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Research and Education for the Development of Integrated Crop-Livestock-Fish Farming Systems in the Tropics

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Cover: Small-scale integrated crop-livestock-fish farming in a rainfed area of Northeast Thailand. This rice farm has a small fishpond that provides fish, permits dry season cultivation of vegetables on the dikes and supplies drinking water for livestock.

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Preface

Successful integration of aquaculture with agriculture is a complex subject, not least because of the poorly developed research base for aquaculture in comparison with that of agriculture. Aquaculture science is a relatively new field of study; moreover, it is clear from the research output and teaching programs of most institutions involved in the subject that, despite a profession of interest in integrated agriculture-aquaculture, the attention of their scientists remains narrowly focused on the fish and the aquatic environment rather than on the farmer and the whole farm. This is not surprising as most of the professional scientists involved in aquaculture were educated as life scientists (principally zoologists) or as specialists in aquatic science (particularly fisheries) and they prefer to stay within their primary disciplines.

An attempt is made in this publication to create a framework for a truly interdisciplinary approach to research and education in integrated farming - a fusion of agricultural and aquaculture sciences. It has been prepared by two aquatic biologists, albeit experienced in integrated farming research and education, and an agriculturist with a special interest in farming systems. I recognize that an aquatic bias still shows through in this document, but I believe that it is unique as a first step towards a formal integration of the sciences supporting integrated agriculture-aquaculture farming systems.

Integration of aquaculture with agriculture is more developed in Asia than in any other region of the world. However such integrated farming systems are presently used by only a very small minority of farmers (<1%) in a few countries and have not progressed far in terms of productivity and efficiency from their traditional beginnings. This point is often missed by donors and development agencies who, seeing that Asia produces 75% of the world's cultured fish production and that Chinese integrated farming principles have a long and successful history, fail to recognize that vast potential still exists for many more of Asia's numerous and needy small-scale farmers to enjoy the benefits of integration of aquaculture into farming systems. To realize this potential requires a new research and education program, as is proposed in this publication.

For Africa, the potential for aquaculture and integrated farming development is far less certain. In the growing campaign by donors and research and development agencies to develop appropriate systems to improve the nutrition and livelihood of African peoples, there appears to be a tacit assumption that aquaculture and integrated farming systems incorporating aquaculture have high potential for development in Africa. This assumption has little basis in fact. For many African nations there are serious constraints to aquaculture and integrated farming development, such as adverse environmental conditions for fish growth (aridity, high altitude/low temperature); underdeveloped/shifting agriculture; labor shortages; lack of interest in fish husbandry; competition from capture fisheries in fish markets; social attitudes/taboos and other factors.

It is, of course, probable that integrated farming systems incorporating fish *will* flourish in some African countries in which major constraints are absent or surmountable and for which the necessary research and production trials can be undertaken. Meanwhile, a cautious approach to aquaculture development is needed; not a rush into development by transfer of foreign technologies. Such a cautious approach should best be undertaken in parallel with further research for the development of Asian integrated crop-fish and crop-livestock-fish systems for which reliable management guidelines are still lacking.

What are the prospects that this new approach will succeed? I believe that they are excellent, given adequate recognition by scientists and donors of the potential of integrated farming and the need for research and education to underpin its development. The United Nations Development Programme already has taken an admirable lead by supporting ICLARM to produce this study and engage in related planning work. Other donors are beginning to support integrated farming research and development, including aquaculture components, in Africa as well as in Asia. On a most encouraging note, the Consultative Group on International Agricultural Research (CGIAR) and its Technical Advisory Committee (TAC) have begun to take a strong interest in aquaculture and its potential for responding to more substantial research. A CGIAR involvement in aquaculture research would greatly increase contact between agricultural and aquaculture scientists and thus benefit integrated farming programs. The professional expertise that would be needed to pursue this research is becoming available as more economists and social scientists trained in agricultural institutions are now taking an interest in the integration of aquaculture with agriculture.

Finally, one might ask why combine Research and Education? It is my view that the two are inseparable if the develoment of integrated farming systems is to succeed and thereby make a greater contribution to food supply and livelihood. The agricultural and aquaculture researchers needed for the work outlined here must educate themselves, and a new generation of professionals committed to this broader view of integrated farming systems must merge.

I would like to take this opportunity to thank many colleagues around the world who helped review early drafts of this manuscript. Your ideas and reactions have helped the authors considerably.

