,200	100
b. Variable costs:			
Fry	M$	297	35
Feed		190	22
Fertilizers		60	7
Labor		270	32
Others		30	4
Total	M$	847	100

*M$1 = US$0.46.

Other major components of the variable costs were labor charges and feed expenses which constituted 32 and 35%, respectively. As far as labor is concerned, it was assumed that fishfarm operators spent an average of 1 hr/d at the fishfarm over the 9-mo period. Fertilizers accounted for only 7% of the total variable costs and many operators used animal wastes rather than chemical fertilizers for reasons of low cost and high availability.

Table 4 shows the expected production and revenue from a 0.25-acre pond. The production depends on several variables: stocking, mortality and growth rates. The mortality rates were between 5 and 25% depending on the species: rather low compared to other studies (Malik 1976). Table 5 estimates the gross profit of M$1,059, assuming a total revenue from a 0.25-acre pond of M$1,906. This represents a return on capital invested of 48%, which seems high compared with other studies (Tan Cheng Eng 1973). This is probably because our study excluded the portion of fish produced for home consumption from the saleable harvest data. If the saleable quantities were reduced to allow for this, the gross profit and rate of return on capital would be lower. Furthermore, depreciation was not computed and deducted from the gross profit figure.

3. Discussion of Freshwater Fish Farms as a Supplementary Occupation in Land Development Schemes

The foregoing analysis was based on a small sample which may not be entirely representative, but it does

Table 4. Average stocking, harvest and revenue data for 0.25-acre fish ponds in the Belara Scheme, 1979.

Species	Number stocked	Mortality %	Number harvested	Average weight (kati)*	Total production (kati)*	Price per kati* (M$)**	Total revenue (M$)**
Grass carp *(Ctenopharyngodon idella)*	60	25	45	5.0	225	1.60	360
Big head *(Aristichthys nobilis)*	45	10	40	4.0	160	1.60	256
Lee Koh *(Cyprinus carpio)*	350	15	297	1.5	446	1.40	624
Indonesian carp *(Puntius gonionotus)*	500	5	475	1.0	475	1.40	666
	955		857		1,306		M$1,906

*1 kati = 0.604 kg.
**M$1 = US$0.46.

give an indication of the economic viability of freshwater fish farms as a supplementary source of income for small-scale farmers. It also indicates that small sized ponds can generate significant income, which recommends their use by settlers under land development schemes, particularly schemes sponsored by FELDA. It has been reported that 58.7% of FELDA settlers have no supplementary income, while those who have only a small percentage (16%) earned $100 or more. Table 6 lists typical sources of supplementary income. Because FELDA encourages settlers to seek supplementary sources of income, we recommend the development of aquaculture projects in land schemes. While not all the areas under FELDA schemes may be suitable for aquaculture development, it should be strongly supported where possible. Table 6 indicates the greatly increased revenue from 0.25-acre rubber plots converted to freshwater aquaculture. Such gains would encourage settlers to earn supplementary income closer to home. It is therefore suggested that more feasibility studies should be carried out for establishing freshwater fish farms under FELDA schemes.

Table 5. Summary of costs, revenue, gross profit and return to capital for a 0.25-acre fish pond in the Belara Scheme, 1979.

Fixed costs (A)	M$*2,200
Variable costs (B)	847
Revenue (C)	1,906
Gross profit (D) = (C) − (B)	1,059
Return to capital (E) = $\frac{D}{A} \times 100$ = 48%	

*M$1 = US$0.46.

Table 6. A comparison of the revenue obtained from various areas of rubber lands before and after conversion to 0.25-acre fish ponds. (Source: Land Development Digest and Aquaculture Projects, Belara Scheme, 1979).

Lot size	Average revenue (M$)* from quarter acre lots for 9 mo	Average gain in (M$)* revenue when converted to fish farms
6 acre lots	118	941
7 acre lots	137	922
8 acre lots	154	905

*M$1= US$0.46.

Summary

1. This study was undertaken on the premise that integrated farming systems are potentially important in raising the income level as well as the standard of living of small-scale farmers.

2. Aquaculture has been highlighted in land development schemes only recently and its contribution to the total fish supply is small. With the current trends in the capture fishery sector and the present fish prices situation, however, freshwater aquaculture is becoming increasingly important, and subsidy programs introduced by the government will encourage it further.

3. This study, although limited and possibly unrepresentative, nevertheless indicates the profitability of establishing small but well-stocked and well-maintained fish ponds. Ponds of 0.25 acres seem to be quite efficient in terms of operation and production and give high and encouraging returns.

4. The cost of establishing 0.25-acre fish ponds in land schemes was found to be lower than the gain in revenue from sale of fish calculated on the basis of a monthly production period. This recommends encouraging the settlers of land development schemes to venture into aquaculture to supplement their income. There is however a need for further feasibility studies on establishing fish ponds in specific areas.

Acknowledgments

Mr. Nasaruddin Arshad wishes to thank ICLARM, SEARCA and the National University of Malaysia for sponsorship, and the Dean, Faculty of Economics, and Head, Department of Agricultural and Resource Economics, National University of Malaysia for leave to present this paper.

References

Abraham, P.D., Editor. 1978. Proceedings of the Seminar on the Integration of Animals with Plantation Crops, organized by Malaysian Society of Animal Production and Rubber Research Institute of Malaysia, Pulau, Pinang, 13-15 April 1978. 255 p.

Government of Malaysia. 1976. Third Malaysian Plan, 1976-1980, Government Press, Kuala Lumpur. 430 p.

Khoo Khay Huat. 1976. Optimal utilization and management of fishing resources, p. 40-50. *In* L.J. Fredericks (ed.) Proceedings of the Seminar on the Development of the Fisheries Sector in Malaysia. Journal of the Malaysian Economic Association, Vol. XIII Nos. 1 and 2, June/Dec. 1976.

Malik, U. 1976. An economic appraisal of freshwater fish development in Peninsular Malaysia, p. 161-174. *In* L.J. Fredericks (ed.) Proceedings of the Seminar on the Development of the Fisheries Sector in Malaysia, Journal of the Malaysian Economic Association, Vol. XIII Nos. 1 and 2, June/Dec. 1976.

Tan Cheng Eng. 1973. Report on a survey of the economics of fish culture in Selangor, West Malaysia. 19 p.

A Case Study on the Economics of Integrated Farming Systems: Agriculture, Aquaculture and Animal Husbandry in Nepal

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Abstract

A two-year economic case study is presented of a small Nepali farm 14 km east of Kathmandu. In the first year the farmer concentrated on cereal crops while in the second year he added a piggery, combined duck raising with fish culture and used improved varieties of cereals. The first year income was Rs 9,058. The second year income was Rs 10,592 from crops and a total of Rs 15,660 from duck-fish culture. Detailed economics are given for both years on a product by product basis.

Introduction

Nepal is predominantly a mountainous country with an economy based on agriculture. The present estimated population of the country is 13.74 million and the population growth rate of about 2.2% per annum is exerting high pressure on available natural resources. The 1971 population census revealed that 94.4% of the population are involved in agriculture and 96.16% live in rural areas. The mountain and hill (upland) areas and the Terai (plain) share 62.39% and 37.61% of the total population while the corresponding distribution of cultivated land is 35.22 and 64.78%. The agriculture land available per man in the upland areas is 0.1 ha compared to 0.3 ha in the Terai. There is no scope for bringing additional land under cultivation in the upland areas where agriculture is already overburdened. This has resulted in mass migration of the hill people to the Terai and destruction of valuable forest resources.

As many as 75% of farming families hold less than 1 ha of land and live on a subsistence or near subsistence economy. It has been already realized that increasing their income is a prerequisite for economic as well as social development. A series of steps, such as land reform, credit facilities, introduction of high yielding crop varieties, more use of chemical fertilizer, integrated rural development and small farmers' programs, have greatly assisted rural people to increase their production and income. Attention has recently been focused on the traditional systems for multicrop production (e.g., paddy-soyabean, maize-soyabean-other beans) and the integration of agriculture with aquaculture and animal husbandry (pig, duck, poultry, buffalo and other cattle). These production systems have been developed empirically by the farmers themselves and are still largely aimed at fulfilling only the farmers' own food requirements.

Case Study

OBJECTIVES

Although multicrop and integrated production systems have a long history, there is a lack of scientific information on their methodology, management and economic viability. The objectives of this case study were to develop reliable, quantitative management guidelines and economically viable production methods for integrated farming systems combining agriculture, aquaculture and animal husbandry, with modifications appropriate to local conditions.

SELECTION OF THE FARMER AND SCOPE OF THE STUDY

The farmer was selected from a small village 14 km east of Kathmandu and is considered representative of the mass of the rural population. He holds less than 1 ha of land and has recently taken up integrated farming. He was trained to record the labor and other inputs used for different crops for two successive years: one, for agriculture alone, and two, for integration of agriculture, aquaculture and animal husbandry. The capital required was obtained through the Agriculture Development Bank and technical support was provided by extension workers and the Fisheries Development Section of the Department of Agriculture.

In the first year, the farmer grew mainly local varieties of cereals, while in the second year he combined carp culture with pig and duck farming and used improved varieties of cereals. To avoid the confusion between the two management systems, the first year has been termed year-I and the second year-II.

FARM RESOURCES: LAND, LABOR AND CAPITAL

The topography of the farm is shown in Figure 1, and the areas of high and low land available for year-I and year-II are given in Table 1. The high land is rainfed and has no irrigation facilities. A small spring and an irrigation canal from the nearby stream irrigate the terrace and other low land throughout the year. In year-I, the farmer had a total land area of 1 ha out of which he owned 0.550 ha and rented 0.450 ha. In year-II, however, the farm area was reduced to 0.850 ha (0.775 ha owned and 0.075 ha rented).

For year-I, the farmer had family labor available totalling 11 persons including 8 adults (5♂ + 3♀). For year-II, the labor force was reduced to 6 including 4 adults (3♂ + 1♀). In both cases, only two persons were employed on a fulltime basis.

The capital required for the farmers' agricultural practices remained unchanged during both years. The introduction of aquaculture and animal husbandry, however, required additional capital.

CROPPING PATTERNS AND LAND USE

In both years, high priority was given to cereal crops as these provide staple diets. Table 2 summarizes the cropping patterns and land use. It should be noted that for year-II, less land was available for cereal farming (see also Table 1). The fish ponds for year-II were constructed on low land using a total of 0.250 ha (net water surface area 0.150 ha). The farmer decided to raise only a limited number of ducks because of his lack of experience: the ponds could support much higher numbers. Similarly, for pig raising, the farmer was not able to evolve an efficient production system during year-II. His efficiency has since improved. The farmer showed considerable enterprise, however, in breeding both pigs and fish for supplying piglets and fingerlings to other local farmers. These operations provide excellent returns on time and other inputs compared with alternative crops.

At present, there is no obvious way to increase the cropping intensity of twice a year by adding a crop to the existing rotation other than by irrigating an extra small fragment of land. By far, the most important rotation on low land is paddy plus soyabean followed by wheat or potatoes or vegetables. For high land, maize plus soyabean or other beans; or chillies followed by wheat or rapeseed or vegetables are the corresponding alternatives.

FARM ECONOMICS

1. Expenditure

The expenditure incurred by the farm for each crop is given in Tables 3 to 12. In year-I, labor accounted for more than two-thirds of the total input costs for crop farming but fell in year-II when there was increased expenditure required for fertilizer. For aquaculture and animal husbandry (pig and duck) in year-II, depreciation and interest on capital were the major costs followed by feed costs. The total expenditure for crop farming was Rs 5622.00 (year-I) and Rs 5258.00 (year-II) and Rs

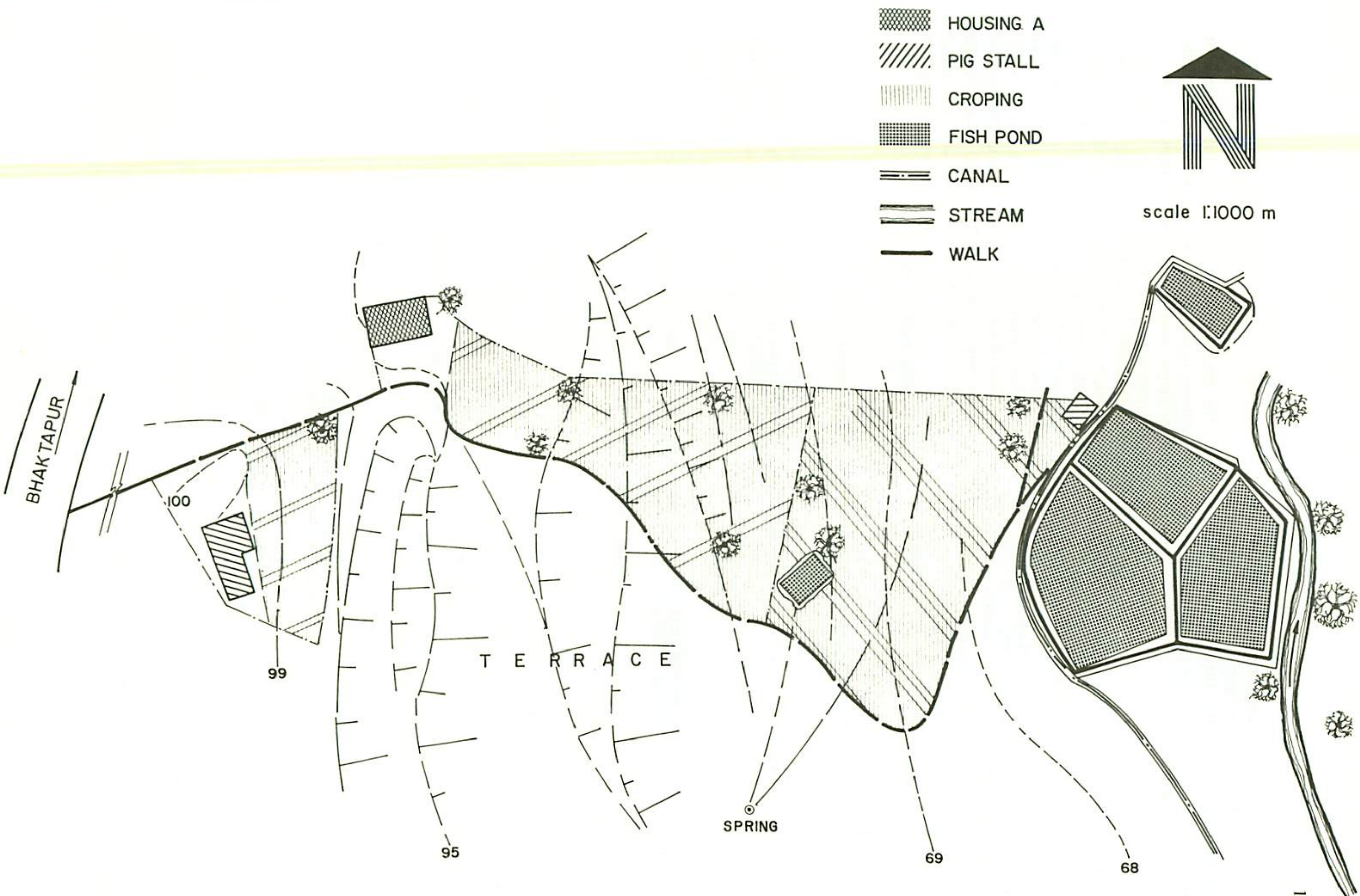

Figure 1. Topography of the integrated farm near Kathmandu.

11,041.00 for the duck-fish farming and piggery.* The expenditure/ha for crop farming was Rs 2819.00 (year-I) and Rs 4780.00 (year-II). The total and area-related costs varied from crop to crop, with the highest cost incurred for paddy farming.

*1 US$ = Rs 12.25.

Table 1. Land available (ha) for different purposes during successive years on a single farm holding in Nepal; year-I, agriculture alone; year-II, integrated agriculture, aquaculture and livestock raising.

Farm	Total area	High land	Low land
Year-I	1.000	0.487 Area for agriculture 0.487	0.572 Area for agriculture 0.520
Year-II	0.850	0.307 Area for agriculture 0.272 Pigsty area 0.035	0.543 Area for agriculture 0.293 Fish pond area 0.250

2. Income

The gross farm income consists of the sales value of the main crops and by-products either consumed by the farm family, sold, exchanged or restocked at current farm gate prices. The farm under study produces some other livestock and associated products (e.g. milk, goats, chickens, etc.) in addition to those recorded here but on a very minor scale. These have been ignored here, as the study has been focused mainly on land use. The income from crop farming was Rs 9058.00 (year-I) and Rs 10592.00 (year-II) at the current prices, while duck-fish farming and the piggery paid Rs 15660.00. The incomes/ha from crop farming were Rs 4542.00 (year-I) and Rs 9629.00 (year-II). The total gross and area-related incomes varied from crop to crop with the highest derived from paddy farming.

3. Profitability

From crop farming, the net profit/ha was at Rs 1710.00 (year-I) and Rs 4840.00 (year-II) compared to Rs 13856.00 from duck-fish farming and Rs 33000.00 from the piggery. Thus, the average income/ha from agriculture, aquaculture and animal husbandry was

Table 2. Cropping patterns and land use (ha) during successive years on a single farm holding in Nepal: year-I, agriculture alone; year-II, integrated agriculture, aquaculture and livestock raising.

	Land use	1st crop (Mar-Oct)		2nd crop (Oct-Mar)		Total area cropped/yr	Cropping intensity/yr
		Crop	Area	Crop	Area		
Year-I	Low land 0.512	Paddy + Soyabean	0.512	Wheat Potato Vegetables	0.400 0.100 0.012	1.024	2
	High land 0.488	Maize + Soyabean Chillies	0.450 0.015	Wheat Rapeseed	0.250 0.215	0.930	2
	Total 1.000		0.977		0.977	1.954	2
Year-II	Low land 0.293	Paddy + Soyabean	0.293	Wheat Potato	0.175 0.118	0.586	2
	High land 0.250	Maize + Soyabean Chillies	0.225 0.025	Wheat Rapeseed Vegetables	0.175 0.050 0.025	0.500	2
	Total 0.543 for agriculture		0.543		0.543	1.086	2
	Ponds for fish and ducks 0.250						
	Piggery: 0.050 Pigstall and surrounding area						

Rs 7179.00. The net profit/ha for agriculture varied from crop to crop with paddy production the highest at Rs 9456.00.

The net profits can also be compared in relation to labor inputs by dividing the total profit by the total number of man-days used. The average returns/man-day were Rs 7.55 (year-I) and Rs 21.52 (year-II) out of which duck-fish farming and the piggery contributed Rs 23.98 while crop farming contributed Rs 19.79.

The return to capital invested is obtained by dividing the total output by the total cost of inputs and indicates the efficiency of the farm. The ratio varies from 1.61 for year-I to 2.02 in year-II for crop farming and 1.42 for combined duck-fish farming and the piggery: Table 13. The ratios for year-I and year-II for some individual crops were as follows: paddy, 1.48 and 2.00; maize 2.12 and 1.52 and wheat 1.15 and 2.02.

Discussion

The case study shows some of the important factors which have helped the farmer to increase his production of various crops with the limited resources of land, labor and other inputs. The increased production of various crops using an integrated farming system has increased his income too.

The direct benefits of an integrated farming system of agriculture, aquaculture and animal husbandry compared to agriculture alone can be summarized as follows:

1. The labor requirement for intensification of agriculture decreased by 39% while the production of agricultural crops alone increased by 56%. Also, the move to integrated farming system which requires the addition of a 5% increase in labor compared to agriculture alone has given a 19% increase in income.
2. The use of waste materials from one operation has reduced expenditure on inputs and helped to raise production for other operations.
3. The move to integrated farming yields fish, ducks and pig meat which are considered as cash crops by the farmer. These are much more valuable than cereals alone and help raise the economy of the rural farmer above the subsistence or near subsistence level.
4. The production of animal protein in the form of fish, ducks and pig meat improves the diet of the farmer.

The input:output ratio for aquaculture and animal husbandry is low compared to crop farming which reflects the farmer's limited resources for such capital intensive operations and his lack of technical knowledge which must be remedied by technical assistance.

This study was carried out with a single farmer. Environmental, social and other factors may vary from place to place but the authors feel that the study indicates the attractions of integrated farming systems to assist the rural farmers according to their requirements and conditions. In this study, pigs were included in the integration of livestock, but in certain parts of the country farmers may hesitate or refuse to accept these on social and religious grounds. Therefore, there is a need to study integrated farming using dairy or beef-cattle or buffalo as well as pigs so that integration of livestock with agriculture and aquaculture can easily be tailored to the choice of the rural farmer.

With the possible combinations of cattle or pig and even poultry, there is also room for domestic biogas production in integrated systems when processing the available manure for field use. Biogas operation would give the rural farmers who are deprived of hydroelectric power the benefits of gas lighting and gas fuel for domestic use. It would also help to reduce public health hazards in the villages, protect the farmers from the effects of unprocessed wastes, and help to reduce the expense of waste disposal.

In addition to all these recommended developments, a detailed resource study has to be carried out to determine availability of land for the various crop combinations to optimize production and maximize the income of the rural farmer.

Table 3. Expenditure and income for the paddy (p) plus soyabean (s) crop during successive years on a single farm holding in Nepal (US$1 = Rs 12.25; 1 Doko = 15 kg).

		Year-I			Year-II		
		Total land: 0.512 ha			Total land: 0.250 ha		
		Rice variety: Chinan			Rice variety: Taichung		
Items	Unit	Total used or harvested	Unit price in Rs	Total cost or value in Rs	Total used or harvested	Unit price in Rs	Total cost or value in Rs
Expenses							
1. Labor	man-days	89♂, 62♀	10♂, 5♀	1,200.00	54♂, 44♀	10♂, 5♀	760.00
2. Inputs							
Seed	kg	30p, 3s	2.00p, 3.66s	71.00	37.5p, 3s	2.00p, 3.66s	86.00
Manure	Doko	75	2	150.00	100	2	200.00
Fertilizer	kg	150	2	300.00	300	2	600.00
Lime	–	–	–	–	150	–	45.00
Insecticides	Rs	–	–	40.00	–	–	90.00
3. Other costs							
Land rent	Rs	–	–	985.00	–	–	575.00
Land revenue	Rs	–	–	50.00	–	–	–
A. Total Cost	Rs			2,796.00			2,356.00
Cost/ha	Rs			5,460.00			9,424.00
Income							
Paddy	kg	2,000	2	4,000.00	2,250	2	4,500.00
Soyabean	kg	45	3.66	165.00	60	3.66	220.00
B. Gross income	Rs			4,165.00			4,720.00
Net profit (B–A)	Rs			1,369.00			2,364.00
Profit/ha	Rs			2,673.82			9,456.00

Table 4. Expenditure and income for the wheat crop during successive years on a single farm holding in Nepal (US$1 = Rs 12.25; 1 Doko = 15 kg).

		Year-I			Year-II		
		Total land: 0.645 ha			Total land: 0.350 ha		
		Variety: Lerma 52			Variety: Lerma Roho		
Items	Unit	Total used or harvested	Unit price in Rs	Total cost or value in Rs	Total used or harvested	Unit price in Rs	Total cost or value in Rs
Expenses							
1. Labor	man-days	65♂, 53♀	10♂, 5♀	915.00	32♂, 29♀	10♂, 5♀	465.00
2. Inputs							
Seed	kg	40.8	1.47	60.00	51	1.47	75.00
Manure	Doko	50	2	100.00	100	2	200.00
Fertilizer	kg	25	2	50.00	75	2	150.00
A. Total cost	Rs			1,125.00			890.00
Cost/ha				1,744.00			2,543.00
Income							
Wheat	kg	884	1.47	1,300.00	1,224	1.47	1,800.00
B. Gross income	Rs			1,300.00			1,800.00
Net profit (B–A)	Rs			175.00			910.00
Profit/ha	Rs			271.00			2,600.00

Table 5. Expenditure and income for the potato crop during successive years on a single farm holding in Nepal (US$1 = Rs 12.25; 1 Doko = 15 kg).