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July 1988

Research and Education for the Development of Integrated Crop-Livestock-Fish Farming Systems in the Tropics

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Introduction

There is a pressing need to increase the productivity and profitability of farming in developing countries. According to the study "Agriculture Towards 2000" (FAO 1981), in which the future development of world agriculture was analyzed, by the year 2000 the world population will be more than 6 billion (it passed the 5 billion mark in July 1987) and the demand for agricultural products in third-world countries will double. Small-scale farmers comprise the bulk of the population of the developing world and the challenge is to raise their productivity per unit area per unit of time and per unit of capital input because the amount of arable land per person is declining due to overpopulation. Productivities are also declining due to environmental degradation; for example, deforestation, leading to more unstable water resources and soil erosion. There is a need to improve the efficiency of utilization of the limited resource base of small-scale farmers through the promotion of integrated farming to improve their diet, balance risks among various farming subsystems, provide fuller employment and generate surplus produce for sale. Indeed integrated farming systems offer great prospects for the development of sustainable third-world agriculture with minimal adverse environmental impact. This is particularly relevant for those farms which are operated under rainfed conditions. These comprise about 70-80% of the total agricultural land.

Grigg (1974) studied the evolution of the major farming systems of the world as he believed that a knowledge of the past would enable us to better understand present farming systems and aid their future development. In a second major treatise, he considered the relationship between population growth and agrarian change from a historical perspective (Grigg 1980). He stressed that the need for successful production responses in agriculture in the developing world is imperative. It is ironical that the food production potentials of the tropics, where year-round production is often possible, have not often been realized. Although most third-world farmers grow monocultures of rice or maize, there is a wide variety of traditional cropping patterns in the humid tropics. The production potentials of the latter remain to be fully exploited (Hoque 1984). Hoque referred to crops but the same applies even more to livestock and fish, the other subsystems in an integrated crop-livestock-fish farming system.

Why include a fish subsystem in an integrated farm? Fish have many advantages as farm produce. They are a highly nutritious and valuable traditional food in much of Asia and Africa. Fish provide about 25% of animal protein for human consumption in Africa and from 28 to 80% in South and Southeast Asian countries. Fish are *small,* valuable units of saleable protein and once grown can be kept alive on maintenance diets with little or no loss of condition for later harvesting at will. They are excellent converters of low grade feeds into high quality animal protein because, unlike terrestrial livestock, they do not need to use dietary energy to maintain body temperature or posture.

A holistic farming systems approach is taken in this study because the greatest potential for fish culture lies with farmers who are already engaged in the production of crops and livestock. The idea is to bring aquaculture to resource-poor, small-scale farmers who have limited access to the off-farm inputs necessary to exploit modern farming technology. Fish are produced by recycling byproducts of agronomy and animal husbandry into animal protein. Nutrient-rich pond water and mud are potential resources for adjacent crop products. Aquaculture thereby becomes the third partner alongside existing crop and livestock farming subsystems on small-scale farms. The cost of raising fish in such integrated farming systems would be lower than in systems using pond inputs from agro-industry and would be feasible for small-scale farmers.

The greatest scope for the development of integrated crop-livestock-fish farming systems is in the humid tropics. This is where the need is also greatest. Trewartha's modification of the Köppen System of classification of climates (Money 1978) is used in this review (Fig. 1). Tropical climates are defined as those with the mean temperature of the coolest month greater than 18°C (Money 1978; Oldeman and Frère 1982). This allows tropical fish to grow year-round. Three types of tropical climate are recognized in the system:

1. A Rainy Climate with either no dry season or a short dry season, but with enough rainfall to support rainforest (and therefore fodder) year-round;
2. A Wet and Dry Climate (tropical savannah) with distinct wet and dry seasons; and
3. A Semi-Arid Climate with a long dry season and a short rainy season.

Aquaculture is possible in climates 1 and 2 but generally not in climate 3. Water shortages in climates 2 and 3 could constrain not only fish culture but also the availability of pond inputs (forage and byproducts from crop and livestock subsystems).

The integrated farming systems discussed in this study make use of tropical fish, particularly the omnivorous tilapia which has been hailed as the "aquatic chicken" of the future (Pullin 1985a). Tilapias breed and grow year-round in the tropics. The Subtropic Humid Climate, with year-round rainfall and the mean temperature of the coldest month between 0 and 18°C is included in Fig. 1 because it covers China, the origin and a current exponent of integrated crop-