		Year-I			Year-II		
		Total land: 0.100 ha			Total land: 0.075 ha		
		Variety: Local			Variety: Kupri Jyoti		
Items	Unit	Total used or harvested	Unit price in Rs	Total cost or value in Rs	Total used or harvested	Unit price in Rs	Total cost or value in Rs
Expenses							
1. Labor	man-days	15♂, 10♀	8♂, 5♀	170.000	13♂, 11♀	8♂, 11♀	159.00
2. Inputs							
Seed	kg	56.25	4.44	250.00	56.25	4.44	250.00
Manure	Doko	5	2	10.00	25	2	50.00
Fertilizer	kg	–	–	–	25	2	50.00
A. Total cost	Rs			430.00			509.00
Cost/ha	Rs			4,300.00			6,787.00
Income							
Potato	kg	675	4.11	750.00	1,012.5	1.11	1,125.00
B. Gross income	Rs			750.00			1,125.00
Net profit (B–A)	Rs			320.00			616.00
Profit/ha	Rs			3,200.00			8,213.00

Table 6. Expenditure and income for the maize (m), soyabeans (s) and other beans (b) crop during successive years on a single farm holding in Nepal (US$1 = Rs 12.25; 1 Doko = 15 kg).

		Year-I Total land: 0.450 ha Variety: Local			Year-II Total land: 0.225 ha Variety: Khumal yellow		
Items	Unit	Total used or harvested	Unit price in Rs	Total cost or value in Rs	Total used or harvested	Unit price in Rs	Total cost or value in Rs
Expenses							
1. Labor	man-days	46♂, 30♀	8♂, 5♀	518.00	19♂, 17♀	8♂, 5♀	237.00
2. Inputs							
Seed	kg	7m, 6s + b	2.00m 3.66s + b	36.00	7m, 3b + s	2.00m, 3.66b + s	25.00
Manure	Doko	25	2	50	100	2	200.00
Fertilizer	kg	–	–	–	75	2	150.00
Lime	Rs	–	–	–	–	–	55.00
Insecticides	Rs	–	–	–	–	–	90.00
3. Other costs							
Land revenue	Rs	–	–	120.00	–	–	90.00
A. Total cost	Rs			724.00			847.00
Cost/ha	Rs			1,608.00			3,764.00
Maize	kg	544	2	1,088.00	408	2	816.00
Soyabean	kg	95	3.66	348.00	127	3.66	465.00
Beans	kg	16	3.66	59.00	–	–	–
B. Gross income	Rs			1,495.00			1,281.00
Net profit	Rs			771.00			434.00
Profit/ha	Rs			1,713.00			1,929.00

Table 7. Expenditure and income for the chillies crop during successive years on a single farm holding in Nepal (US$1 = Rs 12.25; 1 Doko = 15 kg).

		Year-I Total land: 0.037 ha Variety: Local			Year-II Total land: 0.075 ha Variety: Local		
Items	Unit	Total used or harvested	Unit price in Rs	Total cost or value in Rs	Total used or harvested	Unit price in Rs	Total cost or value in Rs
Expenses							
1. Labor	man-days	15♂, 9♀	8♂, 5♀	165.00	11♂, 9♀	8♂, 5♀	133.00
2. Inputs							
Seedlings	–	–	–	20.00	–	–	25.00
Manure	Doko	2	2.50	5.00	25	2	50.00
Fertilizer	kg	–	–	–	25	2	50.00
A. Total cost	Rs	–	–	190.00	–	–	258.00
Cost/ha	Rs			5,135.00			3,440.00
Income							
Chillies	kg	56	13.33	747.00	67.5	13.33	900.00
B. Gross income				747.00			900.00
Net profit (B–A)	Rs			557.00			642.00
Profit/ha	Rs			1,505.00			8,560.00

Table 8. Expenditure and income for the rapeseed crop during successive years on a single farm holding in Nepal (US$1 = Rs 12.25).

		Year-I			Year-II		
		Total land: 0.237 ha			Total land: 0.100 ha		
		Variety: Local			Variety: Local		
Items	Unit	Total used or harvested	Unit price in Rs	Total cost or value in Rs	Total used or harvested	Unit price in Rs	Total cost or value in Rs
Expenses							
1. Labor	man-days	9♂, 23♀	8♂, 5♀	187.00	7♂, 7♀	8♂, 5♀	91.00
2. Inputs							
Seed	kg	14	2.5	35.00	20	2.5	50.00
A. Total cost	Rs			222.00			141.00
Cost/ha				937.00			1,410.00
Income							
Rapeseed	kg	171	2.11	361.00	171	2.11	361.00
B. Gross income				361.00			361.00
Net profit (B–A)	Rs			139.00			220.00
Profit/ha	Rs			586.50			2,220.00

Table 9. Expenditure and income for the vegetable crop during successive years on a single farm holding in Nepal (US$1 = Rs 12.25).

		Year-I			Year-II		
		Total land: 0.013 ha			Total land: 0.025 ha		
Items	Unit	Total used or harvested	Unit price in Rs	Total cost or value in Rs	Total used or harvested	Unit price in Rs	Total cost or value in Rs
Expenses							
1. Labor	man-days	9♂, 5♀	8♂, 5♀	97.00	9♂, 7♀	8♂, 5♀	107.00
2. Inputs							
Seed	Rs			20.00			150.00
Other costs	Rs			40.00			
A. Total cost	Rs			157.00			257.00
Cost/ha	Rs			12,077.00			10,280.00
Income							
Vegetables				240.00			405.00
B. Gross income				240.00			405.00
Net profit (B–A)	Rs			83.00			148.00
Profit/ha	Rs			6,385.00			5,920.00

Table 10. Expenditure and income for fish produced from a duck-fish integrated farming operation which commenced during Year-II of a 2-yr study of a single farm holding in Nepal (US$1 = Rs 12.25; 1 Doko = 15 kg).

		Year II		
		Total land: 0.250 ha		
		Water surface: 0.175 ha		
Items	Unit	Total used or harvested	Unit price in Rs	Total cost or value in Rs
Expenses				
1. Labor	man-days	71	8	568.00
2. Inputs				
Fingerlings	No.	400 + 400	8/20	112.00
Manure	Doko	100	2	200.00
Fertilizer	kg	50	2	100.00
Feed for brood fish and fingerlings	kg	500	2	1,000.00
Other costs	Rs	–	–	95.00
Land rent	Rs	–	–	345.00
Land revenue	Rs	–	–	40.00
Depreciation (10% on Rs 5000; 5% on Rs 3000)	Rs	–	–	650.00
Interest (16% on Rs 1000)	Rs	–	–	1,280.00
A. Total cost	Rs	–	–	4,470.00
Cost/ha	Rs			17,880.00
Income				
1. Table fish	kg	180	12	2,160.00
2. Fingerlings	No.	650	8	5,200.00
B. Gross income	Rs			7,360.00
Net profit* (B–A)	Rs			2,890.00
Profit/ha	Rs			11,560.00

*No valuation has been put on brood fish

Table 11. Expenditure and income for ducks produced from a duck-fish integrated farming operation which commenced during Year-II of a 2-yr study of a single farm holding in Nepal (US$1 = Rs 12.25 ; 1 Doko = 15 kg).

Items	Unit	Year II Total water: 0.175 ha Variety: Pekin Total used or harvested	Unit price in Rs	Total cost or value in Rs
Expenses				
1. Labor	man-days	42	8	336.00
2. Inputs				
Ducklings	No.	100	4	400.00
Feed	kg	280	2	560.00
Other costs				
Depreciation (5% on Rs 300)				150.00
Interest (16% on Rs 3000)				480.00
A. Total cost	Rs			1,926.00
Cost/ha	Rs			11,006.00
Income				
Table ducks	No.	100	25	2,500.00
B. Gross income	Rs			2,500.00
Net profit (B–A)	Rs			574.00
Profit/ha	Rs			3,280.00

Table 12. Expenditure and income for pig production in an integrated farming operation which commenced during Year-II of a 2-yr study of a single farm holding in Nepal (US$1 = Rs 12.25).

Items	Unit	Year II Total area: 0.035 Total used or harvested	Unit price in Rs	Total cost or value in Rs
Expenses				
1. Labor	man-days	80	8	640.00
2. Inputs				
Piglet	No.	1♂, 2♀	80	240.00
Feed	Rs			995.00
Medication	Rs			50.00
Miscellaneous	Rs			100.00
3. Other costs				
Land revenue	Rs			20.00
Depreciation (10% on Rs 10,000 construction cost)	Rs			1,000.00
Interest (16% on 10,000)	Rs			1,600.00
A. Total cost	Rs			4,645.00
Income				
1. Piglets	No.	6		1,500.00
2. Pig for meat	No.	1		1,000.00
3. Byproducts				300.00
4. Brood stock		2		3,000.00
B. Gross income	Rs			5,800.00
Net profit (B–A)	Rs			1,155.00
Profit/ha	Rs			33,000.00

Table 13. Expenditure and income summary chart for a single farm holding in Nepal (US$1 = Rs 12.25).

A. Crop farming: bracketed figures after crops refer to appropriate preceding tables	Year-I: Cropped area ha	Year-I: Total labor used man-days	Year-I: Total expenditure Rs	Year-I: Total income Rs	Year-I: Net profit Rs	Year-II: Area used ha	Year-II: Total labor used man-days	Year-II: Total expenditure Rs	Year-II: Total income Rs	Year-II: Net profit Rs
Low land										
Paddy (3)	0.512	151	2,796.00	4,165.00	1,369.00	0.250	98	2,356.00	4,720.00	2,364.00
Wheat (4)	0.645	118	1,125.00	1,300.00	175.00	0.350	61	890.00	1,800.00	910.00
Potato (5)	0.10	25	430.00	750.00	320.00	0.075	24	509.00	1,125.00	616.00
Vegetables (6)	0.013	14	157.00	240.00	83.00	–	–	–	–	–
Total	1.270	308	4,508.00	6,455.00	1,947.00	0.675	183	3,755.00	7,645.00	3,880.00
Cost or yield Rs or man-days/ha		243	3,549.60	5,082.67	1,533.07		271	5,562.96	11,325.92	5,748.14
Input:Output			1 :	1.43				1 :	2.04	
Net profit/man-day (Rs)		6.32					21.20			
Upland										
Maize (6)	0.45	76	704.00	1,495.00	771.00	0.225	36	847.00	1,284.00	434.00
Rapeseed (8)	0.237	32	222.00	361.00	139.00	0.10	20	141.00	361.00	220.00
Chillies (7)	0.037	24	190.00	747.00	557.00	0.075	14	258.00	900.00	642.00
Vegetables (9)	–	–	–	–	–	0.025	16	257.00	405.00	148.00
Total	0.724	132	1,116.00	2,603.00	1,467.00	0.425	86	1,503.00	2,950.00	1,444.00
Cost or yield Rs or man-days/ha		182	1,541.44	3,595.30	2,026.24		202.35	3,536.47	6,941.18	3,397.65
Input:Output			1 :	2.33				1 :	1.96	
Net profit/man-day (Rs)		11.11					16.79			
Sub-total for crop farming	1.994	440	5,624.00	9,058.00	3,414.00	1.10	269	5,258.00	10,595.00	5,324.00
Cost or yield Rs or man-days/ha		226	2,893.00	4,659.46	1,756.17		245	4,780.00	9,631.82	4,840.00
Input:Output			1 :	1.61				1 :	2.02	
Net profit/man-day (Rs)		7.76					19.79			
B. Duck-fish and piggery operations, which commenced in Year II: bracketed figures refer back to appropriate preceeding tables										
Fish culture (10)						0.250	71	4,470.00	7,360.00	2,890.00
Duck raising (11)						on ponds	42	1,926.00	2,500.00	574.00
Piggery (12)						0.035	80	4,645.00	5,800.00	1,155.00
Total						0.285	193	11,041.00	15,660.00	4,619.00
Cost or yield Rs or man-days/ha							677	38,740.35	54,947.37	16,207.01
Input:Output								1 :	1.42	
Net profit/man-day (Rs)							23.93			

Acknowledgments

The authors offer their deep thanks to Mr. S.B. Nepali, Director General, and Mr. K.B. Keshary, Deputy Director General, both of the Animal Science Division, and to Mr. A.N. Bhattarai, Deputy Director of the Training and Extension Division, Department of Agriculture, for reviewing the manuscript and giving valuable suggestions. The authors are very grateful to the farmer, Mr. K.B. Basneyt, for his excellent cooperation. Sincere thanks are also due to our colleagues of Fisheries Development Section for their assistance during the study period as well as during the preparation of this paper. Special thanks are due to Mr. S.B. Thapa and Mr. Y.P. Gupta who helped in the topographical survey of the farm.

Bibliography

Anon. 1970. Farm Management Studies in selected Districts, Economic Analysis and Planning Division, Ministry of Food and Agriculture, HMG, Kathmandu. 177 p.

Lee, C.Y. 1971. Analysis of Marketing Problems of Government-Run Commercial concern: Two case studies in Nepal. Economic Analysis and Planning Division, Ministry of Food and Agriculture, HMG, Kathmandu. 60 p.

Pandey, S., S. Devkota, M. Iles, I. Neupane, M. Sharma, S.B. Rana, S. Adhikari and B. Thapa. 1979. Impact Study of Small Farmers Development Project (Nuwakot and Dhanusha Districts), Agriculture Projects Services Centre, Kathmandu. 111 p.

Upadhaya, S.K. 1979. Supply of Agricultural Inputs to Small Farmers for Adoption of Integrated Crop and Livestock system. Agriculture Projects Services Centre's Seminar paper (mimeo). Kathmandu. 6 p.

Integrated Agriculture-Aquaculture Farming Systems in the Philippines, with Two Case Studies on Simultaneous and Rotational Rice-Fish Culture

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Abstract

A brief review is given of experimental and commercial integrated farming systems in the Philippines: rice-fish, vegetables and animal-fish combinations. The major part of the paper is devoted to the development of rice-fish culture technology using tilapias and common carp. The yields of fish vary with the stocking density and inputs used, i.e., with or without fertilization and supplemental feeding. With supplemental feeding, fish yields of about 400 to 700 kg/ha are estimated at total stocking densities of 10,000 to 15,000. Two case studies with economic analyses are included, comparing simultaneous and rotational rice-fish culture.

1. Integrated Agriculture-Aquaculture Farming Systems in the Philippines

Introduction

The integration of agriculture and aquaculture farming systems, although not a new concept in the Philippines, is only just beginning, and crops and livestock still take precedence over aquatic products. Integration as a possible means of improving the efficiency of farm resource utilization has not received much attention in the past, perhaps because of the preponderance of monocropping and the lack of technology, aquaculture being a much younger science than agriculture. Also, integration of agriculture and aquaculture is a complex process in which each commodity in the system requires a different technology which at times must be modified to achieve a compatible and complementary system.

Institutional research on the integration of agriculture and aquaculture began in the early seventies, when government support for aquaculture and fisheries research was increased. Despite the limited nature of research-based technology, a few enterprising individuals have developed their own integrated systems, learning by personal experience.

Documented information on integrated systems in the country is scarce and data from private operators are not usually available, except for those operating in conjunction with research institutions.

Integrated Systems Currently in Use

Only a few of the possible integrated systems are in use: some by the private sector, others in an advanced stage of government-funded research or demonstration. The following examples illustrate the limited scale of these activities:

1. RICE-FISH AND VEGETABLES

A pioneering study using this combination was made at a 1-ha farm in Muñoz, Nueva Ecija by Francisco Carbonel. The farm, which was producing three crops of rice per year, as well as taro, onions and other vegetables, and providing a gross income of approximately ₱10,000*, was modified, in 1973, so as to culture fish, too. About ₱12,000, obtained through a bank loan, was invested.

The farm consists of two main parts. The first part consists of three small ponds, which serve as breeding and nursery sites for the *Tilapia zillii*. The ponds, which are lined with concrete blocks, are about 1,000 m^2 in total area. The second part, used for rice-fish culture, is about 8,000 m^2 in area. The two parts are separated by paddy dikes (about 1.5 to 2 m wide) totaling about 1,000 m^2 in surface area. The dikes are planted to such various vegetables as eggplant, pechay (*Brassica* sp.), native onion, tomatoes and beans, together with citrus fruit and banana. Taro (*Colocasia esculenta*) is also planted along the base of the perimeter dikes.

The farm has an independent and reliable water supply, with underground channels running along the dikes to the delivery points. The water supply is designed to enable flooding, when necessary, of the dike surfaces on which vegetables are planted. With this integrated setup, the gross income of the farm reportedly increased from ₱10,000 to ₱25,000/yr.

The Central Luzon State University (CLSU), attracted by this innovative idea, developed in 1977 a similar 1-ha farm on campus for a monitoring and economic feasibility study. The farm was named the CLSU Model Farm (MF). The farm layout is given in Figure 1. Total development cost for the MF was ₱45,745, excluding the cost of building the farmhouse which was about ₱11,700. The setup is largely multiple cropping of rice with other crops, including *Tilapia zillii*, in a rice-fish culture system. From June 16, 1978 to March 31, 1979 the MF derived a net income of ₱8,412.14 from 14 crops. A summary of income and expenses is presented in Table 1.

2. PIGS, FORAGE, RICE, FISH AND OTHER CROPS

The Sanvictores Farm has two integrated operations in Rizal and Bulacan provinces. The Rizal farm pumps liquid pig manure first to paragrass (*Brachiara mutica*) and napier (*Pennisetum purpureum*) fields. The run-off is then led to a water chestnut plantation and overflows from this to a backyard catfish pond. No data is available on the catfish production but the water chestnut plantation produces an average of 2 kg of bulbs per m^2 in 9 mo, selling at about ₱46/kg. This corresponds to ₱80,000 gross income per hectare.

3. PIGS, POULTRY, DUCKS AND FISH

There are now a few integrated farms combining pig or chicken raising with fish culture on a trial basis. Promising research results have been obtained by the University of the Philippines at Los Baños (UPLB) in the utilization of pig manure to produce methane gas, culture chlorella for animal feed, and fertilize fish ponds. A commercial fish pond owner (Ernesto Jamandre of Iloilo) has also integrated pig production with fish culture. Fresh manure, urine and washings from pig pens first pass through digestion chambers to produce methane for household use. Liquids from the digestion chambers overflow directly to milkfish (*Chanos chanos*) rearing ponds. The owner reports that the high cost of pig feed is compensated by the savings derived from the use of pig manure instead of commercial fertilizer in the fish ponds, but no data are available.

Although duck raising for meat and eggs has been practiced in the Philippines for years, integrated duck and fish farming is rarely practiced.

The Importance of Integrated Systems

If and when integration of crops, livestock and aquaculture becomes widely practiced in the Philippines, most of the benefits will accrue to the rural sector particularly in landlocked areas, such as Central and Northern Luzon. The need for integration and efficient utilization of farm resources will soon be felt, first because land ownership per family will be limited as a result of land distribution, through the Land Reform Program. In Central Luzon, the average farm size is slightly less than 3 ha (Sevilleja and McCoy 1979). The limited size of the farm holdings means limited areas for cultivation and hence, the need to maximize land utilization to produce more food and increase self-sufficiency. Second, the spiraling cost of meat products and the recent surplus in rice production, which will cause marketing problems, also recommend integration. In 1979 the rice surplus was 555,000 t. As the second major component of the Filipino diet is fish, some of the rice production areas should be converted to fish production. There are, moreover, enormous areas of marginal wetlands adjacent to the rice areas that could be used to produce fish. This would also be preferable to reclaiming the few remaining mangrove areas for fish pond construction to increase fish supply.

*US$1.00 = ₱ (Philippine pesos) 7.33.

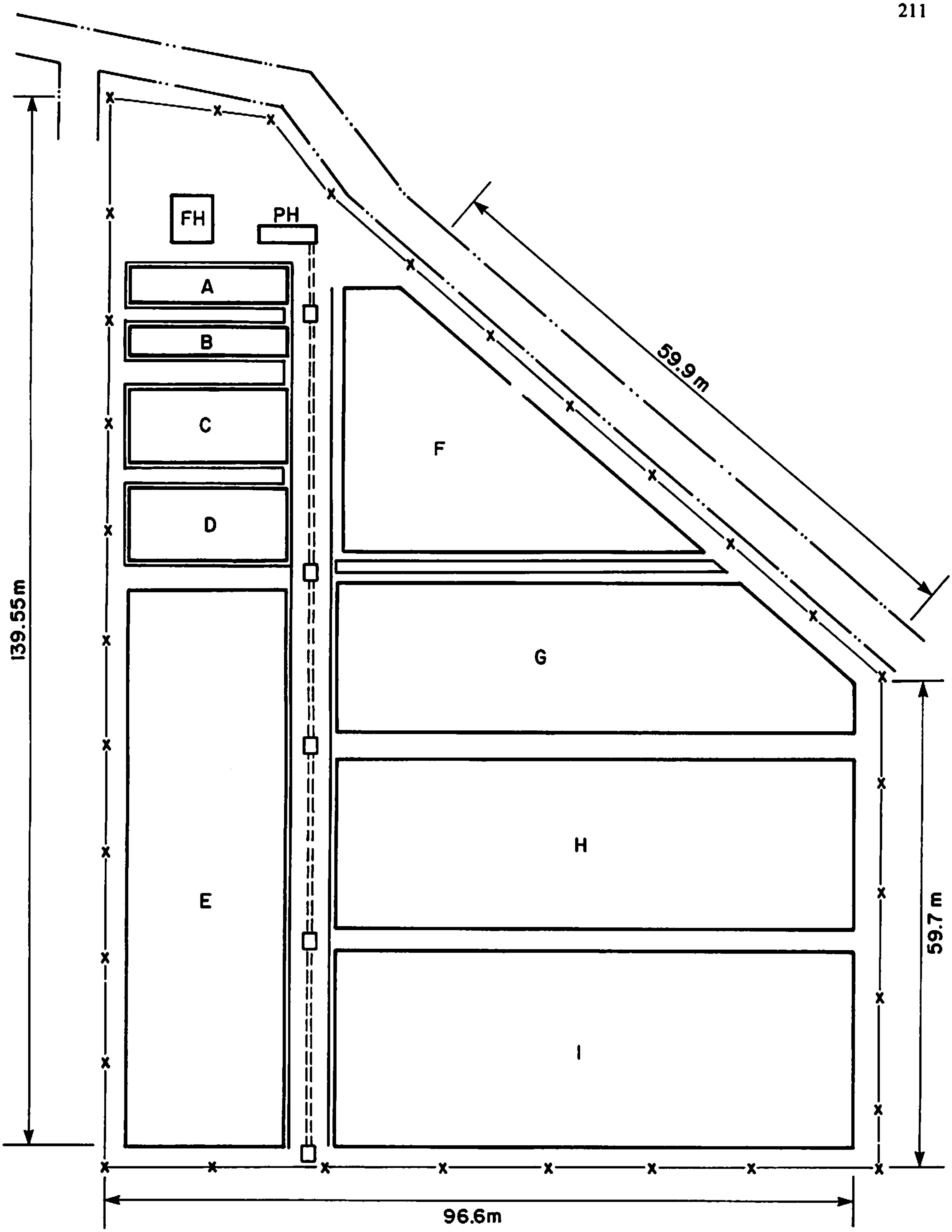

Figure 1. Layout of the Central Luzon State University model farm. A & B, nursery ponds. C & D, breeding ponds. E-I, rice-fish paddies. FH, model farm house. PH, pump house. Scale 1:700.

Third, a recent Presidential proclamation has indicated a policy shift from grain production to production of protein foods, such as fish and legumes, to improve the nutrition of the people. Established production programs for carbohydrate-based foods will continue but more emphasis and funds will be directed towards protein production. It has been reported that about 70 to 80% of Filipinos do not receive the recommended 50 g daily consumption of fish and that the majority of these live in the rural areas.

Disposal and Marketing of Products

The marketing system for agricultural products is much more developed and stable than for fish. Indeed, the inadequacy of the marketing system of the fisheries industry in the Philippines is well-recognized and is scheduled for improvement under the government's current Integrated Fisheries Development Plan. Sevilleja and McCoy (1979) review past studies on nationwide marketing and projected consumption of milkfish, marketing practices and problems of municipal fishermen in Mindanao, and the movement of fish from Central Luzon. These indicate that 71% of the tilapias and 67% of the carp sold in Manila came from provinces in Central Luzon. Furthermore, about 6.4% of the total fish landed were also transported into this region (excluding substantial quantities of smoked and dried fish) while 20% went outside Metro Manila and 29% into unspecified northern provinces.

The integration of aquaculture with agriculture is not, however, expected to cause any problems in the supply and marketing of crops and livestock. The marketing system for agricultural products can also handle aquatic products from integrated systems.

Current Research and Development Initiatives

The high potential of integrated farming has resulted in some notable research activities including:

1. RICE-FISH RESEARCH

An extensive research program on the production of fish in paddy fields was initiated in 1974 at the Freshwater Aquaculture Center (FAC) of CLSU. The program, which is still in progress, includes production tests on combined rice-fish culture, alternate cropping of rice and fish, and production of fry or fingerlings in paddies with or without rice. The advances made in this area are the subject of case studies presented below.

2. ANIMAL-FISH RESEARCH

This began in 1977 as a cooperative effort between CLSU and ICLARM. The initial objectives of the project are to determine the maximum rate of pig and duck waste loading in fish ponds and the optimal combination of fish species which can be marketed in the country. A 2-ha facility was constructed for this purpose and preliminary results obtained from the first 180 d of tests are presented elsewhere (see Cruz and Shehadeh, this volume).

Research and Development Needs

If integrated agriculture-aquaculture systems are to be practiced more extensively in the future, some constraints have to be removed. More research is needed for the genetic improvement of fish and land animals and to evaluate the pesticide problem in fish-crop integration. Some progress has been achieved in producing fish in paddy fields receiving insecticides, but this remains to be

Table 1. Summary of model farm income and expenses from June 16, 1978 to March 31, 1979 (Undan 1979) (US$1.00 = ₱7.34).

	₱
A. Gross Income	
1. Rice	P 4,506.89
2. Taro (gabi)	3,345.40
3. Onion	3,125.45
4. *Tilapia zillii*	1,121.00
5. Eggplant	518.70
6. Tomato	329.90
7. Bitter melon (gourd–*Momordica charantia*)	94.45
8. Pechay	71.75
9. String Beans	66.00
10. Squash	58.30
11. Okra (*Hibiscus esculentus*)	38.50
12. Sponge gourd (patola–*Luffa cylindrica*)	36.00
13. Corn	19.20
14. Sweet potato	24.85
Total gross income	P13,356.39
B. Expenses	
1. Hired labor	P 593.50
2. Animals and machinery	1,319.30
3. Supplies and materials	1,766.45
4. Rent	
–Farm	825.00
–Thresher	440.00
Total expenses	P 4,944.25
Net income	P 8,412.14

verified and extended at the farm level, to ensure that farmers will use the recommended pesticides and methods of application.

The following strategies are suggested for research and development:

1. Pilot Testing Schemes

Technologies transfered from other countries should be evaluated in pilot schemes and modified, if necessary, to suit local conditions.

2. Credit Assistance

Adequate credit assistance must be provided by government or private financing institutions to prospective practitioners of integrated farming systems.

3. Technical Assistance and Training of Manpower

Pilot testing schemes must be serviced by personnel trained by qualified instructors in appropriate institutions. The resulting technologies can be disseminated by training prospective farmers. Generally, farmers are only experienced in producing one crop and they are usually reluctant to risk their limited capital by adopting a new technology, unless the chance of success is high.

4. Fry Banks and Hatcheries

A tremendous quantity of fish seed will be needed if the country adopts integrated farming practices. For rice-fish culture, the requirements for one million ha of irrigated paddies will range from 5 to 10 billion fry, which could not be met at present by the combined effort of all government freshwater hatcheries. More government and private hatcheries are urgently needed, and the dependence of farmers on the government for fish seed must be reduced by training them in seed production. This has already been started at the FAC, where training in rice-fish culture also incorporates techniques for the production of tilapia fry and fingerlings in paddies, ponds and net enclosures.

5. Distribution Centers for Domestic Animals

There must be adequate and accessible supplies of suitable livestock.

6. Animal Feeds and Raw Materials

Adequate supplies of animal feeds and raw materials must be available at economical prices.

7. Marketing Outlets and Prices

Market research is essential for the products of integrated farming to ensure adequate profit margins.

2. Case Studies

(a) Simultaneous Rice-Fish Culture

Rice-Fish Culture Technology at the Freshwater Aquaculture Center (FAC) of the Central Luzon State University (CLSU)

A program on rice-fish farming has been in progress at the FAC, CLSU since 1974 (Arce and dela Cruz 1978). Its immediate objective is to develop low-cost appropriate technology for the production of fish in rice farms, with the long-term aim of increasing the availability of protein and improving the nutrition of people in landlocked areas. Improved technology for rice-fish farming has been developed and is currently being implemented and disseminated through a pilot program. Information on the technology, field verification tests, and production economics are presented in this case study.

DESCRIPTION OF THE RICE-FISH CULTURE AREA

Rice-fish production tests were conducted in a 2.5-ha experimental area with clay soil. Most of the trials were in paddies measuring 200 m^2 with a few of 100 m^2 (Figure 2). Each paddy is surrounded by earthern dikes approximately 50 cm wide at the base, 30 to 40 cm at the top, and 40 cm high, to maintain the water depth at 10 to 15 cm (Figure 3). Each paddy has a central trench to serve as a fish refuge in case of an unexpected drop in water level, as a passageway for easy movement of fish around the paddy, and as a catch basin during harvest (Figures 3 and 4). The trench is 0.4 to 0.5 m deep and 0.5 to 1.0 m wide. This width necessitates as much as 10% of the paddy being left unplanted with rice in a 200 m^2 area. The location and spacing of the trench for a 400 m^2 area are shown in Figure 5.

Every paddy can be filled and drained independently. A canal passes through each paddy to supply water from the irrigation canal and a deep well; the canal is also used to drain off excess water. The water gate in each paddy is located along its width at the center of the dike opposite the trench (Figures 4 and 5). A wire screen with 0.5 cm mesh or four openings per cm^2 is fixed across each gate in a wooden frame to prevent the entry of wild fish from the canal and the escape of stocked fish.

FISH CULTURE

Sarotherodon niloticus, S. mossambicus and common carp (*Cyprinus carpio*) were assessed the most promising species for culture with rice. It was found out that *S. mossambicus* has to be sexually segregated to avoid excessive reproduction and crowding in the paddy, resulting in the production of small fish. *S. niloticus* is less prolific than *S. mossambicus* and reproduces later, which allows the stocking of mixed sexes.

Tests on stocking densities indicated that 3,000 to 4,000 common carp or 5,000 tilapia (either all male *S. mossambicus* or mixed-sex *S. niloticus*) per hectare were most appropriate for monoculture without supplemental feeding. For the polyculture of common carp and tilapias, initial results show that stocking rates of 2,000 carp with 4,000 tilapia per hectare give the best yields. Several experiments indicated that the mean daily gain in weight of tilapias grown in paddies without supplemental feeding was 0.37 g. This means that their size at stocking must be about 15 g, to exceed 50 g in 100 d, and 20 to 25 g for a shorter culture period of 80 d. If properly programmed, the usual fish culture period in paddies with International Rice Research Institute (IRRI) varieties is about 80 to 100 d.

ADAPTABILITY OF FISH TO RICE CULTURE

The IRRI varieties used in the trials were IR-26, 30, 36, 38, 40, and the recently developed IR-42. The procedures used in land preparation, planting calendar, weed control and fertilization, were those recommended under the Masagana 99, a nationwide government rice program started in 1974, with some modifications in water management and pest control. With regard to fertilization, the standard basal and top dressing applications were used at rates of 150 kg/ha of NPK 16-20-0 and 75 kg/ha of urea (45-0-0), levels which are not toxic to fish. Acid forming fertilizers, such as ammonium sulfate, should not be used for top dressing, and the type and application rate of fertilizer should be determined for each location.

The weeds in the paddies can be controlled mechanically or chemically. The use of herbicides, such as 2,4-D, IPE (dichlorophenoxy acetic acid) formulations, and Machete (Butachlor) does not harm the fish.

Insecticides should provide effective pest control without being harmful to fish or humans. Selective use and proper methods of application of pesticides were the main considerations in this study. Furadan (Carbofuran), a systematic insecticide, has given good results so far in rice-fish culture with respect to fish survival. Analysis of fish flesh has shown that the fish were safe for human consumption when the chemical was applied by root-zone injection in liquid form or by soil incorporation in granular form (broadcast prior to transplanting). The latter method is considered more practical for large areas. Furadan is applied at 1.0 to 1.5 kg active ingredient (a.i.) per hectare mixed with basal fertilizers, during the final harrowing. A single application is usually sufficient for the entire rice culture period. For late infestation, however, especially by the brown planthopper *(Nilaparvata lugens)*, spraying of Furadan F at the base of plants is recommended (Arce 1977). Before spraying, the field should be drained until all the fish have collected in the central trench.

RICE AND FISH PRODUCTION DATA

The consolidated production data for both fish and rice from tests conducted during 1974-1978 are presented in Table 2. The fish yields ranged from 78 to 293 kg/ha without any supplemental feeding. Only four trials out of 14 produced less than 100 kg/ha of fish; this is considered a satisfactory minimum yield per cropping. The rice yields ranged from 70 to 138 cavans/ha. A cavan was traditionally about 46 kg but is now 50 kg. These yields were within the range of those of adjacent farms which did not practice rice-fish culture, demonstrating that the unplanted area occupied by the central trench did not cause any significant reduction. Low rice yields in some trials were attributed to inclement weather, typhoon damage and rat infestations.

RICE-FISH CULTURE TECHNOLOGY VERIFICATION AND DISSEMINATION (DELA CRUZ 1979)

The nationwide verification and dissemination of rice-fish technology (TVD) began in 1976 under the sponsorship of the Ministry of Agriculture and Ministry of Natural Resources, with CLSU-FAC providing the technical expertise. A national Rice-Fish Coordinating Committee (RFCC), composed of 10 government agencies, has been organized, with the National Food and Agriculture Council (NFAC) as the lead agency.

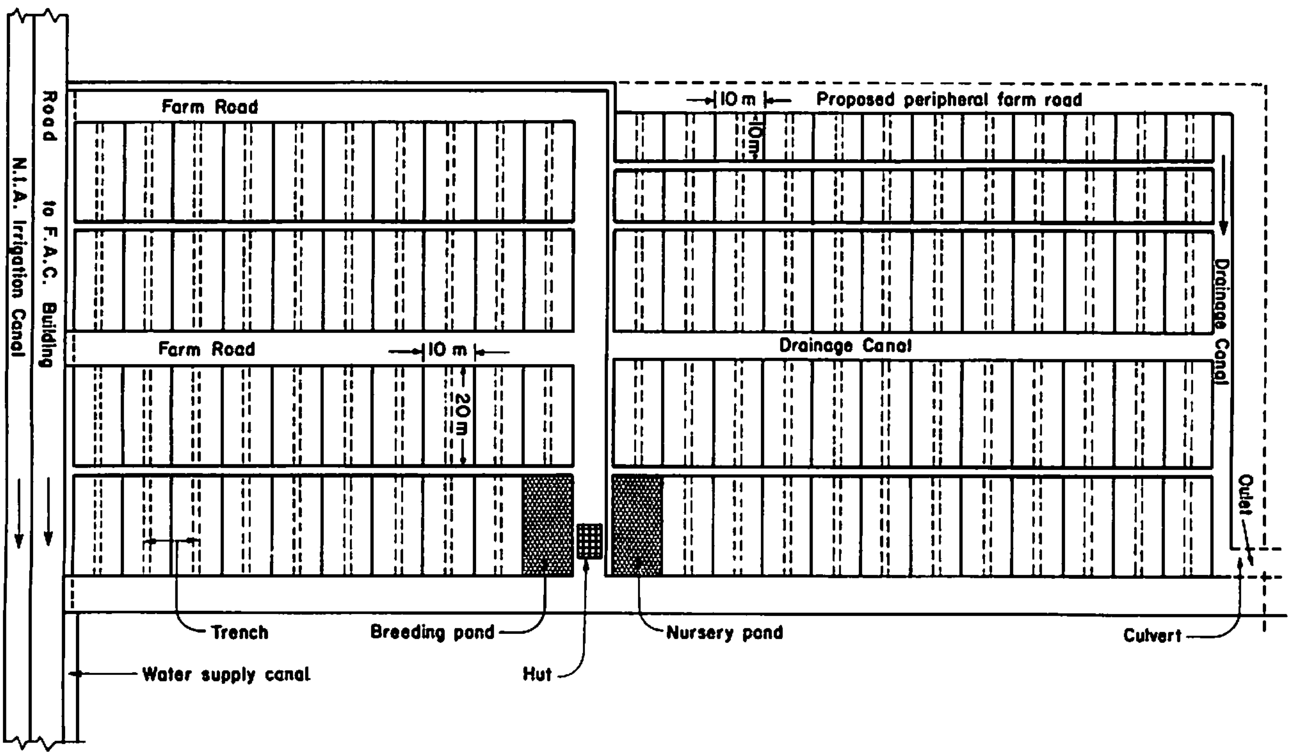

Figure 2. Layout of rice-fish culture area at the Freshwater Aquaculture Center, Central Luzon State University. Scale 1:1,000.

The TVD is divided into two phases: field testing and pilot implementation. A total of 38 production technicians from the Bureau of Plant Industry (BPI), Bureau of Agricultural Extension (BAE) and Bureau of Fisheries and Aquatic Resources (BFAR) were trained in order to take charge of the field tests.

These utilized paddies of the same area as those used at the FAC. Two series of test trials were conducted and only limited success was attained during the first series in 1976, due to lack of coordination between agencies. The second series, from October 1977 to March 1978, yielded promising results, however, in terms of combined rice and fish production. Results from 19 trials at selected sites gave an average production of 204 kg of fish/ha and 116 cavans of rice, compared to an average rice production of 122 cavans/ha for conventional paddies without fish (here, 1 cavan = 50 kg).

Encouraged by this, the RFCC decided to initiate the pilot implementation phase in May 1979. This phase will cover a much larger area than the field tests. The target area for May-October 1979 is 1,030 ha, with a total fingerling requirement of 5.15 million. The training of additional production technicians and cooperating farmers will be conducted simultaneously. A total of 78 persons have been trained as of May 1979.

Socioeconomic studies are also incorporated in the pilot implementation phase. These will provide baseline data on cooperating farmers and their communities; document and analyze existing rice-fish farming practices other than those disseminated by the national program; provide information on the economics of rice-fish farming and marketing of products, and assess possible changes generated in rural communities by the new practice. This information will help to determine the feasibility of adopting rice-fish as a nationwide program.

The rationale, strategy and goals of the TVD program are summarized in Figure 6. Although the adoption of rice-fish culture technology may be a slow process, it is hoped that it will eventually improve human nutrition, particularly in rural areas.

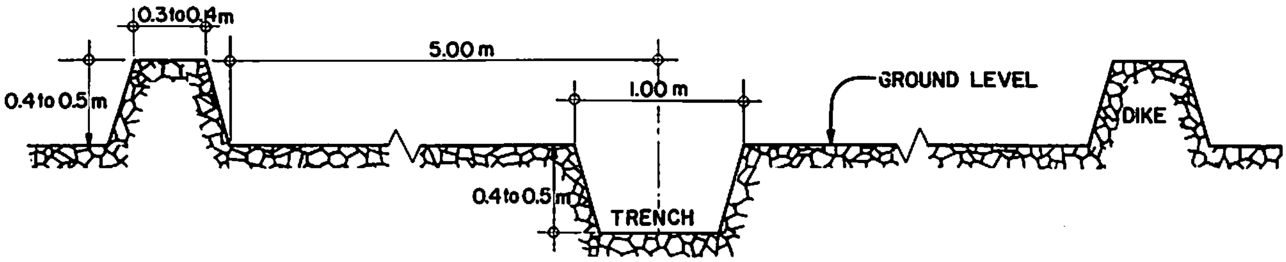

Figure 3. Cross section of paddy, dike and trench (not drawn to scale).

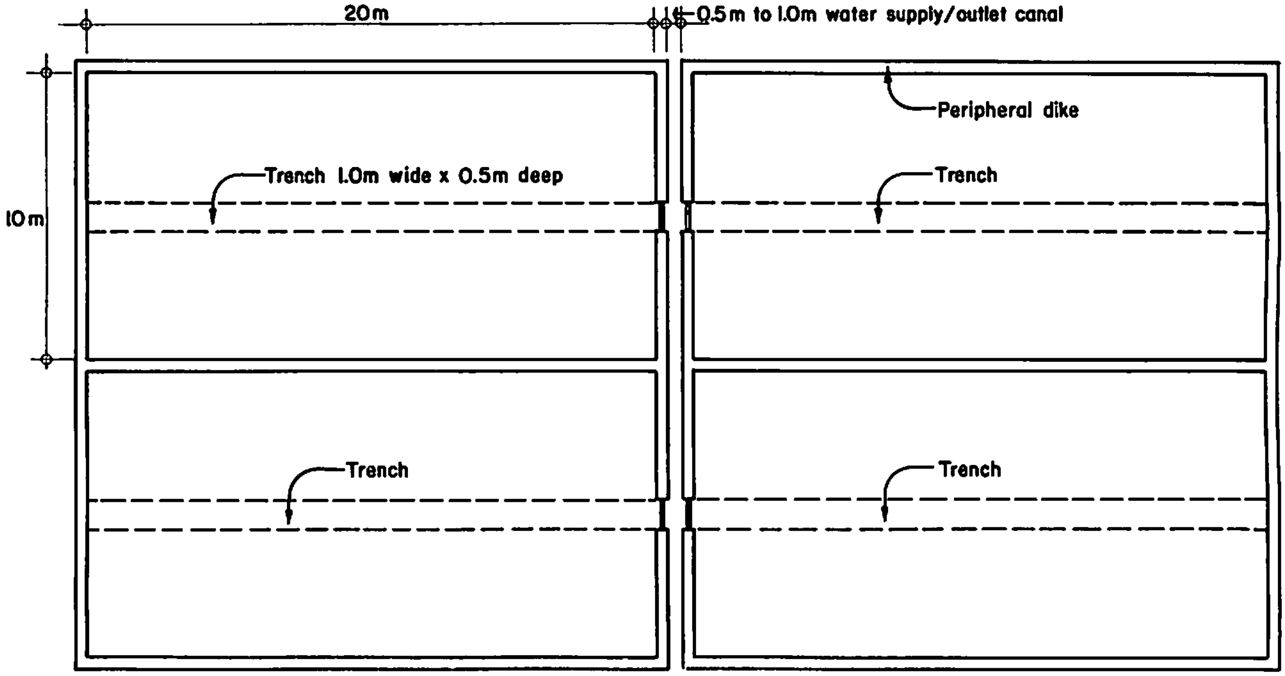

Figure 4. Location of trench for a 10m x 20m paddy. Scale 1:200.

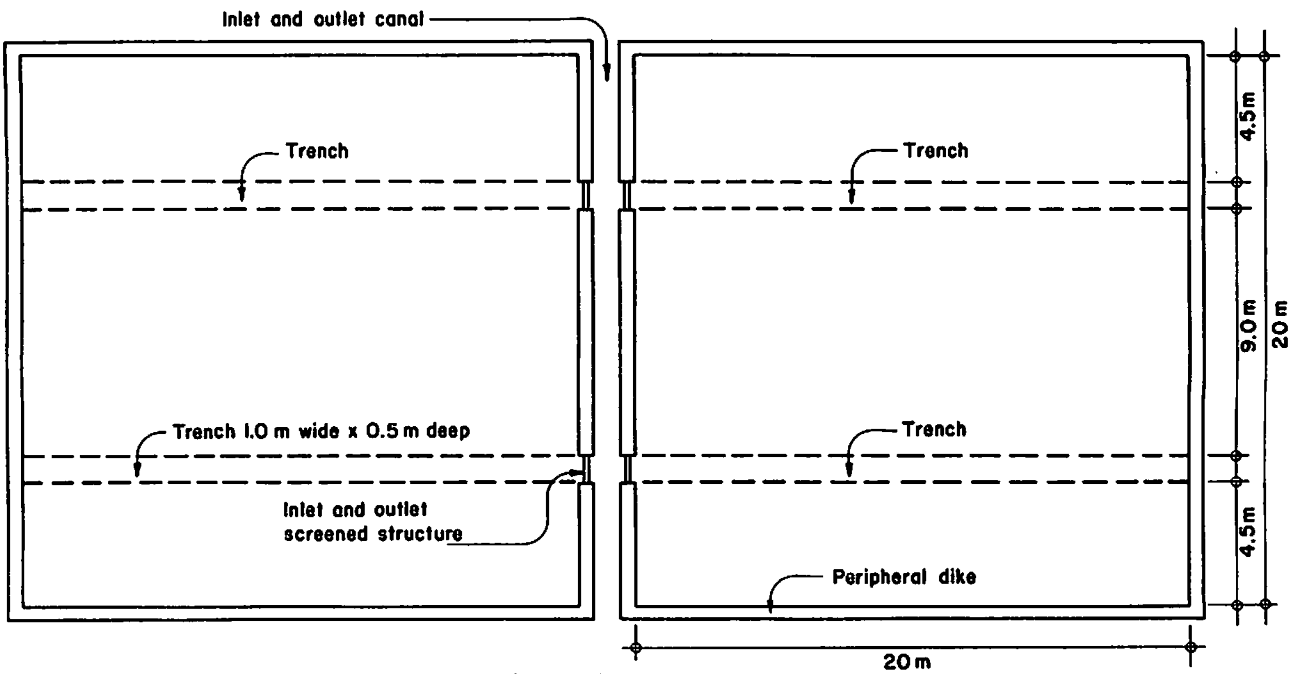

Figure 5. Location and spacing of trench for a 20m x 20m paddy. Scale 1:200.

PRODUCTION AND MARKETING OF PRODUCTS

The only information available on the economic prospects for rice-fish culture is the comprehensive marketing study carried out by Sevilleja and McCoy (1979) for Central Luzon. The following information is extracted from their report. Central Luzon has an estimated population of 4,321,000 in the provinces of Bataan, Bulacan, Nueva Ecija, Pampanga, Tarlac and Zambales. Called the rice bowl of the Philippines, it contains over 300,000 ha of irrigated riceland. Farms with adequate irrigation can usually grow two or three crops of rice annually. The region derives its fish produce from three principal sources; commercial marine fisheries (using over 3-t gross weight vessels), municipal marine fisheries (shallow water, inshore, using vessels of less than 3 t), and inland fisheries. The coastal areas of Bataan, Pampanga and Zambales have both commercial and municipal fisheries and all the provinces have some areas devoted to fish ponds. The region has a total of 52,307 ha of fish ponds, representing about 30% of the national total. The largest concentrations and areas of fish ponds are found in Bulacan and Pampanga. Most of the fish ponds in Nueva Ecija are either unmanaged or managed on a limited seasonal basis. Commercial fisheries contribute about 2% of the estimated total fish production in the region, compared to 28% from municipal fisheries. Inland fisheries (brackishwater ponds, swampland, lakes, rivers, irrigation canals and rice paddies) account for 70%.