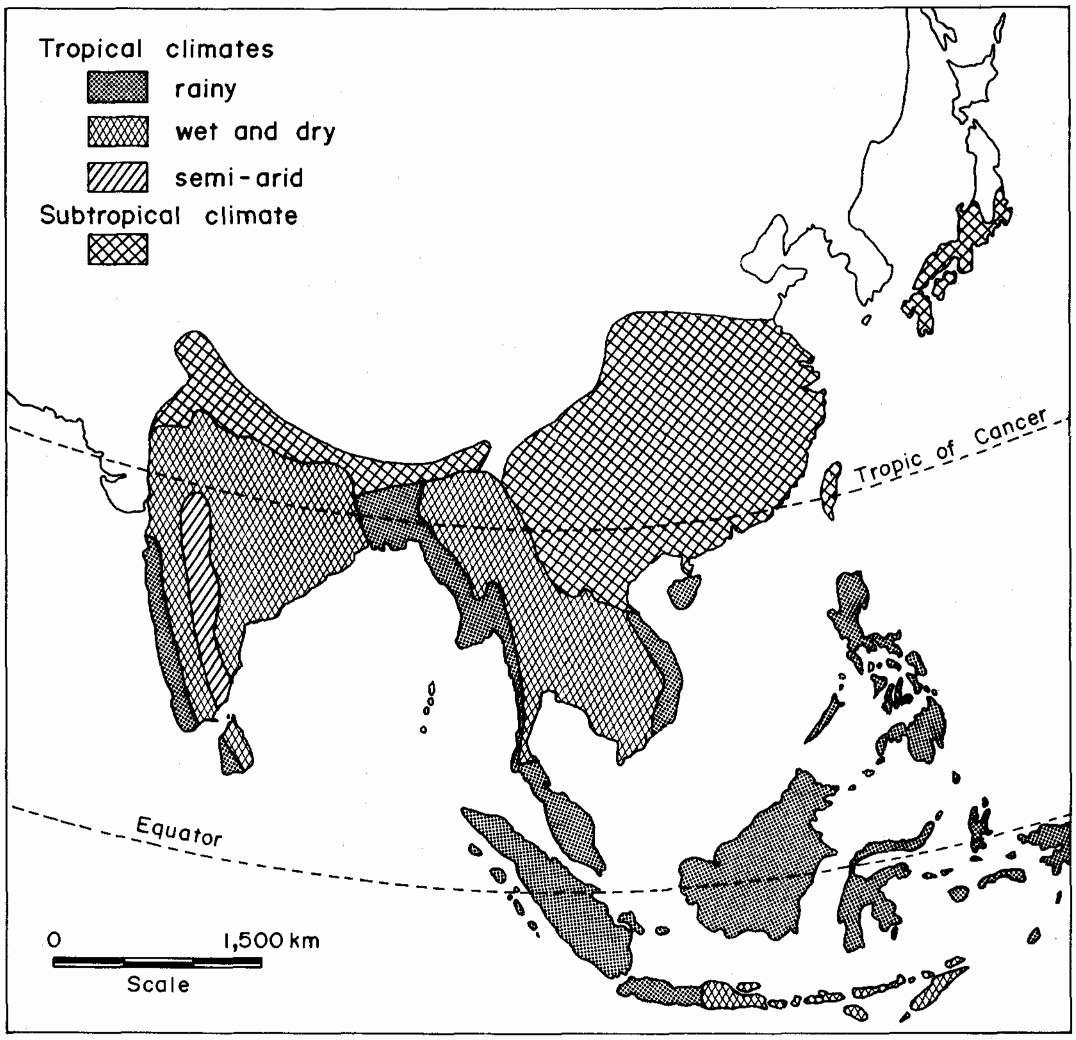

Fig. 1. The Trewartha modification of the Köppen system of classification of climates. This is based upon a theoretical concept of reduction of all elevations to sea level. Within these climatic zones, potential sites for integrated crop-livestock-fish farms depend on local conditions (adapted from Money 1978).

livestock-fish farming. However, only eurythermal warmwater fish species can normally be cultured in China. The growing season varies from 8 to 11 months in the Yangtse and Pearl River Basins, respectively, because of seasonally low winter temperatures. Research for the development of tropical integrated farming systems should be conducted in the tropics unhindered as far as possible by seasonal climatic constraints.

Recognizing then the scope for development of integrated crop-livestock-fish farming systems in the tropics, what information and expertise are available? Both are very limited; hence the need for a program of research and education as outlined in this study. Tropical aquaculture has a weak research base (Pullin and Neal 1984) compared with agronomy and animal husbandry. This weakness has been exacerbated in integrated farming research and development by the narrowly-based educational background and hence narrow vision of many researchers and developers. For example, most aquaculture scientists understand and see only the fish and their requirements and do not take into account the complete resource system.

A holistic view of the farm is essential. Aquaculturists must learn to understand existing crop and crop-livestock farming systems and agricultural researchers the fish farming subsystem. The processes of research and education for the development of integrated farming systems are therefore closely interlinked. This calls for an innovative approach to bring aquaculture into the mainstream of agriculture. There is a need for researchers and educators who, while seeking the inputs of specialist crop, livestock and aquatic scientists to answer specific questions, are themselves *generalists,* researching and educating others by means of a whole farm perspective and a broad interdisciplinary mix of biology, economics and social science.

There is a vast literature on crop and livestock production in tropical third-world countries but comparatively little on integration of these with aquaculture. Information on crop-livestock-fish integrated farming systems has been collected by Temprosa et al. (in prep.) as an annotated bibliography. Published information and the expertise of the participants of a workshop convened in 1986 to set the scene for a new program of research and education for the development of crop-livestock-fish integrated farming systems were used for this study (Appendix I). The evaluation and development of farming systems, the identification of the target groups, geographical scope, and potential impact of the incorporation of a fish subsystem are considered first. Detailed frameworks are then given for research and education, followed by a discussion on institutional aspects.