Marketing is carried out entirely by private enterprise or individual brokers without any governmental supervision. The system is characterized by too many middlemen, large quantities of low quality fish, extreme fluctuations in supply, and poor and inadequate handling facilities. It is estimated that more than 80% of the profits go to the brokers, leaving less than 20% to the fishermen. There are few cold storage and ice making plants in the region and most of the fish are sold fresh. Low quality fish are processed (dried or smoked).

Market demand of fish in the region was estimated on the basis of expected changes in population and estimated consumption of fish. The population is expected to increase from 4,321,000 in 1977 to 4,889,000 by

Table 2. Results (treatment means) of rice-fish production tests (1974-1978) using *Sarotherodon mossambicus*, *S. niloticus*, common carp *(Cyprinus carpio)* and catfish *(Clarias batrachus)*. (1 cavan = 46 to 50 kg).

Year	Trial	Rice variety	Rice yield cav/ha	Fish species	Stocking density (per ha)	Total mean weight of fish at harvest (g). For polyculture individual weights are bracketed.	Fish yield (kg/ha)	Fish culture period (days)
1974	1	IR-26	83	*S. mossambicus**	6.7 kg	Excessive tilapia reproduction		
				C. carp*	6.2 kg		130	109
				Catfish*	10.5 kg			
1975	2	IR-26	75	Male *S. mossambicus*	3,300 fish	40.4	78	84
1975	3	IR-26	73	*S. mossambicus**	30 kg	80.1	89	94
				C. carp*	30 kg		108	
1976	4	IR-30	71	*S. mossambicus**	30 kg	69.8 (56.0)	177	87
				C. carp*	30 kg	48.5 (121.0)		
	5	IR-32	93	C. carp	3,000 fish	82.5	187	82
	6	IR-32	113	*S. niloticus*	3,000 fish	41.6	94	96
	7	IR-36	92	*S. mossambicus*	4,000 fish	33.2	86	68
	8	IR-38	115	*S. niloticus*	4,000 fish	45.0	108	75
1977	9	IR-36	138	*S. niloticus*	5,000 fish	52.0	110	94
	10	IR-38	117	*S. niloticus*	3,000 fish	60.9	135	110
	11	IR-40	131	*S. niloticus**	4,000 fish	47.5 (128)	293	94
				C. carp*	2,000 fish	94.7 (165)		
	12	IR-40	129	*S. niloticus*	5,000 fish	51.3	151	104
	13	IR-40	87	*S. niloticus*	5,000 fish	32.7	133	72
		IR-40	88	*S. niloticus*	5,000 fish	41.9	176	72
		IR-40	95	*S. niloticus*	5,000 fish	47.6	211	72
1978	14	IR-36	70	*S. niloticus*	5,000 fish	42.7	188	69
		IR-36	82	*S. niloticus*	5,000 fish	49.4	199	69
		IR-36	80	*S. niloticus*	5,000 fish	54.8	220	69

*Polyculture

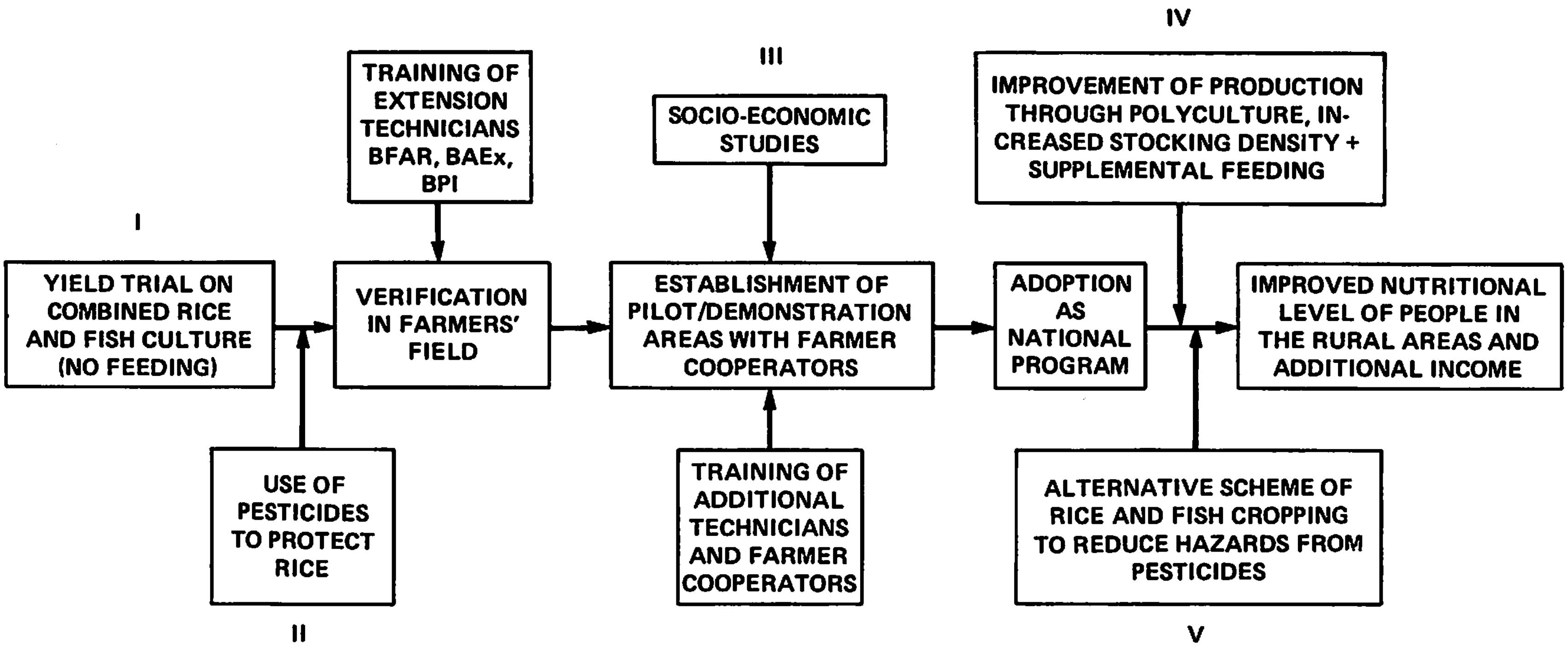

Figure 6. Research areas (I-V) and flow-chart for a rice-fish culture technology verification scheme in the Philippines.

1980 and 5,308,000 by 1982. Based on an annual per capita consumption rate (1975) of 17 kg, the market demand for fish is projected to be 83,113 t in 1980 and 90,236 t in 1982. Thus fish supply must rise to 167,693 t (1980) and 192,064 t (1982) if the National Economic Development Authority (NEDA) and BFAR goal of 34.3 kg annual per capita consumption is to be met.

ECONOMIC FEASIBILITY OF RICE-FISH CULTURE

The following economic analysis is taken from Sevilleja and McCoy (1979) whose report was based on the results of studies at the FAC. The inputs were derived from generally accepted culture and management practices, using 1975 prices.

1. Labor Requirement

The average total labor required per hectare for rice-fish culture is 76.61 man-days, compared to 70.51 for rice production alone. The construction of trenches and drainage canals, cleaning and repairing dikes, and stocking and harvesting of fish account for this increase. Labor costs were computed on the basis of 8 hr/man-day at ₱1.25/hr: an annual total of ₱766.10. The costs for construction, transplanting and harvesting account for 56.6% of this.

2. Capital Investment

Before fish production is possible, additional investment is needed for construction of trenches, drainage canals and drainage structures, and purchase of nets, harvesting buckets and wire screens. These extra items for fish culture constitute an annual cost of ₱335. The annual costs of the farm building, hand tractor and water pump are ₱75, ₱350 and ₱250, respectively, giving a total annual cost of ₱1,010. The farm building and hand tractor are needed for rice production, even without fish. The pump is needed to supply water for both fish and rice production.

3. Costs and Returns

Costs and returns per hectare were also analyzed for one production period only. A net return of ₱2,869.77/ha was estimated for rice-fish culture; this corresponds to a 31.95% return on capital (calculated from average investment figures).

4. Partial Budget

The culture of fish in rice paddies requires several minor changes in farm business organization. A partial budget was developed to estimate possible changes in costs and returns (see Table 3). This indicates that fish culture in rice paddies is profitable and can provide an additional net income of about ₱448/ha for each production period. A higher figure of ₱651/ha was estimated by the NFAC, using the results of the second nationwide field test series in 1978.

(b) Rotational Cropping of Rice and Fish in Paddies

Rice farming is the main agricultural occupation in Central Luzon and in several areas of the country during both wet and dry seasons. In irrigated areas, rice farming is usually successful during dry season when the climatic conditions favor growth, but wet season crops often give lower yields due to such climatic hazards as typhoons, strong winds, prolonged rains and floodings (Table 4). These affect drainable lands as well as low lying areas. Fish culture in rice fields during the wet season, instead of rice, offers a logical alternative crop during this period of climatic risk. Alternate cropping of rice and fish is possible in areas where the chance of flooding is minimal.

This method of farming could give the following advantages:

1. Reduction of pesticides accumulation in fish tissues, since rice and fish are grown at different times and in different areas, and pesticides will have been partially degraded by harvest time and subsequent stocking.
2. Better pest control, since the life cycles of the insect pests are disrupted.
3. Mutually beneficial interaction between the fish and rice crops, since residues from fish culture can act as fertilizers for planted rice and rice stubble submerged in water after harvest provides a medium for development of fish food organisms ultimately decomposes, providing further fertilization for rice crops.
4. Decreased rice production costs, since the paddy bottom is soft and clean after fish harvest and allows immediate seeding or transplanting. When filamentous algae are abundant, a single harrowing with the soil is sufficient.
5. Low construction cost compared to regular fish ponds as dike construction cost is reduced (the water depth in the modified paddy fields is about half that of conventional fish ponds).

A series of experiments is being conducted at the FAC to evaluate the potential yield from an ordinary paddy field stocked with fish during the wet season. The immediate objective is to develop an appropriate fish paddy facility to produce a fish crop that will match income from rice production under normal weather conditions. Suitable management and culture techniques will also need to be developed and the eventual objective is to develop a technology for rotational rice and fish cropping.

TECHNOLOGY DEVELOPMENT STRATEGY

A reversible use facility was required to permit consecutive cropping of rice and fish. Development trials were performed, using the 200 m^2 plots used for simultaneous rice-fish culture tests in Case Study A. The first trial was designed to determine the yield attainable from a fish paddy with a water depth of 10 to 15 cm (as used in the rice-fish culture system). The paddy was treated every 2 wk with inorganic fertilizer (50 kg/ha of NPK 16:20:0) and stocked with *Sarotherodon niloticus* at 5,000/ha with or without supplemental feeding, using fine rice bran at 5% body weight/d, adjusted monthly. The results showed that the mean yield of fish was as high as 219 kg/ha with fertilizer alone and 247 kg/ha with supplemental feeding (Table 5). These yields are low, however, and unacceptable for a rotational cropping scheme, as they fail to match income rice production under normal weather conditions.

The next trials were therefore designed to increase production in the same area by increasing the stocking density up to 10,000 fish/ha and the depth of water to 30 to 40 cm (Table 6). The yields from fertilized paddies did not improve despite the increase in stocking density. Although the mean yield reached 207 kg/ha at 10,000 fish/ha, the low recovery of 57.5% implies that the water

Table 3. Partial budget for testing profitability of introducing rice-fish culture on a per hectare basis. (Sevilleja and McCoy 1979). (1 cavan = 50 kg; US$1.00 = ₱7.34)

Item	Value (₱)
A. Additional receipts	
a. Marketable tilapia (200 kg @ ₱6/kg)	1,200.00
B. Reduced costs	
a. Fertilizer (0.41 bag @ ₱64.87/bag)	26.60
b. Insecticide (0.74 qtr @ ₱22.40/qtr)	16.58
c. Herbicide (1.16 kg @ ₱4.71/kg)	5.46
d. Seed (0.15 cav at ₱57.50/cav)	8.62
e. Others, including landlord's share and harvester/thresher share	99.47
Subtotal	156.73
C. Total credits (A + B)	1,356.73
D. Additional costs	
a. Labor (6.10 man-days @ ₱10/man-day)	61.00
b. Fingerlings (5,000 monosex tilapia fingerlings @ ₱0.07 each)	350.00
c. Drainage structures	40.00
d. Nets	25.00
e. Wire screens	30.00
f. Harvesting buckets	50.00
g. Irrigation fee	11.85
h. Repairs (1.12 man-days @ ₱10/man-day)	11.20
i. Depreciation	13.38
j. Other	28.87
Subtotal	621.30
E. Reduced receipts	
a. Threshed rice (5 cav @ ₱57.50/cav)	287.50
F. Total debits (D + E)	908.80
G. Change in net income (C – F)	447.93

Table 4. Mean rice yields from several trials at the Freshwater Aquaculture Center, Central Luzon State University, 1977-79.

	Rice production			
	Wet season		Dry season	
Year	Variety	Kg/ha	Variety	Kg/ha
1977	IR-32	5,052	IR-38	4,916
	IR-32	4,754	IR-40	5,908
	IR-40[a]	4,353	IR-36	5,764
	IR-32[a]	4,435		
	IR-32[a]	4,762		
	IR-34[a]	4,819		
	IR-36[a]	3,372		
	IR-36[a]	3,839		
1978	IR-36[a]	2,700	IR-42	4,901
	IR-40[a]	2,980	IR-42	4,937
			IR-36	3,579
			IR-36	3,982
1979			IR-36[b]	1,391
			IR-36[b]	2,087
			IR-36	6,571
			IR-36	6,897
			IR-42	7,140
			IR-42	5,942
			IR-42	6,306
			IR-42	6,714
			IR-42	7,275
			IR-42	6,881
			IR-42	6,305

[a]The yields were affected by typhoons at varying degrees.
[b]Rat infested.

cannot support this number of fish without supplemental feed. Optimal stocking density with fertilization alone appears to be about 7,000/ha.

A dramatic increase in yield was demonstrated, however, with supplemental feeding and a stocking density of 10,000/ha. High recoveries of 83.7 to 86.3% were obtained, with corresponding mean yields of 520 to 589 kg/ha (Table 6).

Subsequent trials were designed to further increase the yield through polyculture of *S. niloticus* with common carp (*Cyprinus carpio*) and supplemental feeding of rice bran. Table 7 shows that the highest mean yield of 692 kg/ha was obtained with a tilapia and carp combination of 10,000 and 5,000/ha, respectively. The single best yield using this combination was 830 kg/ha obtained in one of the three replicates.

ECONOMIC ANALYSIS
COST AND RETURN

A simple cost and return analysis was performed, using the average yield of 692 kg/ha composed of 470 kg of marketable tilapia and 222 kg of common carp (Table 8). This was compared to the cost and return of rice production alone.

The analysis shows that the return of ₱2,098.88 from the fish is lower than the return from a rice enterprise by ₱245.80. This favorable margin for rice can only be realized, however, under normal weather (no typhoon) and good harvesting conditions. Under bad weather conditions it is evident from Table 9 that the cost and return analysis could easily shift in favor of fish production in paddies during the wet season.

The analysis also shows that rice culture involves higher expenses than fish culture. The benefit-cost ratios of the two enterprises appear to be almost identical: 1.74 and 1.73 for rice and fish, respectively. These were computed by dividing the expected benefit by the expected cost. This analysis suggests that the decision to go into either rice or fish production is mainly a matter of personal preference but there are other complementary benefits and incentives for rotational rice and fish cropping systems that need further consideration.

COMPLEMENTARY BENEFITS

A further trial was conducted to test the reduction in the amount of fertilizer needed for rice following the fish crop. Table 10 shows that the mean yields of rice

Table 5. Yield of *Sarotherodon niloticus*, with and without supplemental feeding, alone or in combination with rice culture after 94-d culture at a fixed stocking density of 5,000/ha with water depth of 10 to 15 cm.

Input	May 1977				May 1978	
	Fish only		Rice-fish		Rice-fish	
	Recovery (%)	Yield (kg/ha)	Recovery (%)	Yield (kg/ha)	Recovery (%)	Yield (kg/ha)
Fertilization only	83.0	164	43.0	110	80.0	220
Fertilization and supplemental feeding	104.0	247	72.0	195	57.0	171

Table 6. Yields of *Sarotherodon niloticus* at various stocking densities in 30 to 40-cm water depth after various culture periods: December 1977, 93 days; May 1978, 72 days; December 1978, 116 days.

Stocking density per ha	December 1977		May 1978				December 1978	
	Fert. only		Fert. + sup. feed		Fert. only		W/ sup. feed	
	Recovery (%)	Yield (kg/ha)	Recovery (%)	Yield (kg/ha)	Recovery (%)	Yield (kg/ha)	Recovery (%)	Yield (kg/ha)
5,000[a]	35.0	73	57.0	171	80.0	220	–	–
5,000	65.7	115	93.3	391	–	–	–	–
7,000	83.3	190	75.9	393	–	–	–	–
10,000	57.5	207	86.3	589	–	–	83.7	520

[a]Combined rice-fish culture at water depth of up to 15 cm.

Table 7. Yields of *Sarotherodon niloticus*, with or without common carp at higher stocking densities in 30 to 40-cm water depth with supplemental feeding. December 1978: culture period, 116 days.

Stocking density (fish/ha) S. niloticus + C. carp		Recovery (%) S. niloticus : C. carp		Mean weight (g) S. niloticus : C. carp		Estimated yield (kg/ha)
10,000	0	83.7	0	67.1	0	520
12,500	0	60.3	0	67.9	0	495
15,000	0	44.6	0	59.5	0	398
10,000	+ 2,500	45.5	29.3	62.8	236.1	423
10,000	+ 5,000	76.7	41.7	60.9	105.9	692

Table 8. Cost and returns in Philippine pesos of polyculture (*Sarotherodon niloticus* and common carp, *Cyprinus carpio)*, with supplemental feeding in a 1-ha fish paddy (US$1.00 = ₱7.33).

Item	Value (₱)
I. Returns	
470 kg of marketable tilapia at ₱7.50/kg	3,525.00
222 kg of common carp at ₱6.50/kg	1,443.00
Total (A)	4,968.00
II. Cost	
Fingerlings	
10,000 *S. niloticus* fingerlings at ₱0.08 each	800.00
5,000 common carp at ₱0.05 each	250.00
Feed	
1,270 kg fine rice bran at ₱0.75/kg	952.50
Fertilizer	
386.5 kg 16:20:0 (N:P:K) at ₱1.71/kg	660.92
Labor	
18.7 man-days at ₱11.00/man-day	205.70
Total (B)	2,869.12
III. Net returns (A-B)	2,098.88

planted in the former fish paddy were slightly lower by 378 kg/ha (with no fertilization) and 132 kg/ha (with one fertilizer application) than conventional rice culture. The latter, however, required three fertilization treatments. The corresponding cost of fertilizers applied was zero, ₱374.25 for single application in rotational cropping and ₱645.75. Although conventional rice cropping gave the highest yield, the value of the yield increments of 378 and 132 kg does not compensate for the extra cost of fertilizer (Table 10).

Another significant observation was the abundant growth of *Hydrilla* sp. in paddies stocked only with *S. niloticus* and the relative absence of weeds and algae

Table 9. Cost and returns in Philippine pesos of rice production during the wet season in a 1-ha fish paddy (US$1.00 = ₱7.33).

Item	Value (₱)
I. Returns	
Threshed rice, 5,000 kg at ₱1.10/kg (A)	5,500.00
II. Cost	
A. Cash	
Rice	
Seed (2 cav[a])	110.00
Fertilizer	
6 bags 14:14:14 (N:P:K) at ₱79.50/bag (50 kg)	477.00
3 bags 45:0:0 (urea) at ₱90.50/bag (50 kg)	271.50
Insecticide	
2 bags Furadan 3G at ₱120.00/bag (16.7 kg)	240.00
Hired labor	
58 man-days at ₱11.00/man-day plus rotavation cost of ₱300.00	938.00
Other expenses[b]	100.00
Subtotal	2,136.50
B. Noncash	
Harvester/thresher share (500 kg)	550.00
Unpaid operator and family labor (20.12 man-days)	221.32
Irrigation fee (3.5 cav)	192.50
Samahang Nayon[c] contribution (1 cav[a])	55.00
Subtotal	1,018.82
Total cost (B)	3,155.32
III. Net returns (A-B)	2,344.68

[a]1 cavan = 50 kg.
[b]Include transportation, food, fees, tax, etc.
[c]Samahang Nayon: a local community organization.

Table 10. Comparison of rice yields (kg/ha) and savings (₱) in fertilizer between rotational rice and fish cropping, on one hand, and monocropping of rice, on the other.

Replications	Rice cropping after fish		Monocropping of rice
	No fertilizer	Fertilized once[a]	Fertilized 3 times[b]
1	6,690	6,840	6,563
2	6,950	7,340	7,472
3	7,050	7,250	7,790
Mean	6,897	7,143	7,275
Cost of fertilizer	0	₱374.25[c]	₱645.75[c]

[a]Basal fertilization at the rate of 150 kg/ha of 14:14:14 (N:P:K) and 75 kg/ha of 45:0:0 (urea).
[b]Same as in a) plus two applications of 45:0:0 (urea) at 75 kg/ha each.
[c]Computed at ₱79.50/bag (50 kg) for 14:14:14 and ₱90.50/bag (50/kg) for 45:0:0. (US$1.00 = ₱7.33)

when combinations of *S. niloticus* and common carp were stocked. This was attributed to the higher turbidity of the water caused by the carp feeding habits, which may also reduce the production cost of rice by cleaning the soft paddy bottom sufficiently to allow direct seeding or transplanting. This would save the cost of plowing and harrowing (₱300/ha).

On the whole, the results of the rotational cropping experiments are encouraging. Through proper management, it should be possible to reduce the cost of the main inputs of fertilizer and supplemental feed. The benefits derived from the fish paddy can be further increased by adding other fish species or other crops, such as taro, to the system.

Acknowledgment

My deep thanks go to Eduardo A. Lopez, my co-investigator in the rice and fish culture project, and to the FAC laborers, who all put in hard work and gave me so much cooperation in the project; to Ruben C. Sevilleja, who helped me in the economic analysis, and to other research instructors and assistants, who helped in the preparation of the figures.

References

Arce, R.G. 1977. Rice-fish culture (Palay-isdaan). Freshwater Aquaculture Center, Central Luzon State University, Philippines (mimeo). 7 p.

Arce, R.G. and C.R. dela Cruz. 1978. Improved rice-fish culture in the Philippines. Paper presented at the Second Regional Afro-Asian Conference of the International Commission on Irrigation and Drainage, Manila, Philippines, 5-6 December 1978. Tech. Pap. No. 10. 10 p.

Cruz, C.R. dela. 1979. Technology generation, verification and dissemination in the production of fish in rice fields. Philippine Council for Agriculture and Resources Research. Seminar Paper Series No. 17. Los Baños, College, Laguna.

Sevilleja, R.S., and E.W. McCoy. 1979. Fish marketing in Central Luzon, Philippines. Research and Development Series No. 21. Auburn University, Alabama, U.S.A. 23 p.

Undan, R.C. 1979. The CLSU model farm of the future. Philippine Society of Agricultural Engineers. Seminar paper. Manila, Philippines.

Bibliography

Arce, R.G. and C.R. dela Cruz. 1977. Design/layout considerations in a freshwater rice-fish culture farm in the Philippines, p. 335-346. *In* Proceedings of a Joint Workshop on Aquaculture Engineering (with emphasis on small-scale aquaculture projects) of the South China Sea Fisheries Programme and the Southeast Asian Fisheries Development Council, Tigbauan, Iloilo, Philippines, 27 November-3 December 1977.

Cruz, C.R. dela. 1976. Livestock-fish-crop integration of small farmer level. Country paper prepared for the 13th FAO Regional Conference for Asia and the Far East, Manila, Philippines, 5-13 August 1979. 14 p.

Fishery Industry Development Council (FIDC). 1979. Philippine fisheries: major developments in the 1970s and direction for the 1980s. Ministry of Natural Resources, Quezon City, Philippines. 72 p.

National Food and Agriculture Council (NFAC). 1978. Annual report. Ministry of Agriculture, Quezon City, Philippines. 60 p.

Preliminary Results of Integrated Pig-Fish and Duck-Fish Production Tests

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Abstract

Pig-fish and duck-fish production trials are described using 40 or 60 pigs/ha and 750 or 1,250 ducks/ha of pond surface, with total fish stocking densities of 10,000 or 20,000/ha (85% *Sarotherodon niloticus*, 14% *Cyprinus carpio* and 1% *Ophicephalus striatus)*. The highest net yields were obtained with the 60 pig/20,000 fish and 750 ducks/20,000 fish combinations: 1,950 kg/ha and 1,690 kg/ha, respectively, from 90-day culture periods. Comparisons with control ponds receiving inorganic fertilization and measurements of water quality parameters (pH, dissolved oxygen and ammonia) are included.

Introduction

The rising cost of high protein fish feed and inorganic fertilizer, as well as the general concern for energy conservation, have brought about increased interest in the utilization of animal manures in aquaculture and in the traditional systems which integrate animal husbandry with aquaculture.

Recent experiments have demonstrated that considerable fish production can be obtained when animal manures are properly applied to fish polyculture systems. Moav et al. (1977) reported a daily gain of 35 kg/ha (8t/ha/240d) from a fish polyculture system (silver carp, common carp, grass carp and tilapia) receiving liquified cowshed manure. Polyculture of carps, channel catfish and largemouth bass, with wastes from 66 pigs/ha as the only source of nutrients, yielded 4 t/ha/yr (Buck et al. 1978). A daily yield of 32 kg/ha (7.6t/ha/240d) was achieved in ponds receiving only duck droppings (Wohlfarth 1978) and supplementary addition of chicken droppings under conditions of intensive fish culture increased fish yield by 21% and decreased the feed conversion rate by 0.4 units (Rappaport and Sarig 1978). Similar findings reported in earlier literature were reviewed by Woynarovich (1979).

Much of this information is germane to temperate and/or subtropical climates. Although integrated animal-fish farming has a long history in Southeast Asia, production methods are not well documented, if at all, and formal experimentation is only just beginning. Furthermore, the classic polyculture systems used are based on Chinese or Indian carps, which are either not marketable or fetch low prices in some countries like the Philippines.

In the case of the Philippines (Central Luzon), where average farm size is less than 3 ha (Sevilleja & McCoy 1979), integrated animal-fish farming could be an appropriate means for increasing returns from a limited land area and reducing risk by diversifying crops. However, before a development effort can be mounted to popularize animal-fish farming, available production methods need to be adapted to the prevailing tropical climate and locally marketable fish species, and the economic viability of the system needs to be ascertained.

Accordingly, a research project was initiated in 1977 at the Freshwater Aquaculture Center (FAC) of the Central Luzon State University (CLSU), to 1) design a fish polyculture system that would provide the highest economic return, giving manure as the only nutrient source, 2) determine the maximum pig or duck stocking rate per unit area of freshwater fish pond, and 3) clarify the economics of the developed production system(s). This paper presents the preliminary findings from the first 180 d of a series of production tests.

Methodology

A special facility was constructed consisting of 12 ponds each of 1,000 m^2 area for the pig-fish tests and 12 ponds each of 400 m^2 for the duck-fish tests with the animal pens on top of the dikes (Figure 1).

The tests were run for 180 d, which corresponds to the pig rearing period from weaned piglet to market size (finished) pig. The ducks were grown as layers and kept in the pens for the same period of time. Two fish production tests of 90 d each were conducted during this period, as the preferred tilapia market size in Central Luzon (60 g) can be attained or surpassed in 90 d at the FAC.

The factorial experimental design consisted of two animal stocking rates of 40 and 60 pigs/ha; 750 and 1,250 ducks/ha. Fish production in conjunction with each animal stocking rate was tested at stocking densities of 10,000 and 20,000 fish/ha with manure as the only input. Two control ponds received only inorganic fertilizer (N:P:K, 16:20:0) at the rate of 50 kg/ha every 15 d. Each combination was duplicated during the first 90-d fish production period and replicated three times during the second 90-d period.

Weaned piglets (Large White-Landrace cross) weighing 18 to 20 kg each, and Pekin ducks of 500 to 700 g were fed and managed according to standard procedures recommended for the Philippines (PCARR 1976, 1977). Manure from pig pens was washed into the ponds via narrow concrete canals, while duck droppings were collected and broadcast on the ponds. In both cases, manure was dispensed to the ponds daily at 8:00 to 10:00 am. The ducks were allowed to graze on the ponds daily and nylon screens inside the ponds protected the dikes from their foraging activities.

The fish species and densities used were:

Sarotherodon niloticus (Nile tilapia)	8,500/ha	17,000/ha
Cyprinus carpio (common carp)	1,400	2,800
Ophicephalus striatus (Snakehead or mudfish) a tilapia predator	100	200
	10,000/ha	20,000/ha

The growth of fish, pigs and ducks was monitored every other week. Dissolved oxygen and water temperature were recorded with an oxygen/temperature meter (Yellow Springs Instruments; YSI 54 AR) at 6:30 am on alternate days. Early morning ammonia-ammonium concentration was determined weekly with a specific ion meter (Orion, Model 47A) and an ammonia electrode (Orion, 95-10). All readings were taken at a depth of 0.5 m in three locations along the long axis of the ponds and a mean value calculated. Fish were harvested at the end of each culture period by draining the ponds and fish recovery rates, production and other pertinent growth data recorded.

Results

A. PIG-FISH TESTS

1. First 90-d Test Period (Table 1, Figure 2)

Net fish yields increased with pig stocking rates and fish density to a maximum of 958 kg/ha (10.7 kg/ha/d), with tilapia and carp mean weights of 43 and 80 g, respectively, from the 60 pigs-20,000 fish/ha combination. Control ponds receiving inorganic fertilizer produced a maximum of 560 kg/ha (6.2 kg/ha/d) which is roughly equivalent to the yield from ponds with 40 pigs and between 10,000 and 20,000 fish/ha, and to 58% of the yield from the 60-20,000 combination.

The growth rate of tilapia (Figures 3, A & B) increased with pig stocking rates and decreased as fish density increased. A maximum final mean weight of 73 g was obtained with the 60-10,000 combination. Individual mean weights from other combinations were 54 g or less. Tilapia growth levelled off at a mean weight of 35 g in the 40-20,000 combination indicating that maximum carrying capacity was reached at the given fish stocking densities and pig biomass (manure delivery). Growth also levelled off in control ponds at mean

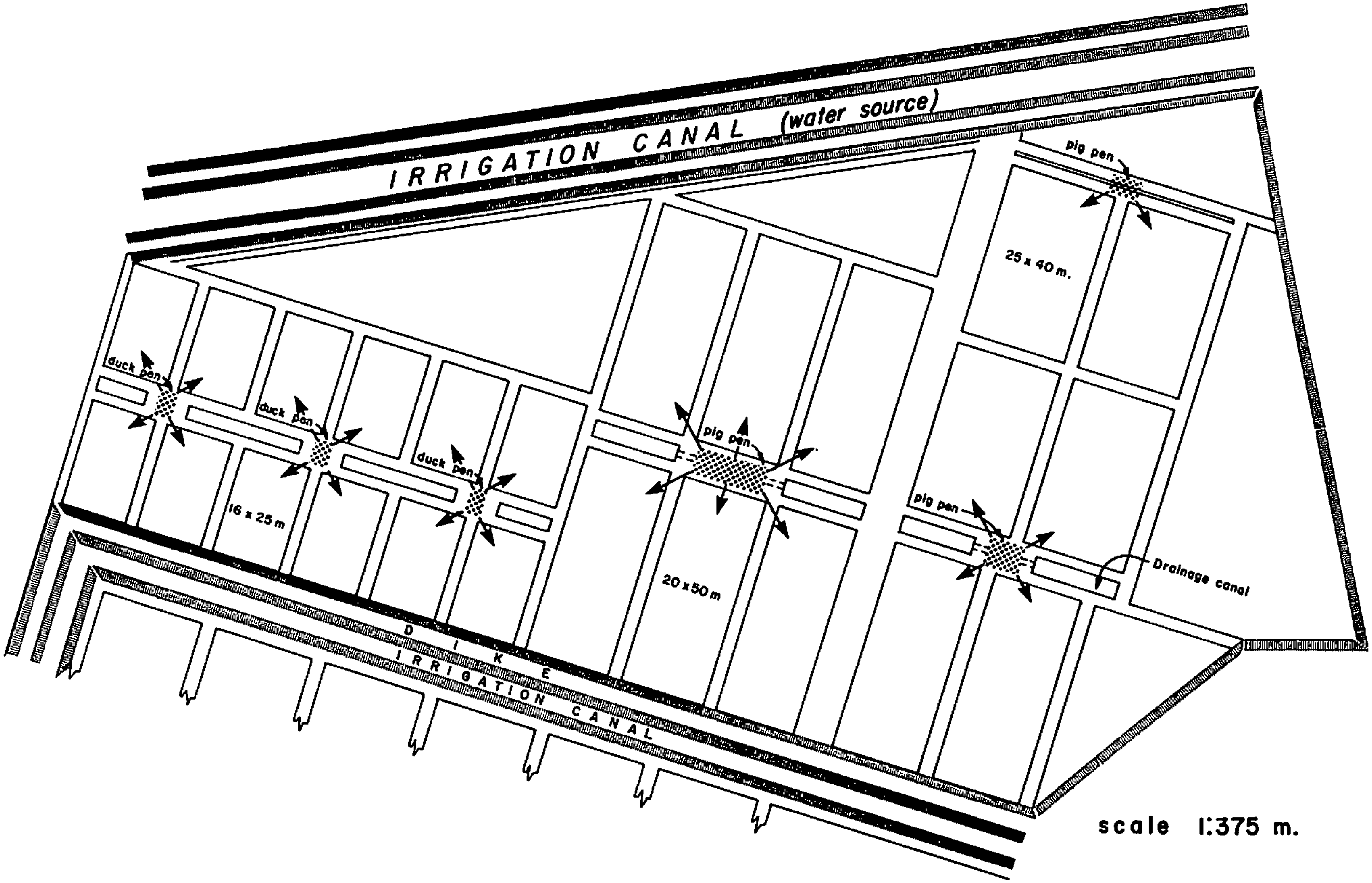

Figure 1. Layout of the experimental facility showing the relationship of animal pens to fish ponds. Arrows indicate waste delivery.

weights of 52 and 33 g at the low and high fish densities respectively after 60 d and began to decrease towards the end of the culture period.

Final individual mean weight of carp was also highest (149 g) in the 60-10,000 combination (it was not possible to follow carp growth because the fish evaded sampling nets successfully). Carp yields from the 60-10,000 and 60-20,000 combinations were identical, indicating that the carrying capacity for carp at the given fish and pig stocking rates was reached.

Although the 60-20,000 combination gave the highest fish yield, the 60-10,000 combination could prove more profitable if significantly higher prices can be obtained for larger fish. Another point worth noting from the comparison of yields from control ponds and those receiving manure from 40 pigs is that a 40-15,000 combination would result in savings equal to the price of 300 kg of 16:20:0 fertilizer over 90 d.

Initial and final individual mean weights of pigs for the 90-d period were about 20 and 52 kg, respectively (Table 3).

2. Second 90-d Test Period (Table 2, Figure 2)

Since this test series was initiated with pigs of about 56 kg mean weight (Table 3) carried over from the first test period, as compared to 20 kg mean weight in the latter, both fish growth rates and net yields were expected to be higher due to increased manure delivery.

As can be noted from Table 2 and Figure 2, net yields again increased with pig and fish stocking rates to a

Table 1. Fish production *(Sarotherodon niloticus, Cyprinus carpio* and *Ophicephalus striatus)* in pig-manured ponds during the first 90-day test period (September-November 1978). Production figures represent means of duplicate ponds.

Pigs/ha	Species	Stocking fish/ha	Individual mean weight (g) Initial	Final	Gain (g)	Average daily gain (g)/fish	Recovery %	Yield (kg/ha) in 90 d
0 (control)[1]	*S. niloticus*	8,500	6.7	48.7	42.0	0.5	90.4	376.1
	C. carpio	1,400	12.2	119.2	107.0	1.2	100.0	176.1
	O. striatus	100	1.0	165.8	165.8	1.8	45.0	7.5
	Total	10,000				3.5		559.7
0 (control)[1]	*S. niloticus*	17,000	3.8	26.7	22.9	0.3	78.5	357.0
	C. carpio	2,800	3.4	22.7	19.3	0.2	100.0	78.6
	O. striatus	200	1.0	97.5	96.5	1.1	65.0	10.5
	Total	20,000				1.6		446.1
40	*S. niloticus*	8,500	4.0	53.6	49.6	0.6	72.8	329.0
	C. carpio	1,400	3.2	109.4	106.2	1.2	100.0	155.0
	O. striatus	100	1.0	161.9	160.9	1.8	45.0	7.1
	Total	10,000				3.6		491.1
40	*S. niloticus*	17,000	4.5	35.1	30.6	0.3	92.5	552.4
	C. carpio	2,800	4.6	46.0	41.4	0.5	90.5	116.7
	O. striatus	200	1.0	167.7	166.7	1.9	80.0	13.4
	Total	20,000				2.7		682.5
60	*S. niloticus*	8,500	4.9	73.2	68.3	0.8	87.3	542.0
	C. carpio	1,400	4.7	149.3	144.6	1.6	100.0	209.5
	O. striatus	100	1.0	200.0	199.0	2.2	25.0	4.9
	Total	10,000				4.6		756.4
60	*S. niloticus*	17,000	2.5	43.1	40.6	0.5	72.2	742.0
	C. carpio	2,800	3.0	80.1	77.1	0.9	97.0	195.7
	O. striatus	200	1.0	186.1	185.1	2.1	90.0	20.5
	Total	20,000				3.5		958.2

[1]Inorganic fertilizer NPK (16-20-0) applied @ 50 kg/ha/15 days.

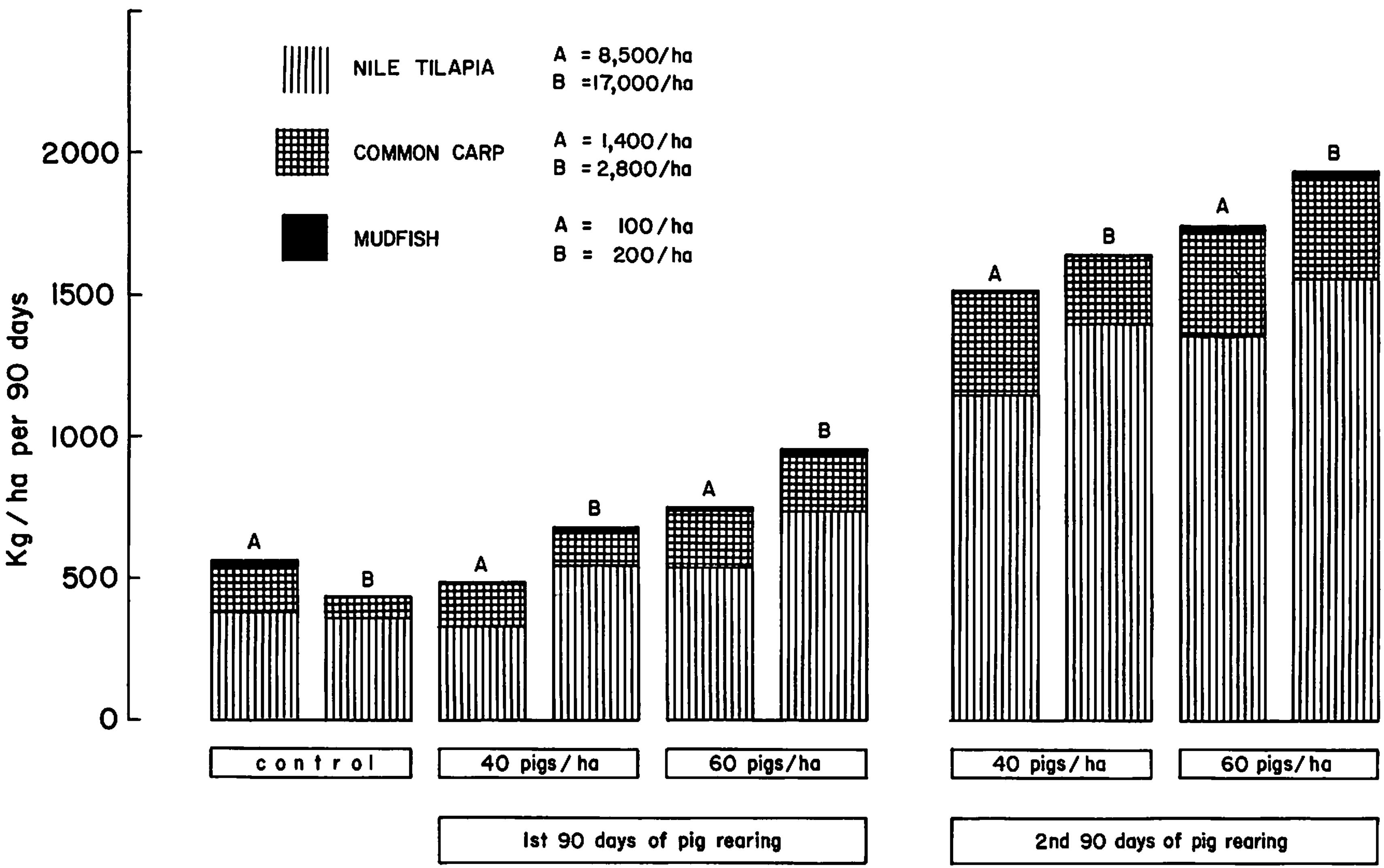

Figure 2. Individual and cumulative net yields of nile tilapia *(Sarotherodon niloticus)*, common carp *(Cyprinus carpio)* and mudfish *(Ophicephalus striatus)* cultured together for 90-day periods in ponds receiving pig manure. The columns represent the means from duplicate ponds over the 1st 90 days and triplicate ponds over the 2nd 90 days.

maximum of 1,950 kg/ha (22 kg/ha/d), with tilapia and carp mean weights of 119 and 181 g, respectively, from the 60-20,000 combination.

Tilapia growth rates (Figure 3C) followed the same pattern as in the first test period. A maximum mean weight of 166 g was obtained from the 40-10,000 combination, as compared to 120 g from 60-20,000 combination. Tilapia growth did not level off in any of the test combinations indicating that the manure delivery rate did not limit growth as in the case of the 40-20,000 combination in the first 90-d period. However, at fish densities of 10,000/ha, tilapia growth did not increase with increased pig stocking rate. This indicates that at 60 pigs/ha, more food was produced than could be utilized by the fish biomass.

Carp yield was highest (370 kg/ha) in the 60-pig combinations but was essentially the same at both fish densities, indicating that the carrying capacity for carp was reached with 60 pigs.

Initial and final individual mean weights of pigs during the second 90-d culture period were 57 and 102 kg, respectively (Table 3).

3. Water Quality

Early morning (6:30 A.M.) water temperature was 25 to 29°C (minimum-maximum) during the first 90-d test period (September to November) and 21 to 27°C during the second period (January to March). pH varied between 7.5 and 9 in control ponds and pig-fish ponds during the first period and between 8 and 9 in pig-fish ponds during the second period. There were no discernible differences in pH between the various pig-fish combinations during either test period.

Special attention was paid to dissolved oxygen concentrations in pond water as an indicator of manure overloading, particularly during the second test period when water temperature was lower and manure loading higher than in the first period. Early morning dissolved oxygen (Figure 4) varied between 3 and 8 ppm in control ponds. Fish density and pig stocking rates did not affect oxygen concentrations in either test period. Concentrations in pig-fish ponds during the first period began to decrease steadily from control values on the 66th day but remained above 3 ppm. During the second

Table 2. Fish production *(Sarotherodon niloticus, Cyprinus carpio* and *Ophicephalus striatus)* in pig-manured ponds during the second 90-day test period (January-March 1979). Production figures represent means of triplicate ponds.

Pigs/ha	Species	Stocking fish/ha	Individual mean weight (g) Initial	Final	Gain (g)	Average daily gain (g)/fish	Recovery %	Yield (kg/ha) in 90 d
40	*S. niloticus*	8,500	3.7	166.1	162.4	1.8	83	1,156
	C. carpio	1,400	71.4	344.7	273.3	3.0	73	356
	O. striatus	100	103.6	263.0	159.4	1.8	27	8
	Total	10,000				6.6		1,520
40	*S. niloticus*	17,000	2.8	92.0	89.2	1.0	90	1,408
	C. carpio	2,800	71.4	166.5	95.2	1.1	52	253
	O. striatus	200	103.6	238.3	134.8	1.5	25	11
	Total	20,000				3.6		1,672
60	*S. niloticus*	8,500	3.2	160.5	157.2	1.7	100	1,364
	C. carpio	1,400	71.4	358.8	287.4	3.2	75	373
	O. striatus	100	103.6	217.8	114.2	1.3	50	11
	Total	10,000				6.2		1,748
60	*S. niloticus*	17,000	3.9	119.9	115.9	1.3	78	1,576
	C. carpio	2,800	71.4	181.1	109.7	1.2	71	353
	O. striatus	200	103.6	305.3	201.7	2.2	35	21
	Total	20,000				4.7		1,950

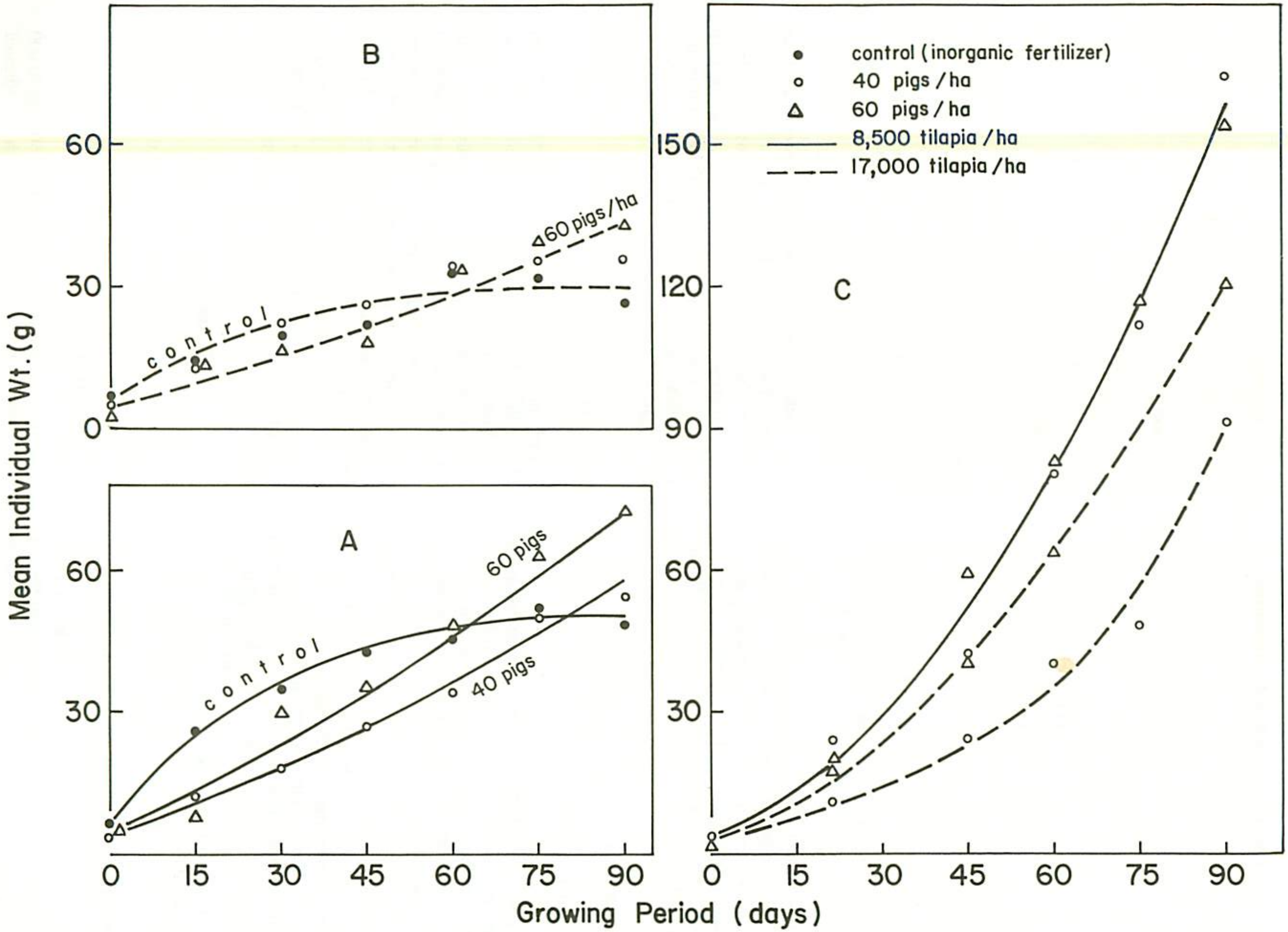

Figure 3. Growth rates of *Sarotherodon niloticus* at two stocking densities in ponds receiving pig manure: A–mean individual weights of fish stocked at 8,500/ha in duplicate 0.1-ha ponds receiving manure from 40 and 60 pigs/ha during the 1st 90 days of a pig production cycle and inorganic fertilizer (NPK:16:20:0) for comparison. B–as A but with 17,000 fish/ha comparing 60 pigs/ha and inorganic fertilization. C–as A and B but with triplicate ponds during the 2nd 90 days of the pig production cycle with no inorganic fertilization for comparison.