The Concept of Integrated Farming Systems

A Definition of Integrated Farming

The word integrated is derived from the Latin verb "integrare" which means to make whole, to complete by addition of parts, or to combine parts into a whole. The crop, livestock and fish subsystems may function independently in certain farming systems, and their products be only additive. However, an output from one subsystem in an integrated farming system which otherwise may have been wasted becomes an input to another subsystem resulting in a greater efficiency of output of desired products from the land/water area under a farmer's control. There is synergism in integrated farming since the working together of the subsystems has a greater total effect than the sum of their individual effects.

The main biological feature of an integrated farming system is byproduct recycling; but improved space utilization, in which two subsystems occupy part or all of the space required for one subsystem, may be an important aspect of increased productivity. A major socioeconomic benefit of integrated farming is that inputs to the various subsystems that comprise the farming system tend to be intra-farm, with a diminished reliance on inter-farm or agro-industrial inputs. Integrated farming systems also spread the risks associated with farming because of the increased diversity of produce. They also lead to a more balanced diet for the farming family that chooses to eat some of its own produce.

The Development of Integrated Farming Systems

A schema is presented in this study of the possible evolutionary development of integrated farming systems to set the research framework recommended here in an appropriate context (Fig. 2). The three major categories of farming - settled agriculture, shifting cultivation and pastoral nomadism - are adopted from an example of a classification of world farming systems by Spedding (1979). However, settled agriculture is divided here into three phases - crop dominated, integrated crop/livestock and industrial monoculture - to emphasize the role that integrated farming systems can play in bringing aquaculture to resource-poor, small-scale farmers with limited access to often costly off-farm inputs. The rationale for the three phases of settled agriculture is derived largely from studies of the agricultural farming systems of the world and their evolution by Whittlesey (1936), Duckham (1959, 1966), Duckham and Masefield (1971) and Grigg (1974, 1980). A simplified schema cannot represent all possible variants of the world's agricultural systems (Spedding 1979) but it is a useful conceptual framework for this study.

Hunting/gathering/fishing preceded the development of agriculture but are still of importance in many third-world countries, particularly with regard to fish. Indeed, the capture of wild fish, as opposed to aquaculture, is still the major source of fish in most third-world countries.

Shifting cultivation involves periodic shifts to new land as the fertility of the original patch is exhausted. This is now confined mainly to mountainous areas. There is little potential for integration with aquaculture because of the restricted area suitable for pond construction in mountain terrain and because of the migrations of the society. The earliest form of agriculture in the tropics was thought to be "vegeculture", based on vegetative propagation of roots (taro, cassava, yams, sweet-potatoes, and arrowroot) and the collection of tree fruits such as bananas

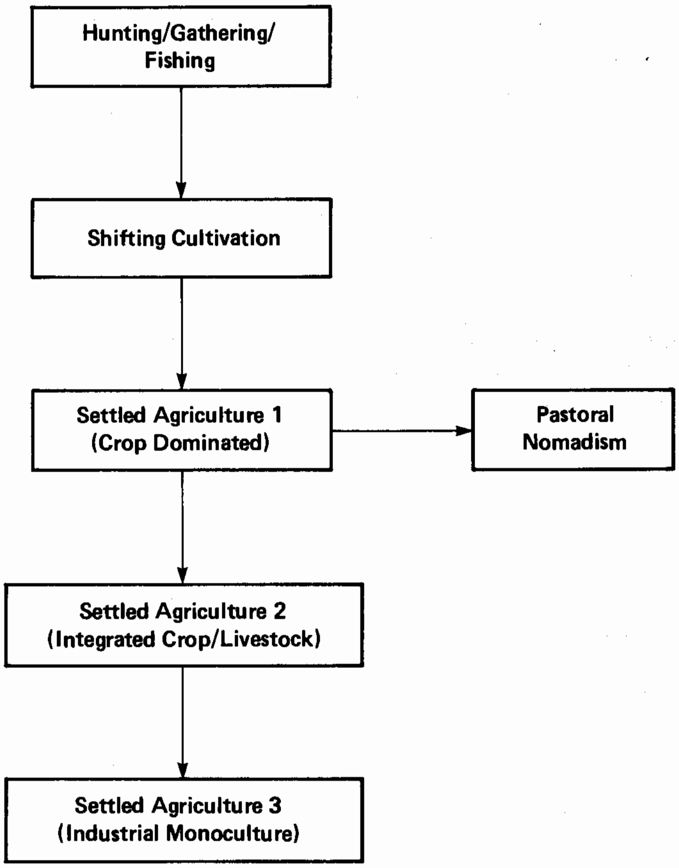

Fig. 2. A schema of possible evolutionary phases in farming systems development.

and coconuts. Pigs and poultry were probably domesticated as scavengers. Vegeculture was displaced after about 3,500 BC by "seed" agriculture, based on wet-rice cultivation, with large ruminants as draught animals; it survives only in remote areas and in mixed gardens (Grigg 1974).