Table 3. Change in individual mean weights of pigs during the two 90-day test periods.

A. First test period

Combination (pig-fish/ha)	Initial	2	4	Time (wk) 6	8	10	12
40-10,000	19.77	23.95	27.30	32.72	37.50	48.57	53.97
40-20,000	18.67	22.10	26.06	32.92	36.30	47.42	51.80
60-10,000	18.54	22.09	25.46	30.28	34.46	44.08	49.94
60-20,000	19.68	22.35	25.11	30.40	39.08	50.65	56.61
B. Second test period							
40-10,000	61.25	68.66	79.66	85.91	94.58	99.33	105.75
40-20,000	50.60	58.98	69.33	78.66	87.66	93.66	100.91
60-10,000	55.15	63.27	71.99	81.72	89.05	97.16	103.88
60-20,000	60.02	66.18	72.91	82.35	87.88	92.86	97.02

period, oxygen values declined steadily, after 1 mo, from 5 to 1.2 ppm (Figure 4). Ammonia-ammonium concentrations in the second test period increased gradually from 0.22 to 0.35 ppm in all combinations except the 60-20,000 set where a final concentration of 0.78 ppm was recorded.

B. DUCK-FISH TESTS

1. First 90-d Test Period (Table 4, Figure 5)

The results of this test were not as clearcut as the equivalent pig-fish tests because a substantial amount of duck manure was deposited on the dikes and did not reach the ponds, and due to the influence of a typhoon on duck health and growth. The manure problem was eliminated in the second test period with a fence which excluded access to the dikes.

The same general trends noted in the pig-fish tests were nevertheless evident. Yields tended to increase with duck and fish stocking rates to a maximum of 980 kg/ha (10.9 kg/ha/d), with tilapia and carp mean weights of 60 and 96 g, respectively, from the 1,250 ducks-20,000 fish combination. Fish yield from the 750-10,000 combination matched production from control ponds with the same fish density.

2. Second 90-d Test Period (Table 5, Figure 5)

Maximum fish yield of about 1,690 kg/ha (18.8 kg/ha/d), with mean tilapia and carp weights of 98 and 213 g, respectively, was obtained in this test series from the 750-20,000 combination. Yields from ponds with duck stocking rates of 1,250/ha gave lower yields than those with 750 ducks/ha at both fish densities.

The growth curves of tilapia (Figure 6) demonstrate depressed growth at the higher duck stocking rate. Carp production, however, was highest (402 kg/ha) from the 1,250-20,000 combination despite prevailing low oxygen concentrations.

3. Water Quality

Early morning water temperature was 23 to 28°C and 21 to 28°C during the first and second test periods, respectively. pH was 7 to 8 in both periods. Early morning dissolved oxygen declined steadily during both test periods but remained above 2 ppm throughout the first period. During the second period, however, oxygen values were below 2 ppm most of the time, declining to less than 1 ppm towards the end of the period. Ammonia-ammonium concentrations in the second test period increased gradually from 0.19 to 0.30 ppm in all combinations except the 1,250-20,000 set in which concentrations rose to 0.52 ppm.

Tentative Conclusions

In spite of the preliminary nature of the data, some tentative conclusions can be reached:

A. PIG-FISH TESTS

1. The results clearly indicate that 60 pigs-20,000 hectare provide the highest net yield of fish. As indicated in the text, maximum yield may not correspond with

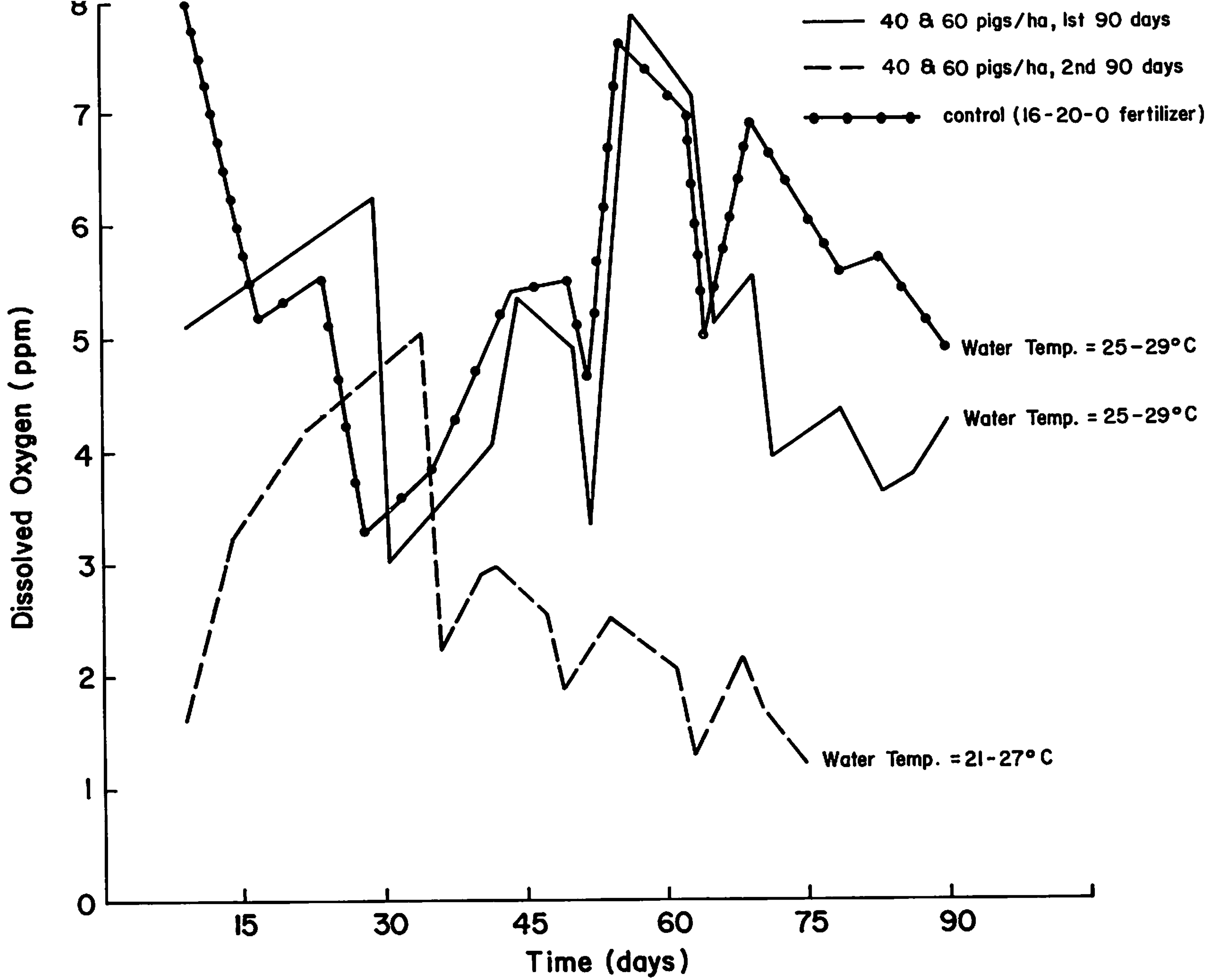

Figure 4. Early morning (6:30 A.M.) dissolved oxygen in ponds receiving pig manure during two consecutive 90-day periods. Data represent mean values from duplicate ponds for the 1st 90 days; controls and triplicate ponds for the 2nd 90 days.

maximum economic return. Much will depend on size-related market price for fish. If a premium is paid for larger fish, then stocking rates must be reduced with a resulting decrease in total net yield. At present, mixed sizes of tilapia are marketed in Central Luzon at a wholesale price of ₱*6/kg while carp fetches about 3 to ₱4/kg. This may change in the future.

2. Assuming for the moment that maximum production and profitability are synonymous, annual fish production with the 60-20,000 combination will depend on the management method used. For example, if pigs are grown from 20 to 100 kg over the pond, then a net yield of 958 + 1,950 = 2,908 kg/ha can be achieved in one pig rearing cycle of 180 d. To this can be added the fish yield (958 kg/ha) from another 90-d period with new pigs to make a total production of 3,866 kg/ha in 270 d. It is evident from our data, however, that fish production during the first 90 d of pig rearing is low due to inadequate manure production, and that doubling the pig biomass during this period would double the fish yield resulting in annual fish production of 1,950 x 3 = 5,850 kg/ha in 270 d.

If adjustment of pig biomass is not feasible, an alternative would be to increase fish production during the initial 90 d with supplemental feed (rice bran).

*US$1.00 = ₱ (Philippine pesos) 7.33.

3. Since dissolved oxygen concentrations were about one ppm during the end of the second 90-d pig rearing period at 60 pigs-20,000 fish/ha, it appears likely that a further increase of pig stocking rate will either reduce fish production or cause fish mortality during the last 90 d of the pig rearing period.

B. DUCK-FISH TESTS

Following the same argument outlined above, and assuming Pekin ducks are raised as layers, then the recommended maximum duck-fish stocking rate is 750-20,000. Maximum net fish yield, after ducks have become regular layers, would be 1,690 kg/ha/90 d, or 5,070 kg/ha in 270 d.

C. FISH COMPOSITION

The above recommendations are based on a fish composition of 85% nile tilapia, 14% common carp and 1% mudfish. This composition was used because fry of these fish can be produced or obtained by farmers in the Philippines fairly easily. However, this system is unstable because it does not include efficient filter feeders. There is particular need to add a nannoplankton

Table 4. Fish production (*Sarotherodon niloticus, Cyprinus carpio* and *Ophicephalus striatus*) in duck-manured ponds during the first 90-day test period (October-December 1978). Figures represent means of duplicate ponds.

Ducks/ha	Species	Stocking fish/ha	Individual mean weight (g) Initial	Final	Gain (g)	Average daily gain (g)/fish	Recovery %	Yield (kg/ha) in 90 d
750	*S. niloticus*	8,500	1.8	69.0	67.2	0.8	76.6	395.0
	C. carpio	1,400	2.3	165.0	162.7	1.8	100.0	196.8
	O. striatus	100	1.0	150.0	149.0	1.7	87.5	9.4
	Total	10,000				4.3		601.2
750	*S. niloticus*	17,000	2.1	61.9	59.8	.7	59.9	489.5
	C. carpio	2,800	2.3	61.2	58.9	.7	95.5	225.3
	O. striatus	200	1.0	135.0	134.0	1.5	37.5	16.0
	Total	20,000				2.9		730.8
1,250	*S. niloticus*	8,500	2.0	71.5	69.5	.8	85.0	502.0
	C. carpio	1,400	2.3	134.3	132.0	1.5	83.9	166.2
	O. striatus	100	1.0	179.9	178.9	2.0	91.7	16.3
	Total	10,000				4.3		684.5
1,250	*S. niloticus*	17,000	2.1	59.7	57.6	.6	61.0	679.0
	C. carpio	2,800	2.3	95.7	93.4	1.0	92.0	290.8
	O. striatus	200	1.0	96.9	95.9	1.1	43.7	9.8
	Total	20,000				2.7		979.6

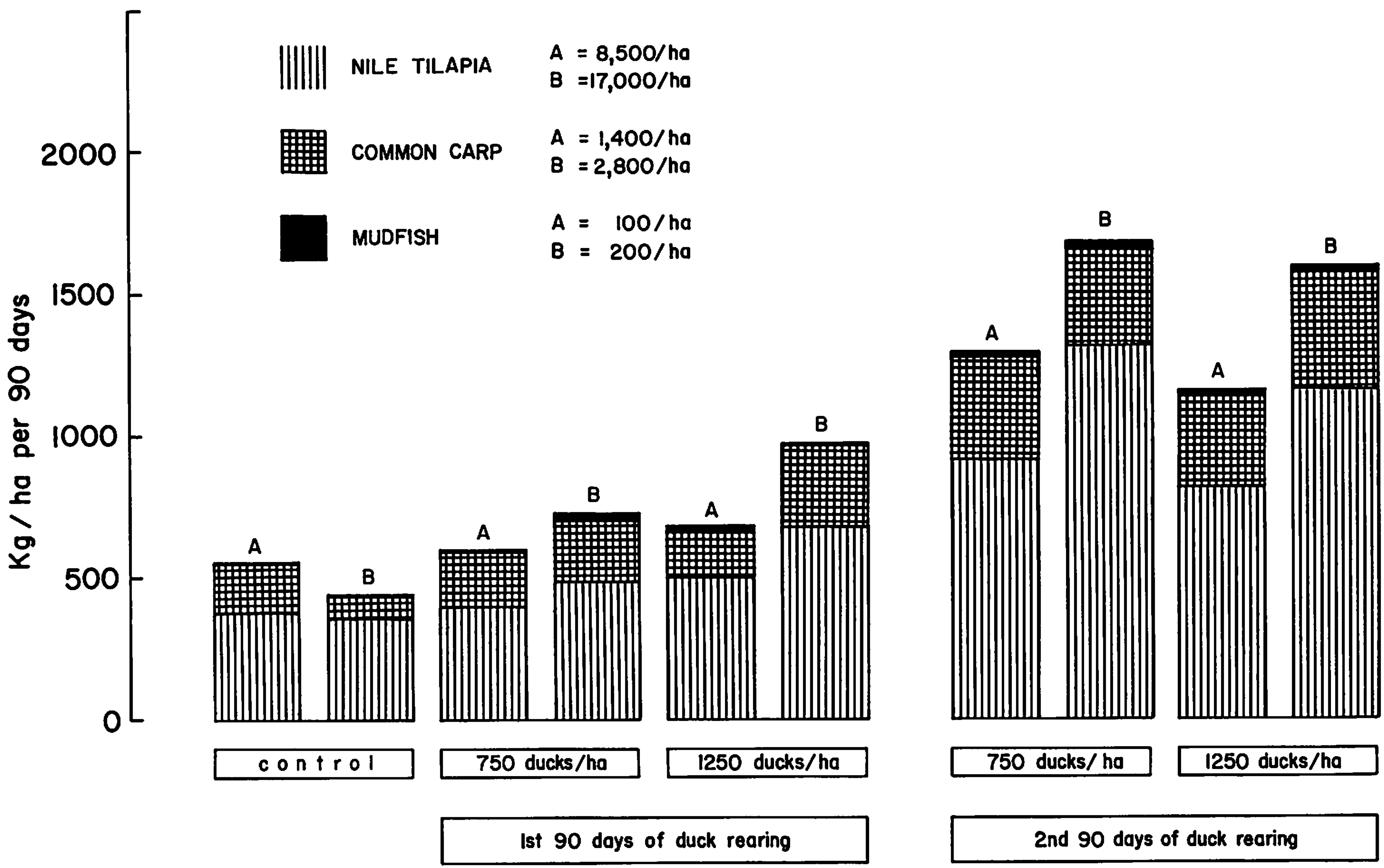

Figure 5. Individual and cumulative net yields of nile tilapia *(Sarotherodon niloticus)*, common carp *(Cyprinus carpio)* and mudfish *(Ophicephalus striatus)* cultured together for 90-day periods in ponds receiving duck manure. The columns represent the means from duplicate ponds over the 1st 90 days and triplicate ponds over the 2nd 90 days.

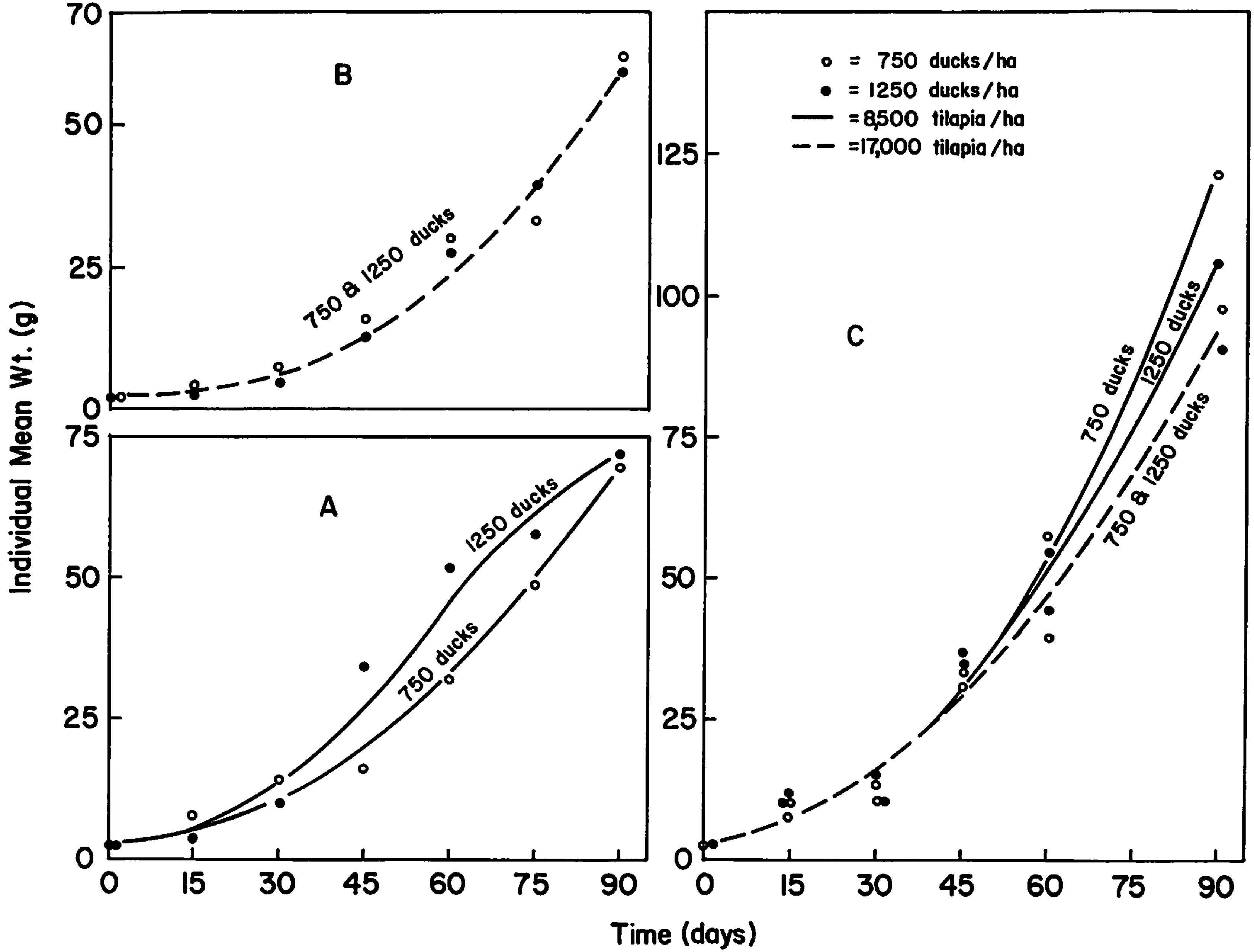

Figure 6. Growth rates of *Sarotherodon niloticus* stocked at two densities in ponds receiving duck manure: A–mean individual weights of fish stocked at 8,500/ha in duplicate 0.04 ha ponds receiving manure from 750 and 1,250 ducks/ha during the 1st 90 days of a duck production cycle. B–as A but with 17,000 fish/ha. C–as A and B but using triplicate ponds receiving manure during the 2nd 90 days of a duck production cycle.

Table 5. Fish production (*Sarotherodon niloticus, Cyprinus carpio* and *Ophicephalus striatus*) in duck-manured ponds during the second 90-day test period (January-March 1979). Figures represent means of triplicate ponds.

Ducks/ha	Species	Stocking fish/ha	Individual mean weight (g) Initial	Final	Gain (g)	Average daily gain (g)/fish	Recovery %	Yield (kg/ha) in 90 d
750	*S. niloticus*	8,500	2.0	121.6	119.6	1.3	90.5	920.3
	C. carpio	1,400	54.5	378.2	323.7	3.6	75.0	368.8
	O. striatus	100	33.7	276.7	243.0	2.7	46.7	15.2
	Total	10,000				7.6		1,304.3
750	*S. niloticus*	17,000	2.0	97.6	95.6	1.1	81.8	1,323.3
	C. carpio	2,800	51.0	213.0	162.0	1.8	61.6	345.8
	O. striatus	200	34.7	232.7	198.0	2.2	37.5	20.5
	Total	20,000				5.1		1,689.6
1,250	*S. niloticus*	8,500	2.0	106.9	104.9	1.2	88.8	824.5
	C. carpio	1,400	56.7	299.7	243.0	2.7	66.7	323.8
	O. striatus	100	39.0	300.0	261.0	2.9	8.3	15.0
	Total	10,000				6.8		1,163.3
1,250	*S. niloticus*	17,000	2.0	90.4	88.4	1.0	79.3	1,174.5
	C. carpio	2,800	48.3	273.3	225.0	2.5	63.7	402.0
	O. striatus	200	40.0	211.0	171.0	1.9	50.0	21.5
	Total	20,000				5.4		1,598.0

feeding fish, like the silver carp (*Hypophthalmichthys molitrix*), to control phytoplankton populations (especially in the duck ponds). The addition of such fish to the system can be expected to increase net yield and reduce oxygen stress. Since silver carp is not marketable in the Philippines, milkfish (*Chanos chanos*) will be added to the system in future tests.

Experiments will also be conducted to test the feasibility of replacing most of the common carp with *Sarotherodon aureus* which is mostly a bottom feeder and would fetch a higher price than carp.

D. FISH GROWING PERIOD

Stocking and draining of fish ponds every 90 d is not practical. It wastes labor, growing time and water. Furthermore, animal wastes cannot be turned into the pond during drainage and harvest operations. The fish growing period should at least match the animal rearing period. Optimally, ponds should be drained only once per year.

E. ENVIRONMENTAL IMPACT

Future tests in this project will include measurements of BOD_5 and nitrogen and phosphorous concentrations in water drained from fish ponds in order to assess the pollution hazard from this effluent. Consideration will also be given to setting aside a small pond area as a receptacle for animal manure during harvest/restocking operations. Such a pond could be stocked with air-breathing fish, such as *Clarias* spp. or *Ophicephalus striatus.*

References

Buck, D.H., R.J. Baur and C.R. Rose. 1978. Utilization of swine manure in a polyculture of Asian and North American fishes. Trans. Amer. Fish. Soc. 107 (1): 216-222.

Moav, R., G. Wohlfarth, G.L. Schroeder, G. Hulata and H. Barash. 1977. Intensive polyculture of fish in freshwater ponds. 1. Substitution of expensive feeds by liquid manure. Aquaculture 10: 25-43.

PCARR. 1976. The Philippines recommends for pork production. Philippine Council for Agriculture and Resources Research (PCARR), Los Baños, College, Laguna, Philippines. 196 p.

PCARR. 1977. The Philippines recommends for duck raising. Philippine Council for Agriculture and Resources Research (PCARR), Los Baños, College, Laguna, Philippines. 44 p.

Rappaport, U. and S. Sarig. 1978. The result of manuring on intensive growth fish farming at the Ginosar Station ponds in 1977. Bamidgeh 30 (2): 27-36.

Sevilleja, R.C. and E.W. McCoy. 1979. Fish Marketing in Central Luzon, Philippines. Research and Development Series No. 21. International Center for Aquaculture, Auburn, Alabama. 23 p.

Wohlfarth, G. 1978. Utilization of manure in fish farming, p. 78-95. *In* C.M.R. Pastakia (ed.). Proceedings of an international conference on fish farming and wastes. Society of Chemical Industry, London.

Woynarovich, E. 1979. The feasibility of combining animal husbandry with fish farming, with special reference to duck and pig production, p. 203-208. *In* T.V.R. Pillay and W. A. Dill (eds.) Advances in aquaculture. Fishing News Books Ltd., Farnham, Surrey, England.

Integrated Agriculture-Aquaculture Studies in Taiwan

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Abstract

In Taiwan the most important integrated farming systems are duck-fish and pig-fish. Rice-fish culture has been discontinued apart from some small-scale rotational fish culture in rice fields. For duck-fish farming, 2,000 to 4,000 mule ducks (mallard x muscovy)/ha are used. The annual gross profit from four duck production cycles of 3,200 ducks is NT$256,000. The annual gross profit from fish polyculture (common and Chinese carps, eels, mullet, tilapias, etc.) from a 1-ha farm raising 2,200 ducks is NT$140,050 (total harvested weight of fish, 5,671 kg). Pig-fish farming was mainly all male tilapia hybrids. Waste-loading can be as high as 250 pigs/ha which produces annually 4,200 kg/ha of tilapias and 150 kg of *Lateolabrax japonicus* which is used as a controlling predator. The respective values of these fish crops are NT$193,200 and NT$18,000. An integrated farm keeping 210 pigs makes a gross profit of NT$253,000 twice a year from pig sales.

Freshwater fish farming has an important place in the inland fisheries of Taiwan. Its expansion is limited only by competition for acreage with plant crops, chiefly rice. Except for eel *(Anguilla japonica)*, soft-shell turtle *(Trionyx sinensis)*, and lately the giant freshwater prawn *(Macrobrachium rosenbergii)*, polyculture is generally the practice. The species cultured are generally the grass carp *(Ctenopharyngodon idella)*, silver carp *(Hypophthalmichthys molitrix)*, big head *(Aristichthys nobilis)*, mud carp *(Cirrhina molitorella)*, common carp *(Cyprinus carpio)*, and mullet *(Mugil cephalus)* in various stocking ratios and small number of snakehead *(Ophicephalus maculatus)* or sea perch *(Lateolabrax japonicus)* to prey on small wild fish.

With the introduction of the Nile tilapia *Sarotherodon niloticus* in 1966, however, and the subsequent development of the hybrid of male *S. niloticus* × female *S. mossambicus* in 1969, the picture has gradually changed. Now almost all the freshwater polyculture farms in the southern one-third of the island have tilapias as their main crop. A considerable number of these farms raise pigs or ducks with fish.

According to the Taiwan Fisheries Bureau, out of a total freshwater fish pond area of 13,640 ha in 1977, 11,393 ha were used for polyculture and about 5,000 ha for integrated agriculture-aquaculture. Most of these integrated fish farms were converted from rice paddies, including some high-yielding paddies, in spite of a government regulation forbidding their conversion. The popularity of integrated farming is doubtless due to its lucrativeness, which is demonstrated in this paper.

Pond Construction

Ponds are usually converted from low-yielding farm land using bulldozers to excavate and level the bottom. Generally 50 to 90 cm of earth is removed and used for construction of the dikes. The height of the dike is about 3 m, measured from the pond bottom, with a slope of 1 in 1 (1 in 0.5 if lined with bricks). A land area of 500 m^2 is reserved for the construction of the duck house or pigsty. This leaves about 0.65 ha of water area for each ha of original land. The total cost of pond construction in Taiwan is NT$*120,000 to 150,000/ha of land (including bulldozing, brick lining of dikes and sluice gate construction).

Duck-Fish Farming

The duck house is built on a suitable spot alongside the fish pond. In the past, the construction materials consisted mainly of bamboos with straw (roofing). Now, cement poles, wooden beams and cement roofing are used. The cement or brick floor is covered with wooden gratings so that the ducks will be isolated from their excreta.

The ducks raised are either the meat-producing mule duck or the egg-producing native duck. The mule duck is a cross of the native mallard and the drake of the muscovy. It is incapable of reproduction and is therefore raised for meat. The native duck (mallard) is raised for eggs.

A duck house of 40 m^2 in floor area will accommodate 450 mule ducks or 250 egg producing ducks. Its cost of construction is about NT$18,400.

The number of ducks that can be kept in a pond of 1 ha varies from 2,000 to 4,000 depending on the depth of water and the abundance of water supply. The newly purchased ducklings generally reach the marketable size of 2.5 kg in 65 to 70 d. Soybean meal, peanut meal, rice bran, corn meal, sweet potato chips, etc. were used formerly as feeds, but pelleted feeds are now almost exclusively used. The prevailing brand gives a feed conversion ratio of 3.5:1 and has the advantages of cleanliness and saving labor.

According to a recent survey, each mule duck raised will yield a profit of about NT$20. The annual profit from four crops of 3,200 ducks each should therefore total NT$256,000.

The egg laying native ducks begin producing eggs in 120 to 150 d when they reach 1.2 to 1.5 kg in weight. For 2 yr, each duck produces about 250 eggs per year, after which it is usually discarded (sold at very low price). The feeds used are about the same as for mule ducks. The number of egg-laying ducks on a 1-ha farm is about 1,500, which will net the farmer NT$90,700 in profit.

For duck-fish and pig-fish farming, the species and number of fish stocked are more or less the same (e.g., Table 1).

Generally, no supplemental feeds are given except in the 2 wk preceding harvest. In the example shown in Table 1, the fish harvest after 1 yr totalled 5,671 kg, sold for NT$200,040. After deducting NT$39,990 for fish fingerling purchase and NT20,000 for feed purchase, the gross profit from fish amounted to NT$140,050.

Pig-Fish Farming

Pig-fish farming is as popular as duck-fish farming in Taiwan, but is beyond the means of small farmers as it requires larger capitalization. The pigsties are of modern construction and the feeds are almost exclusively formulated feeds produced by feed mills.

The number of pigs per hectare generally varies from 150 to 300 of fish pond depending on the depth of the pond water and the abundance of water supply. Pigs are grown up to 90 kg finished weight. With less than 100 pigs per hectare supplemental fish feeds are required whereas at above 300 pigs per hectare, the pond water becomes overeutrophic unless the water supply is abundant.

The price of pork fluctuates a great deal in Taiwan. At the current price of about NT$45/kg for pigs and production costs (mainly purchase of piglets and feeds) estimated at NT$33/kg, an integrated farm keeping 210 pigs sold at 100 kg each stands to earn NT$253,000 gross profit from pig husbandry twice every year.

The stocking and harvesting of fish in a 1-ha pond receiving wastes from 210 pigs are shown in Table 2. The tilapias, hybrids of *S. mossambicus* females and *S. niloticus* males, comprise almost two-thirds of the total harvest and are sold at NT$164,160, more than half the total value of the fish harvest (NT$276,291).

Some farmers stock only male tilapia in their ponds. The fish are harvested at 270 to 500 g and fetch a premium price. Hybrid fingerlings obtained by crossing male *S. aureus* and female *S. niloticus* are not usually 100% male and must be further sexed manually. The experienced sexing experts are paid NT$500 for a

*US$1.00 = NT$36.

Table 1. Stocking and harvesting of fish in a 1-ha duck-fish farm raising 2,200 mule ducks in Taiwan.

Species	Size	Stocking Number	Time	Number	Harvesting Weight (kg)	Time
Grass carp	15 cm	300	Feb.-Mar.	180	324	Oct.-Dec.
Big head	13 cm	300	Feb.-Mar.	255	382	Oct.-Dec.
Silver carp	13 cm	1,200	Feb.-Mar.	960	864	Oct.-Dec.
Mullet	2.5-4.0 cm	3,000	Feb.-Mar.	1,650	495	Oct.-Dec.
Sea perch	5 cm	200	Apr.-June	160	144	July-Dec.
Common carp	4 cm	1,000	Feb.-Mar.	900	540	Oct.-Dec.
Eel	34/kg	40	Feb.-Mar.	32	5	Dec.
Walking catfish *(Clarias batrachus)*	12/kg	72	Feb.-Mar.	56	17	Dec.
Tilapia (mainly *S. niloticus* male × *S. mossambicus* female hybrids)	600/kg	4,740	Mar.-Apr.	10,150	2,900	June-Dec.

Table 2. Stocking and harvesting of fish in a 1-ha pond in Taiwan receiving wastes from 210 pigs.

Species	Size	Stocking Number	Time	Number	Harvesting Weight (kg)	Time
Grass carp	13 cm	300	Feb.-Mar.	210	340	Sept.-Dec.
Big head	13 cm	400	Feb.-Mar.	320	576	Sept.-Dec.
Silver carp	8 cm	1,500	Feb.-Mar.	1,275	765	Sept.-Dec.
Mullet	4 to 5 cm	1,500	Feb.-Mar.	1,050	315	Nov.-Dec.
Common carp	4 cm	1,500	Feb.-Mar.	1,275	612	Sept.-Dec.
Sea perch	5 cm	300	Mar.-June	225	203	July-Dec.
Tilapia	8 cm	30,000	Mar.-Apr.	22,800	4,560	June-Dec.

day's work but their accuracy is only about 90% and sea perch or snakehead have to be introduced to control the resulting reproduction. When 20,000 5 to 12-cm such hybrids are stocked in a 1-ha pond receiving wastes from 250 pigs, about 4,200 kg of tilapia worth NT193,200 and 150 kg of sea perch worth NT$18,000 are produced each year with no supplemental feeding.

Fish Farming in Irrigation Ponds

Fish farming in irrigation ponds is widely practiced in Taoyuan County (northern Taiwan), where about one-half of the 4,000 ha of irrigation ponds are used for polyculture of Chinese carps. The turnover of the pond water is large and the production is consequently low. Recently, however, the application of fertilizers, chiefly superphosphate, has increased the yield per hectare by 50 to 80% when phytoplankton feeders (silver carp) form the dominant species.

Fish Farming in Rice Paddies

The culture of tilapias in rice fields was once promoted by the government but has been gradually discontinued due to prevalent use of pesticides and the low price that the small-size tilapias now bring. Rotation of fish and rice crops is still, however, practiced in some areas.

Integrated Agriculture-Aquaculture Farming Studies in Thailand with a Case Study on Chicken-Fish Farming

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Abstract

Integrated farming systems in Thailand are summarized on a province-by-province basis and their present and future importance are assessed. The advantages of integrated farming are clear from data which indicate that a 6-rai (9,600 m^2) farm integrating crops, livestock production and fish culture can make an annual profit of 24,770 baht, compared to 6,500 baht from rice culture alone. A detailed case study on a 15-rai chicken-fish farm in Chachoengsao Province lists the annual profits as 89,694 baht from chicken eggs and 13,966 baht from fish *(Sarotherodon niloticus)* sales. The respective returns are 36% and 188% of total variable costs.

Background

Agriculture provides the main source of Thailand's food supply and the livelihood of about 70% of her population. Agricultural products are also a major export yielding a considerable amount of foreign exchange: about 70% of the total export income in 1976. There are, however, many bottlenecks which hamper the development of agriculture. Among them are the high population growth rate of 2.5% per annum and the decrease in agricultural landholdings per household, from an average of 16 rai* in 1963 to 14.7 rai in 1975. A further reduction to 11.6 rai is expected by 1985. Thai agriculture is largely subsistence farming which uses traditional methods and, consequently, the production per unit area is very low. Moreover, most farmers are specialists which creates problems of underutilization of agricultural resources.

The solution to these problems requires a multidisciplinary approach by the government to encourage farmers to use modern technology, high yield crop varieties and more fertilizers and pesticides. Education and training of the farmers in farm management is also required so that they will utilize agricultural resources more efficiently.

There are many possible approaches to increasing agricultural production and income, including diversification and integrated farming. The idea of integrated farming is not new. It has been in existence in Thailand for centuries and can be seen in most farm households in the rural areas which combine animal and fowl husbandry with crop raising. These activities are mainly for home consumption and gifts within the community, but not for sale as an additional source of income. They could, however, become an additional source of income if given adequate attention. Integrated agriculture-aquaculture operations can include combinations of fish farming with animal and fowl husbandry or with crop raising.

*1 rai = 1600 m^2

Integrated Agriculture-Aquaculture Practices in Thailand

There is unfortunately no clear record of the origin of integrated agriculture-aquaculture in the country. The first report in 1962 on integrated rice-fish farming revealed that this was practiced very successfully in both Samut Prakarn and in Bangkok Provinces in 1957. The Fisheries Economic Section, Department of Fisheries, carried out a preliminary survey on integrated agriculture-aquaculture practices in 1978-79; it showed that these practices were concentrated in the Central Plain, where the land is fertile and has good irrigation systems. The integrated farms here vary greatly in size. Elsewhere, there were very few examples and these were restricted to the vicinity of natural or manmade lakes.

The types of integrated farms in the various provinces (Figure 1) can be summarized as follows:

1. PATHUMTHANI PROVINCE

The integrated farms in this province are mainly animal-fish and fowl-fish farms. The most popular fish species used are catfish (*Clarias batrachus, C. macrocephalus, and Pangasius aequilabialis*). Aquaculture can provide the main source of income or be secondary in importance to livestock sales.

2. SUPHANBURI PROVINCE

The integrated farms in this province are mainly animal-fish and fowl-fish farms. The most popular fish species are catfish, snakehead (*Ophicephalus striatus*), nile tilapia (*Sarotherodon niloticus*), carp (*Puntius gonionotus*), chinese carps and prawns. The average size of the farms is relatively larger than in other provinces. There are also some farms which grow fruit, such as bananas and mangoes. Aquaculture, however, is the main source of income. Livestock and fruit growing are secondary in importance.

3. NAKHONPATHOM PROVINCE

The integrated farms in this province are mainly animal-fish farms, fowl-fish farms, and orchard-fish farms. The orchards grow mangoes, oranges and bananas. The fish are reared mainly in ditches, the most popular species being snakehead, catfish and nile tilapia. Aquaculture can be either the major or a secondary source of income.

4. CHACHOENGSAO PROVINCE

The integrated farms in this province are mainly the fowl-fish farms and there are very few animal-fish or livestock-crop-fish farms. The most popular fish species are nile tilapia and catfish which are sold mainly as fish seed. Aquaculture is the major source of income.

5. SAMUT PRAKARN PROVINCE

Integrated rice-fish farming was formerly widespread in this province and fish were kept in the rice fields both during the rice-growing season and after harvest. The introduction of pesticides in rice cultivation gradually lessened this practice, as these are highly toxic to the fish. At present, only sepat-siam *(Trichogaster pectoralis)* rearing in the rice field remains.

6. SAMUT SONGKHRAM PROVINCE

The integrated farms in this province are mainly combinations of coconut plantations and fish rearing in ditches. The most popular fish species are snakehead, carp and nile tilapia. Aquaculture is a secondary source of income.

7. SAMUT SAKHON PROVINCE

The integrated farms in this province are mainly combinations of coconut plantations and fish rearing in ditches. There are very few integrated animal-fish farms in this area: far fewer than other aquacultural practices such as fish culture in paddy fields and shrimp farms. Aquaculture here consists mainly of shrimp farms. The most popular fish species are common carp (*Cyprinus carpio*), nile tilapia and carp. Aquaculture is a secondary source of income.

The Importance of Integrated Farming Systems

Although integrated farming in Thailand has been in existence for centuries, there have been very few in-depth studies on its development and economic importance. The adoption of new technology and management techniques to improve farms is also poorly documented and appears to have been very limited. The first report on integrated rice-fish farming in 1962 indicated that such activities were possible and could yield high returns. For example, common carp farming for 6 mo after the rice harvest could produce 22 to 53 kg/rai, and 42 to 51 kg/rai during the rice growing season, with a rice yield about 31% higher than normal. The most successful case was that of a farmer in Chachoengsao Province, cultivating 12 rai for which the production records were: 1959,

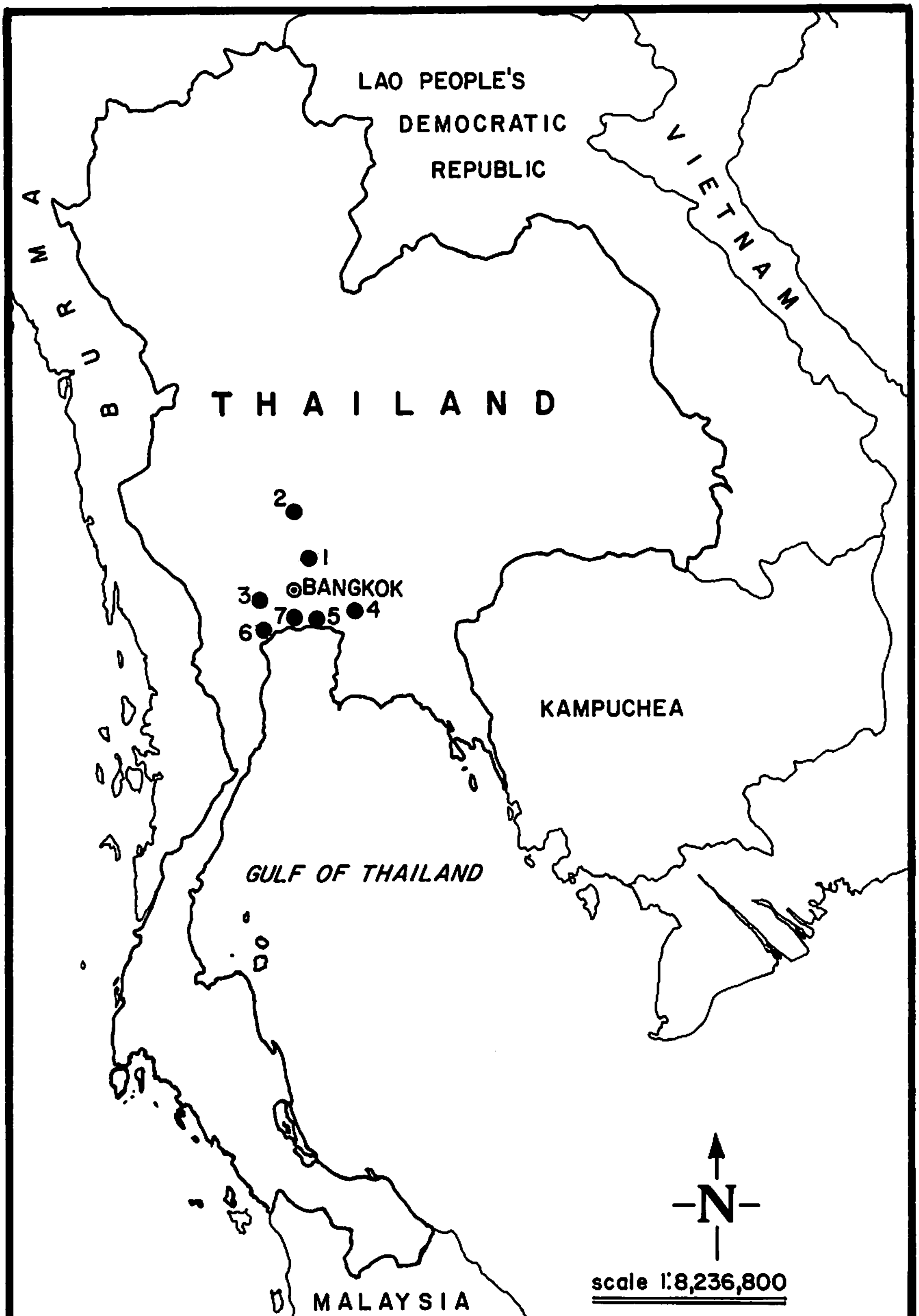

Figure 1. Central plain Provinces of Thailand, where integrated farming is practiced: 1. Pathumthani, 2. Suphanburi, 3. Nakhonpathom, 4. Chachoengsao, 5. Samut Prakarn, 6. Samut Songkhram and 7. Samut Sakhon.

26.6 bin*/rai (rice alone); 1960, 20.8 bin/rai (rice alone); 1961, 45.0 bin/rai (rice) plus 89 kg/rai (fish). These figures show that integrated rice-fish farming can yield much higher returns to farmers.

There was, however, no followup study until 1968-1969 when the Agroeconomic Unit, Central Office, Chainat Province, carried out a systematic study on income and expenditure in farms of various sizes (6, 15 and 25 rai) in the Chaophrya Irrigation Project. The main study involved the selection of representative farms and the injection of slightly improved management techniques and some basic new technology which the average farmer could absorb and follow. This revealed that farms of the sizes studied could yield annual profits of 8,522; 18,679, and 26,212 baht,** respectively, profit being defined in this paper as net return over variable costs. Moreover, a farm of 6 rai with all activities reorganized as an integrated farm (e.g., crops, vegetables, rice, fish ponds, livestock, etc.) would yield an annual profit of up to 24,770 baht compared with only 6,500 baht from rice cultivation alone. Thus, compared to the slight improvements mentioned which give a profit of 31% higher than normal, a reorganized integrated farm shows a 3-fold increase. This study shows clearly that increases in farm income are possible without corresponding increases in the amount of agricultural land. To achieve this, however, farm management techniques and modern technology must combine to fully utilize limited natural resources.

The Thai government has given high priority to agricultural development, particularly in the Fourth National Economic and Social Development Plan (1977-81). Two of its main targets are to reduce income disparities and to increase agricultural output. To reduce income disparities, measures will be taken to redistribute income and to raise the living standard of farmers. To achieve this, it will be necessary to promote agricultural diversification and to increase output in areas with high development potential, as well as in depressed areas.

Disposal and Marketing of Products

Most of the farms are relatively small scale, and produce only small quantities of fish, animals, fowl and other agricultural products mainly for farm-gate sales or low volume sales at local markets. The buyers at the farm-gate are usually local merchants from the province. The farm-gate prices fluctuate in relation to the market prices, but are usually below current market prices by an amount which depends on the quantity of produce, its seasonal availability, and the existing arrangements between farmers and buyers. The larger farms which produce high quantities seem to have a higher bargaining power, which is reflected in the higher farm price that they receive. Large farms, therefore, have less marketing problems than smaller ones. Farm produce is usually paid for after a set period following delivery.