In densely populated pre-industrial societies, most land is under food crops, and livestock are kept mainly as draught animals; scavenging pigs and poultry may be kept as a source of meat. This farming system is called Settled Agriculture Phase 1 (Crop-Dominated). Most of western European agriculture was in this phase until about 1850. The main crop was cereals and fertility of land was maintained by the two and later the three field system in which one strip was left fallow each year to rest the land. There was little or no integration between subsystems because cattle were kept mainly for draught purposes and depended on rough grazing. Most third-world countries are still in Settled Agriculture Phase 1, except for those areas affected by the "Green Revolution" which have "leap-frogged" to Settled Agriculture Phase 3. In some third-world countries, large ruminants feed on stubble in the fields following crop harvest and consume straw. Some of their manure fertilizes the field but the farming system is predominantly crop-based with little integration.

It used to be thought that pastoral nomadism preceded settled agriculture but it is now considered to have been derived from it (Grigg 1974). Nomads live for the most part in arid and semi-arid areas where only grassland is present because of water shortages, and aquaculture has limited potential.

Two major trends between 1300 and 1800 led to the development of the "mixed farming" characteristic of much of western Europe and the eastern USA from about 1850-1945: 1. the reduction and final elimination of the fallow and 2. pasture cultivation, in rotation with crops, which provided feed for livestock. Nitrogen-fixing legumes were sown in mixed pasture with grass and helped to restore soil fertility as well as resting the soil for future cereal production. There was a gradual increase in the importance of livestock after the end of the Middle Ages, which was accelerated by the rise in real incomes in the latter part of the 19th century due to the Industrial Revolution, and an increased demand for livestock products (Grigg 1974). This farming system is called Settled Agriculture Phase 2 (Integrated Crop-Livestock). The integration of crops and livestock is a major feature of mixed farming. Grass is cultivated as pasture, either permanently or in rotation with crops. A variety of crops is grown, particularly cereals, a large proportion of which is fed to animals on the farm or sold to feed mills. In Europe, root crops are also grown and some are fed to pigs and cattle. Livestock products (milk, butter, cheese, beef, poultry, pigs and eggs) are usually a more important source of income for farmers than crop produce. Livestock production is clearly integrated with arable farming because livestock feed on crops grown on the farm, graze the pasture, and their manure helps to maintain soil fertility (Grigg 1974).

Although agriculture has a history of at least 10,000 years, technical change was remarkably slow until the middle of the 19th century. Western European agriculture became progressively more intensive from 1850 by using better seed, more fertilizer and mechanization. Although the trend towards Settled Agriculture Phase 3 (Industrial Monoculture) started about 1850, it is only since World War II that traditional mixed farming with integration of crops and livestock and diversity of products has been replaced by specialization (Grigg 1974). The agricultural revolution in the West is becoming largely dependent on industrial inputs derived from science and engineering which is making farming more independent of the natural environment (Duckham 1959, 1966). The various components of industrial monoculture of modern agricultural technology are: improved varieties, chemical fertilizers, pesticides, herbicides, mechanization, feed concentrates, pelleted feed and pharmaceutical chemicals. Such resources are scarce and expensive in most third-world countries. In the face of increasing technical complexity, a plethora of scientific and industrial inputs, rising labor costs, and the cost advantages of large and specialized farms, there has been a tendency in the West to "simplify" the farming system by reducing the number of enterprises (Duckham 1959, 1966). Farms now are less mixed and many raise only a single product. Modern farm economics have made the need for integrated farming largely redundant in much of the West but there is growing realization that industrial monoculture has much greater adverse environmental effects.

Raising livestock in confinement on feedlots, for which all or most of the feed is purchased off-farm with a total separation of livestock and crop production systems, is a good example of modern farming technology. Raising livestock in feedlots is fundamentally different from the "cut-and-carry" practice in which livestock such as small ruminants or rabbits are "stall-fed" with feed obtained on or near the farm. In the latter, livestock feed comprises a farm subsystem. Feedlot livestock production has been introduced to third-world countries (often on a "turn-key" basis) by vertically-integrated, agro-industrial companies but its benefits for small-scale farmers are questionable.

The organized cultivation of tree crops in plantations was introduced into third-world countries by Europeans and may also be considered as modern farming technology because it generally involves monoculture to provide raw materials for agro-industry.

Most aquaculture in the West and Japan is also industrial monoculture because, in general, single species are raised on pelleted feed and the systems are supported by mechanization (Edwards 1980).

Classification of Farming Systems

A schema is presented to explain the concept of integrating fish culture into existing farming systems based on climate, type of water, water supply and size of farm holding (Fig. 3).

The greatest potential for integration of tropical aquaculture and agriculture lies in freshwater because most agriculture depends on fresh- rather than saltwater. However, some

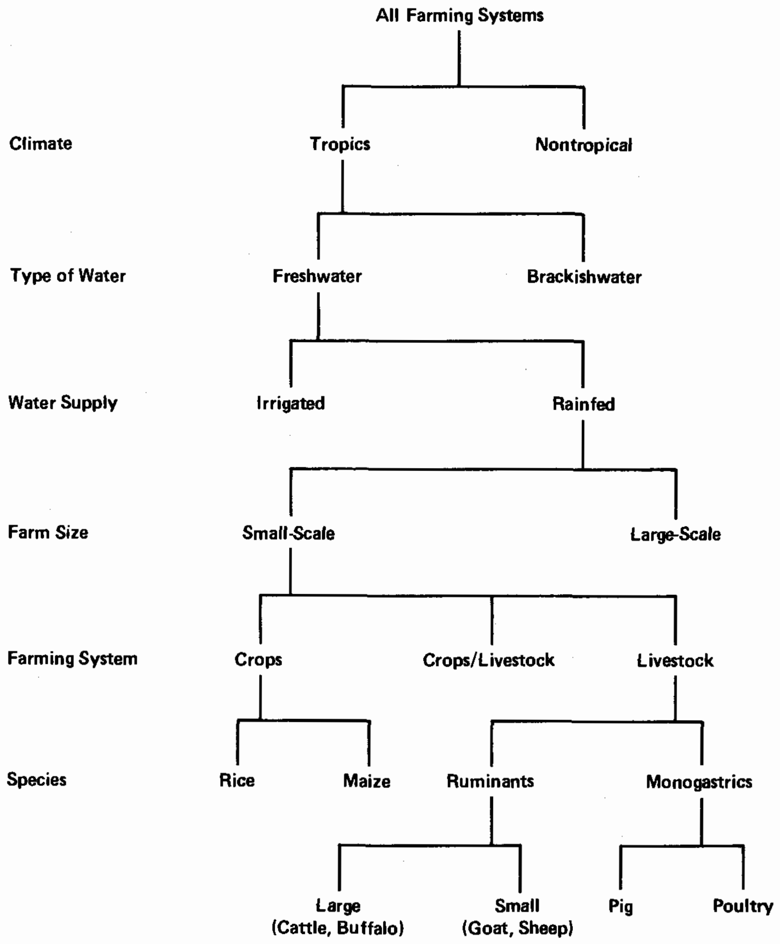

Fig. 3. A classification of farming systems.

brackishwater systems may be considered because rice is also grown in water which can be saline, either seasonally or throughout the year.

There is a need to concentrate future programs on *rainfed* rather than irrigated areas because the former constitute 70-80% of agricultural land and have generally been neglected in development projects. Aquaculture also has great potential in irrigated areas where water stored and channelled to farmers is no longer a constraint in agriculture. However, much of the fish production data generated from successful integrated farming systems in rainfed areas would also be applicable to irrigated areas in a similar climatic zone. There is considerable potential for water storage in rainfed areas through the efforts of the farmers themselves, in contrast to governmental provision of irrigation. Water can be collected and stored for agriculture in areas with variable topography and seasonally heavy rainfall, with aquaculture in the storage reservoirs or tanks. Reservoir construction costs could be amortized in part by the simultaneous use of the water for fish culture. A fishpond is itself a method of water storage and may be used as an emergency water supply for other subsystems on the farm; for example, drinking water for livestock and a water supply for rice nursery beds.

The future research and development focus should be on *small-scale systems* because large-scale farms can usually attract sufficient funds to develop aquaculture without external assistance. The concept of "small-scale" is relative and depends to a large extent on the degree of aridity. The minimum farm size required to support a family is inversely proportional to amount and seasonal distribution of rainfall. A small-scale farm could be less than 1 ha in a Tropical Rainy Climate whereas a small-scale livestock farm could be 1,000 ha in a Tropical Semi-arid Climate with insufficient rainfall to support productive pasture. The term "small-scale" is used in this study to emphasize that the target is *village level or lower* (including family and group operations) and not large-scale commercial operations. A fish pond on an estate farm to augment the diet of farm workers may be regarded as a small-scale farm within the larger estate farm. An increase in integrated farming might not increase the chances of employment on farms for the landless because of widespread un- and under-employment on small-scale farms but it could bring nutritional benefits and should lead to the creation of more jobs in food processing and marketing.