Problems in Integrated Systems

Most of the current integrated farms in Thailand are operated in the traditional way—without proper planning, modern technology or modern farm management techniques—and rely on personal experience. Marketing is therefore a recurrent problem except in very good years. Fish diseases constitute a further major problem which the farmers cannot solve by themselves since they have inadequate experience and knowledge, and such knowledge is not as readily accessible as with other farm animals where feed manufacturers or veterinary supply companies offer services to assist farmers in many cases. A further problem for farmers is the shortage of credit and working capital, which forces them to contract their produce sales to middlemen, usually at unfavorable prices.

Future Trends

Fish is relatively cheaper and higher in protein content than other animal protein sources. To increase food supply to cope with the high rate of population increase requires much more than an increase in agricultural land. Land is a limited resource and if more land is used in agriculture, then forestry will soon be reduced to a degree which will be harmful to the environment. Also, the cost of production could rise. Therefore, a method is needed to produce more food from existing agricultural land, and integrated farming offers a possible solution. Integrated farming will probably play a very important role in national development, as well as in the national economy.

Research Needs

Although integrated farming has now proved to be highly profitable, its practice remains very limited in scale. This is because the relevant scientific and technological information on diversification of methods is unavailable to farmers. To remedy this, there must be a bridge between the information sources and the farmers, perhaps through extension services. A multidisciplinary approach is needed, including technological, economic, social and political aspects which are interrelated. Any approach must, however, be relevant to national,

*1 bin = 10 kg.

**US$1.00 = Baht 20.00.

economic, social and environmental conditions and to the farmers' needs. A systematic study on a pilot farm is recommended, including all the aspects mentioned above.

A CASE STUDY ON CHICKEN-FISH FARMING

Introduction

The farm is located about 3 km from the Chonburi-Chachoengsao Highway at village number 8, Thambon Bang Pra, Amphur Muang, Chachoengsao Province. The farm owner, Mr. Boonlerng Daroonnetr, age 48, is of primary education level (Grade 4). His previous occupation was rice farming, up to 1976 when he changed to chicken-fish farming which remains his present occupation.

FARM RESOURCES

1. Land

The farm is a single piece of land of 15 rai and is subdivided as follows: residential area, 2 rai; two chicken raising sheds and one nursery shed, total area 3 rai; and four fish ponds, total area 10 rai.

2. Labor

There are four household members, three males and one female, all of whom contribute to farming activities. There are no outside employees, except in fish harvesting and fish pond maintenance.

3. Capital

Part of the working capital is from the farmer's personal savings and the remainder is borrowed from a commercial bank and the government bank at interest rates of 15% and 12% per annum, respectively.

The present value of the farm's assets is 504,273 baht: the land is valued at 300,000 baht; the house at 150,000 baht, and the two chicken raising sheds at 39,556 baht (Table 1).

Table 1. Estimated value of the capital assets of an integrated chicken-fish farm in Chachoengsao Province, Thailand in 1978 (1 rai = 1600 m^2; US$ 1.00 = Baht 20.00).

Item	Amount	Present value (baht)
1. Land	15 rai	300,000
2. House	1 Unit	150,000
3. Chicken nursery shed	1 Unit	614
4. Chicken raising sheds	2 Units	39,556
5. Pump	1 Unit	2,000
6. Pump-pipe	1 Unit	800
7. Food mixer	1 Unit	3,333
8. Waterwheel-engine	1 Unit	2,000
9. Waterwheel	1 Unit	1,470
10. Boat	1 Unit	4,500
Total		504,273

FARM OPERATIONS

The farm is classified as a small-scale farm and the operations are organized on a family basis, in which the head of the household is the decision maker. There are two main operations:

1. Chicken Farming

The two raising sheds are built of wood with galvanized corrugated iron roofing and earth floors. Shed number 1 can hold 1,100 chickens and shed number 2 about 400 chickens. The nursery shed is used for rearing the young chickens for up to 4 mo, after which they are moved to the raising sheds. The chickens start to lay eggs after 5 mo and continue up to an average age of 22 mo, when they are replaced by new stock. Each chicken lays an average of 21 eggs per month. The chickens are fed twice daily (morning and afternoon) on commercial "instant" chicken feed, plus some additional food such as broken rice and maize. The eggs are collected in the afternoon. The young chickens cost 10 baht each and are bought locally.

2. Fish Rearing

There are two fish ponds of 2.5 rai each for growing nile tilapia (a further two ponds of similar size account for the 10-rai total pond area but are not yet in use). Each pond holds about 100 kg of broodstock. Two months after establishing the broodstock, the farmer can begin to harvest young fish, with regular harvesting every second month thereafter. The fish are fed rice bran and chicken manure.

DISPOSAL AND MARKETING OF PRODUCTS

The farmer's credit arrangement for chicken feed requires him to sell eggs to the local feed supplier. The supplier delivers feed every week and picks up eggs in return. Any outstanding balance is paid in cash. Surplus eggs are sold to other dealers. The price received from the suppliers of feed on credit is relatively lower than from other dealers, and is also lower than the current market price.

The sale of nile tilapia seed starts 2 mo after the establishment of the broodstock. Marketing is handled by the farmer's relatives, who are responsible for all marketing costs and packaging. The profits are equally divided between them and the farmer.

PRODUCTION COSTS AND PROFITS

In estimating the production costs and profits, it is assumed that all chickens lay 21 eggs per month. The variable costs quoted are for 1978. Table 2 shows that the total variable costs for chicken raising are 238,386 baht, i.e., 158.92 baht/head. The largest component is the cost of feed (95.34% of the total). The cost of young chickens represents only 3.43% of the total. The total returns from egg sales are 325,080 baht or 216.72 baht per head (assuming 0.86 baht per egg). The profit is therefore 86,694 baht or 57.80 baht per head.

From Table 3, the total variable costs for fish production are 7,304 baht or 3.42 baht/kg. The largest component is again feed costs (43.86% of the total). The cost of fish for initial stocking represents 27.48% of the total.

The total return from fish sales is 21,000 baht per annum and the profit is 13,696 baht or 6.42 baht/kg.

Table 2. Variable costs and profit from egg sales for an integrated chicken-fish farm in Chachoengsao Province, Thailand, raising 1,500 chickens in 1978 (US$ 1.00 = Baht 20.00).

Item	Baht	Baht/head	Percentage
1. Young chickens bought in	8,175	5.45	3.43
2. Feed	227,287	151.52	95.34
3. Electricity	324	0.22	0.14
4. Maintenance	500	0.33	0.21
5. Labor (household)	2,100	1.40	0.88
Total	238,386	158.92	100
Return from egg sales	325,080	216.72	
Profit	86,694	57.80	

The profitability of the chicken and fish operations represent 36% and 188% of the respective total variable costs. The total farm profit is 100,390 baht per annum.

Problems and Recommendations

This study shows that integrated chicken-fish farming can yield a very high profit. A comparison of the variable costs of production of an egg (0.63 baht), its farm-gate sales price (0.86 baht), and its retail market price (1.25 baht) shows that the farmer's profit per egg is 36.0%, whereas that of the middleman is 45%. This is considered to be an equitable arrangement.

Table 3. Variable costs and profit from fish sales for an integrated chicken-fish farm in Chachoengsao Province, Thailand, using fish ponds of area 5 rai in 1978 (1 rai = 1,600 m^2; US$ 1.00 = Baht 20.00).

Item	Baht	Baht/kg	Percentage
1. Seed fish bought in	2,000	0.94	27.48
2. Feed	3,000	1.50	43.86
3. Household labor costs	532	0.25	7.31
4. Employees	520	0.24	7.02
5. Fuel	452	0.21	6.14
6. Maintenance	600	0.28	8.19
Total	7,304	3.42	100
Returns from fish sales	21,000	9.84	
Profit	13,696	6.42	

The turnover and total profit are both very high for such a small farm, and should enable the farmer to make adequate savings for his working capital, considering his cost and standard of living. An interview with the farmer revealed, however, a continuing shortage of working capital and the consequential unfavorable credit arrangements with feed suppliers.

To improve the farmer's living standard, technical assistance is more important than financial assistance. Technical assistance should include instruction in modern farm management techniques and the efficient utilization of farm resources, such as land, labor and capital. This can be provided through existing extension and training services. The reasons for recommending technical rather than financial assistance are: first, the high turnover of the farm which, given proper management, could function without additional finance, and second, the high profit of 100,000 baht per annum which is much higher than the national per capita income. The farmer would tend to use additional finance for buying consumer goods rather than for improving farm production.

The percentage profit from fish culture is much higher than from chicken farming and requires very little investment capital. The farmer plans to expand this activity in the near future and it is sound policy. There are, however, several factors to consider when expanding fish production, such as the extent of the market, demand and supply, etc. Nile tilapia is an ideal fish which is easy to culture and reproduces naturally in the ponds. If the farmer plans to produce seed fish only, then the extent of markets for various fish species must be carefully considered. The market for tilapia fry may fall as farmers can easily raise their own.

Bibliography

The following are publications and university theses relevant to integrated farming systems in Thailand.

Amatyakul Chertchai. 1968. Rearing of fish in the rice field. Thai Fish. Gaz. 21(1): 21-28. (In Thai).

Chao On. 1967. The necessity of farm management technique to Thai farmers in the future. Agro-Econ. News (Thailand) 12(127): 8-15 (In Thai).

Fish farming in Chachoengsao province. 1961. Thai Fish. Gaz. 14(2): 91-94. (In Thai).

Indrambarya Boon. 1962. Rice field fish culture in the Lower Chiengrak Klong Dan irrigation project area. Thai Fish. Gaz. 15(3): 215-234. (In Thai).

Kittisarn Chamnian. 1964. Combined rearing of *Clarias* and poultry. Thai Fish. Gaz. 17(4): 389-394. (In Thai).

Meechoosab Pranee. 1963. Comparison on cost and rearing of rice farming and fish farming in rice field in Bankapi District, Bangkok. Bachelors degree thesis. Kasetsart University, Bangkok, Thailand. 72 p. (In Thai).

Petchareon Jit. 1968. Rice field fish culture. Fish culture guide book. Department of Fisheries, Bangkok, Thailand. 16 p. (In Thai).

Prapripong Sakhon. 1967. Study on the consequences of integrated farming promotion in Chachoengsao province. Bachelors degree thesis. Kasetsart University, Bangkok, Thailand. 61 p. (In Thai).

Rodmek Krengsak. 1969. Study on the livelihood of rice fish culture. Agro-Econ. News (Thailand) 17(151): 8-13. (In Thai).

Somboonwong Boonlue. 1962. Experiments on rice field fish culture. Thai Fis. Gaz. 15(4): 395-402. (In Thai).

Sophon Teib. 1957. Experiments on rearing Tilapia in rice field with various degree of fertilizing. Bachelors degree thesis. Kasetsart University, Bangkok, Thailand. 46 p. (In Thai).

Thailand. Ministry of Agriculture and Cooperatives. Agro-Economic Division. 1976. Thai-Agro Statistics Year Book, 1975/76. Contribution No. 54. Bangkok, Thailand. 215 p.

Thailand. Ministry of Agriculture and Cooperatives. Department of Agricultural Extension. 1977. Farmers of 6 rai. Bangkok, Thailand. 17 p. (In Thai).

Thailand. National Economic and Social Development Board. n.d. The fourth national economic and social development plan (1977-1981). Bangkok, Thailand. 365 p.

RESEARCH AND INFORMATION REQUIREMENTS

Research and Information Requirements for Integrated Agriculture-Aquaculture Farming Systems

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Abstract

The major factors which affect the performance of integrated farming systems are identified as energy, materials, space, time and information diversity. In rice-fish farming, the requirements of the rice crop, pesticide use and land/water conflicts all require further study. In animal-fish farming, work is needed on species combination and production systems with particular attention to marketing and to public and animal health. The socioeconomic aspects of integrated farming systems are complex, and the following needs are apparent: increased dissemination of information; detailed socioeconomic analyses; evaluation of different technologies and the impacts of technology transfer; economic, marketing and distribution studies and clear government policies and programs.

The review papers presented at this conference have collectively identified five major factors affecting the performance of the various integrated farming systems:

Energy or its monetary equivalent in terms of subsidy or technological inputs;

Materials, especially water, essential nutrients and pesticides;

Space especially where competition is intense for alternative uses (e.g., cash crops);

Time especially in the rice field systems dominated by high yielding varieties of rice; and

Information diversity especially in interlinkages, management and sociocultural inputs.

These factors are the same that govern any resource system, except that even the simplest integrated farming system comprises a complex set of resource systems. There is a lack of understanding of the role of these critical factors in any single integrated farming system, let alone a comparative evaluation of integrated farming systems. There is therefore a need for increased and comparative understanding of integrated farming systems in terms of these critical factors. Table 1 illustrates the major impacts of the different systems on one and other.

The general discussion has further highlighted three main areas in which research and information issues are important and require follow-up action: rice-fish farming, animal-fish farming and socioeconomic considerations. The specific issues involved and their solutions are summarized in Tables 2, 3 and 4, respectively, and are detailed below.

Rice-Fish Farming

THE FARMING SYSTEM

Since rice production is more important than fish production, there has been considerable emphasis on developing rice varieties with a short maturation period, which demand shallow water, intensive agrochemical (both fertilizers and pesticides) regimes, and a variety of intensive and extensive farming systems. To develop integrated systems the requirements are:

- to refine the rice farming system to incorporate fish;

- to develop a range of fish species for rice-fish farming since there is no universally-accepted species, and there is a wide variety of rice farming systems;
- to increase marginal profit and income by the incorporation of fish, especially for the small-holder;
- to use extended cost-benefit analysis to evaluate different farming systems;
- to enhance the marketing of rice field fish with particular regard to seasonality.

PESTICIDES

Pesticide residues, especially the chlorinated hydrocarbons which persist longer than organophosphates and carbamates, can cause toxicity problems for fish and aquatic food chains, as well as human health hazards. Rice-fish culture therefore depends on the type and timing of pesticide applications in rice culture operations. Note the following points:

- rootzone and soil methods of application should be used.
- development of rotational farming of fish with rice
- standardized screening of pesticides, using sensitive biological indicators from natural ecosystems, should be undertaken.

LAND AND WATER CONFLICTS

Land and water use conflicts occur, especially in terms of water requirements for fish, water retention for fish growth, and the relative suitability of land for agriculture or aquaculture. Here, the needs are:

- to develop special nursery and/or fattening ponds;
- to develop efficient and planned patterns of land and water uses;
- to investigate the resource needs of various designs of integrated farming systems.

MISCELLANEOUS

Several other issues raised have not been fully discussed, including:

- fertilizer availability and cost, resulting in the move from inorganic to organic fertilizers (e.g., manure and wastewaters) and attendant public health aspects;
- predation pressures;
- the substitution of rice by other macrophytic crops, dependent on cost-benefit analysis and marketing infrastructure;
- a reliable supply of fish for stocking, close to rice farms;
- the scaling up of operations from pilot and experimental farms;
- socioeconomics;
- the importance of an information base.

Animal-Fish Farming

LAND AND WATER USE CONFLICTS

Conflicts in land and water use are increasing in pace with urban-industrial competitive demands for water and

Table 1. Impacts in integrated farming systems.

Impacts of on	Fish culture	Food and cash crops	Animal husbandry	Plantation/forestry
Fish Culture	–	Spatial competition Increased water table	Animal feeds Pathogen transfer	Spatial competition
Food and Cash Crops	Organic wastes/fertilizers Pesticide residues	–	Animal feeds Grazing on fallow	Nutrient enrichment Pesticide residues
Animal Husbandry	Organic wastes/fertilizers	Organic wastes/fertilizers Work animals Pest control	–	Nutrient enrichment Destruction
Plantation/Forestry	Organic matter Manures/detritus Water balance Pests/predators	Wind protection Organic matter Manures/detritus Water balance Pests/predators	Animal feeds (leaves) Water balance Pests/predators	–

Table 2. Issues and solutions in rice-fish farming systems.

Issues	Solutions
1. Farming system	
Short rice maturation period Shallow water High inputs (chemicals, technology) Extensive/intensive treatments	Refine complex systems in terms of: Fish species & growth Water dynamics Cost-benefit analysis
2. Pesticide residues	
Persistence Toxicity Health hazards	Develop mixed farming in same area vs. rotational cropping Test effects of pesticide on fish Less toxic compounds, rootzone application, isolation facilities for fish Attempt biological control
3. Land-water uses	
Differing water needs Short water retention Land unsuitability for agriculture	Water reuse: Locate nursery/fattening ponds Improve engineering design of paddy field
4. Fertilizer shortage resulting in move from inorganic to organic fertilizers	Determine health hazards of manure use Attempt use of effluents in irrigation
5. Predation pressures including poaching	?
6. Other aquatic macrophyte-fish combinations	?
7. Supply of fish seed stock	?
8. Socioeconomics	?
9. Fish marketing	?

marginal agricultural lands. Deterioration in water quality occurs, because of multiple use and the lack of quality control. There is a need to examine the organization and design of animal-fish farming systems in terms of serial and/or storeyed units to optimize land and water use and minimize the hazards of untreated water.

SPECIES COMBINATIONS

There are no definitive guidelines for the combinations and relative stocking rates of animal (e.g., pigs, poultry, cattle) and fish species with respect to ecological variables, such as spatial separation land and water area, and the BOD of animal wastes. As a consequence, there are important animal, public health and socioeconomic aspects to consider, including overstocking and the possible nonmarketability of produce. There is a need therefore to define suitable combinations and stocking densities of animal and fish species in relation to the following:

- social acceptability and markets;
- availability of animals and fish;
- income and employment generation;
- public and animal health, with regular inspection;
- genetic improvement of animal and fish stocks;
- animal and fish nutrition with attention to feed quality and feeding technology.

ORGANIC WASTES

There are no definitive guidelines as to the application of organic wastes to fish ponds with respect to frequency, methods, quantity and quality (e.g., composting, water content, fresh or stored). As a consequence, the impacts of the application of organic wastes on the food web, trophic structure (autotrophic/heterotrophic) and water quality are not well known. Fish kills and health hazards are probable consequences. Requirements in this are:

- to standardize the application of organic wastes to fish ponds in terms of BOD loading;
- to determine application rates and methods for optimum trophic utilization and fish production;
- to consider pretreatment of organic wastes for reducing health hazards;
- to experiment with lengthening food chains in order to promote ecosystem resilience;
- to examine the use of aquatic macrophytes, especially for wastewater detoxification;
- to consider the relative benefits of terrestrial and aquatic application of organic wastes and the possibility of terrestrial followed by aquatic application;
- to minimize the problems of excessive eutrophication;
- to introduce health inspection of fish.

PRODUCTION SYSTEMS

There are no guidelines for the size, intensity of production and management levels (e.g., corporate or smallholder) of farming units. There is a need to determine the optimum size for units in relation to production efficiency and to biophysical, technological and socioeconomic variables, with a view to public safety, effluent treatment and water quality control.

Socioconomic Considerations

INFORMATION DISSEMINATION

There is a very low level of communication among research scientists and between scientists and farm managers on integrated farming systems, due to the low priority given to this method of food production

Table 3. Issues and solutions in animal-fish farming systems.

Issues	Solutions
1. Land-water use conflicts	
Urban demand for land Water shortage Deteriorating water quality	Design serial and/or storeyed production units to recycle water and organic wastes
2. Species combinations	
Combinations of animal & fish species	Determine optimum species combinations & stocking rates
Unknown stocking rates	Develop animal husbandry methods and new strains for combination with fish
Animal & human health hazards	Conduct regular health inspection
Socioeconomic aspects	Ensure fish stock supply Ensure basic demand for fish
3. Organic wastes	
Quantity & quality Methods & application rates Impacts on food web & water quality Health hazards and fish kills	Determine BOD loading and optimum methods/application rates method to ensure optimum trophic use & fish production Consider pretreatment of wastes Lengthen food chains Use aquatic macrophyte for detoxification Terrestrial vs or prior to aquatic application Investigate composting Introduce health inspection
4. Production systems	
Different size & intensity of production units	Determine optimum production unit size including consideration of effluent treatment for water quality control

and mutual misapprehensions and over-caution about information flow. There is a need to stimulate information dissemination through newsletters, bibliographies, workshops and further meetings.

DETAILED SOCIOECONOMIC ANALYSES

There are no adequate detailed socioeconomic analyses of the existing varieties of integrated farming systems. There is a need to encourage and support such in-depth studies.

IMPACT OF TECHNOLOGY TRANSFER

The infrastructure for transferring integrated farming systems technologies to farmers is at present inadequate. No evaluation has been made of their impact on actual farming situations. Here, the needs are:

- to develop an infrastructure for extension purposes, for packaging technologies and their adaption to specific social and cultural situations, and for standardizing equipment to facilitate the transfer of technology;
- to evaluate the impact of different technologies on actual integrated farming situations.

MARKETING AND DISTRIBUTION

Inadequate understanding of marketing and distribution systems for fish products has resulted in adverse socioeconomic effects. There is a need to develop marketing and distribution systems according to the marketability of the fish species used, consumer preferences and fish processing technologies. Such systems are especially important for integrated farming systems in which technological inputs are high.

EVALUATION OF DIFFERENT TECHNOLOGIES

Inadequate evaluation in the past of the different technologies available for integrated farming systems has meant that considerable socioeconomic risks attend their use and development. There is a need to document the different technologies, whether high or low level, and to evaluate their performance in terms of cost-benefit, input-output, etc.

EXTENSION APPROACHES

Poor liaison between scientists and farmers has hindered the effective extension and demonstration of integrated farming systems. This situation must be rectified not only for effective extension, but also to understand and evaluate the farmer's decision-making process, his entrepreneurial capacity and the role of pilot farms in promoting and improving integrated farming.

Table 4. Socioeconomic issues of integrated farming systems.

1. Information dissemination
2. Detailed socioeconomic analyses
3. Impact of technology transfer
4. Marketing and distribution
5. Evaluation of different technologies
6. Extension approaches
7. Government policies and programs
8. Validation of different systems
9. Economic feasibility of rice-fish culture
10. Constraints to increasing productivity

GOVERNMENT POLICIES AND PROGRAMS

The impacts on integrated farming systems of government policies and programs are poorly understood. Studies are required in various sectors, such as subsidies, credit requirements, security of land tenure, size of production organization (e.g., small-scale, cooperative) and management techniques.

VALIDATION OF DIFFERENT SYSTEMS

Much of the knowledge on integrated farming systems is based on isolated case studies and farms some of which may be atypical. Further studies are needed in diverse farming situation where constraints and opportunities will vary greatly, especially in terms of employment generation, wages, the nutrition and health of the labor force and the value of the produce.

ECONOMIC FEASIBILITY OF RICE-FISH CULTURE

There is considerable uncertainty about the future of rice-fish farming, indicating the need for economic feasibility studies of rice-fish farming in different situations.

CONSTRAINTS TO INCREASING PRODUCTIVITY

There are many bureaucratic constraints in terms of policy, funding and provision of equipment and personnel for research and development studies on integrated farming systems, especially in government departments (less so in the universities). The low priority assigned to research and development in this field may delay important work by several years. Universities should be encouraged to research integrated farming systems by funding them, encouraging a development orientation and establishing a research network of people and institutions involved in integrated farming research in different countries for the required information base.

In conclusion, it is evident that the constraints to improving and developing integrated agriculture-aquaculture farming systems lie as much in the social as in the natural sciences.

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- Stimulating and assisting further development of agricultural institutions in Southeast Asia, and enlisting their efforts in solving pressing agricultural problems in the region.