Attempts have been made to develop agroclimatic maps based on agronomically significant parameters to compare areas of similar agroclimatic conditions and to establish data on the productivity to be expected (IRRI 1974; Oldeman and Frère 1982). Temperature is not usually a limiting factor in the tropics and the duration of the growing season of crops depends on rainfall, except in areas with controlled irrigation. Farmers traditionally adapt their cropping pattern to the prevailing distribution of precipitation over the year. A workshop at the International Rice Research Institute (IRRI) established eight agroclimatic zones for rice-growing regions in Southeast Asia (IRRI 1974). Agroclimatic zones were based on the monthly rainfall and the number of wet months with 200 mm or more rainfall. The possibilities of growing two rice crops are limited if there are less than five consecutive wet months. If there are more than nine consecutive wet months, the Southeast Asian farmer is most likely to grow two crops of puddled rice. Maps from an FAO Agroecological Zones Project incorporate not only climatic variables but also constraints imposed by soils (Oldeman and Frère 1982). A constraint to both these classification systems is that they concentrate entirely on rainfed agriculture and do not consider additional sources of water such as water from rivers and run-off. The maps are also crop-specific and do not indicate potential cropping pattern options. However, the approach is a useful one and efforts should be made to delineate agroclimatic zones for various integrated farming systems to assist future agricultural development in the tropics.

Characteristics of Asian Farming Systems

Much more is known about Asian than African farming systems from the point of view of integration of aquaculture with agriculture. The emphasis in this study is therefore on Asian systems with the expectation that better understanding of crop-livestock-fish integration in Asia will point the way to similar developments in Africa.

Most small-scale farmers in the third world may be characterized as Settled Agriculture Phase 1 with crops dominant and not integrated with livestock as in the traditional European mixed farming system (Grigg 1974). An important premise of this study is that major increases in farm productivity and profitability can probably be made by moving such farmers up to Settled Agriculture Phase 2 through development of integrated crop-livestock-fish farming systems. The characteristics of a typical Asian farming system are outlined below as an example.

A typical Asian farmer lives with his wife and four children on a farm of approximately 1.5 ha and raises mainly rice. The family owns one or two draught animals and raises several chickens and ducks (Hoque 1984): land tenure and ownership/tenancy arrangements are variable. There may be several enterprises of varying importance (Terra 1958; Webster and Wilson 1966; Grigg 1974) (Fig. 4):

1. wet-rice, almost always present on farms in tropical Asia and often the principal feature of the farm;
2. multiple cropping of other annual crops with rice in the paddy fields;
3. permanent cultivation of annual or perennial crops, including staple roots and tubers on dry land (upland);
4. a mixed garden around the farmstead where fruits, vegetables and root crops are grown; and
5. livestock, cattle or buffaloes kept mainly for draught, and scavenging poultry and/or pigs.

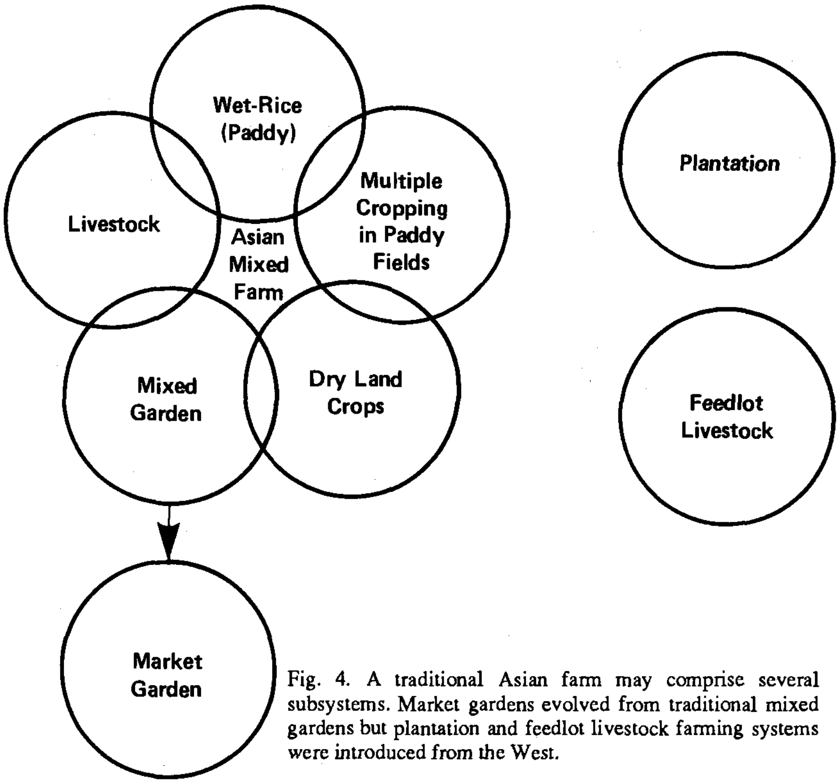

Fig. 4. A traditional Asian farm may comprise several subsystems. Market gardens evolved from traditional mixed gardens but plantation and feedlot livestock farming systems were introduced from the West.

In Asia, as in Europe (in response to increasing population density, particularly near urban areas) there is a tendency for mixed gardening to occupy an increasing proportion of the total arable land on the farm and evolve into market gardening, the growing of vegetables for sale (Terra 1954).

Farming throughout the humid tropics is characterized by the neglect of livestock productivity. Most of the livestock in Southeast Asia are raised on small-scale farms rather than in commercial operations. Buffaloes and cattle are raised primarily as draught animals although they are slaughtered when their working days are over. During the rice growing season the buffaloes and cattle subsist on rough grazing of poor quality and in the off-season for rice they graze on poor quality feed in paddy fields (Javier 1978). Cattle raising for dairy purposes is traditional in the Indian subcontinent but not in Southeast Asia, although there is now increasing interest in dairying among small-scale farmers in the latter region (Grigg 1974; Javier 1978).

Fish culture, contrary to popular belief, is not at all widespread in tropical Asia. Farmers have captured wild fish from rice fields since time immemorial but it has been estimated that less than 1% of the irrigated ricefields in Southeast Asia are used to culture fish (Coche 1967) and little has changed since this estimate. There are a few traditional aquaculture systems in tropical Asia; for example, the Indian major carp polyculture system which until recently was not an example of integrated farming because it was extensive with no fertilizer or feed inputs (Tripathi and Ranadhir 1982). Overseas Chinese were largely responsible for importing integrated fish farming technology to Malaysia, Singapore and Thailand, and perhaps Indonesia (Terra 1958). There has been a significant increase in the development of integrated crop-livestock-fish farming systems in tropical Asia over the past two to three decades but it still probably involves less than 1% of the small-scale farmers in the region.

Overseas Chinese farmers in Malaysia and elsewhere are involved in more intensive cultivation of crops and livestock and sometimes fish. The livestock kept by Chinese farmers, mainly pigs, are well-integrated into the farming system. They are fed mainly on cassava and crop residues such as waste vegetables and rice byproducts and their manure is applied either to crops or to fishponds (Webster and Wilson 1966). However, most small-scale farmers in Asia may be characterized as Settled Agriculture Phase 1 with crops dominant and not integrated with livestock or fish.

Research Framework

General Considerations

This study recognizes the value of a farming systems research approach for third-world agriculture development (IRRI 1982; FAO 1984; Gartner 1984).

There is an urgent need to identify and evaluate through on-station research and adaptive field trials a range of technological packages of integrated farming systems involving aquaculture that are suitable for the small-scale farmer. These should clearly be linked to opportunities and problems in farming communities. An attempt is made in the following section of this study to identify strategies towards this objective by consideration of crop, livestock and fish farming subsystems for a tropical integrated farm. It must be emphasized at the outset that the tropical aquaculture database is so weak compared to those of tropical agronomy and animal husbandry that scientific experimentation is still required to improve technology for seemingly basic aspects of fish husbandry. Furthermore, it is of paramount importance that researchers study existing farming systems in detail for potential sources of pond inputs. Such an approach must include in-depth socioeconomics research, the methodology of which is beyond the scope of this study.

Crop Subsystems

For farms which currently have only crops (which may be grown in multiple cropping systems) the basic question for an integrated farming system incorporating aquaculture is the relative values of crop byproducts such as green manure/compost for the cropping subsystem or as green manure/compost for pond fertilization and/or supplementary feed for fish.

Emphasis should be placed on the major energy crops that dictate the byproducts available on the farm. The major energy foods in the tropics are rice in wet areas, maize in dry or upland areas, and to some extent sorghum where there is less rain. Rice is generally more important than maize in Asia and the reverse applies to Africa.

In the parts of tropical Asia where rainfall exceeds 1,000 to 1,200 mm/year, cropping systems are usually based on rice. Rice is grown at the peak of the rains because rice is the only crop that tolerates flooding. However, it may be possible to plant upland crops such as maize, mungbean, cowpeas, and sweet potato in mixed cropping systems at the end of the rains to utilize residual moisture (Beets 1982).

Multiple cropping has great potential for increasing agricultural productivity. It is defined as growing more than one crop on a piece of land in a year and can take several forms: mixed or intercropping (planting more than one crop on a piece of land at the same time), relay cropping (planting crops in an already established crop) and sequential cropping - double or triple (growing more than one crop on a piece of land at different times in the year). The potential productivity of a multiple cropping system is given by the multiple cropping index (MCI):

$$\text{MCI} = \frac{\text{crop area for 1 year}}{\text{cultivated area for 1 year}} \times 100\%$$

In multiple cropping systems, there is usually a certain optimum proportion of the species in the mixture for dietary, economic, or agronomic considerations (Beets 1982). There is also the question of whether the crop is grown primarily for human, livestock or fish feed.

Fodder crops, particularly legumes could be introduced into existing cropping systems as intercrops, relay crops, or sequential crops without upsetting the regular cropping system (Javier 1978). Various strategies have been discussed by Javier (1978). Aquatic grasses could be grown in ricefields as a fodder crop as an alternative to rice. There are several other possibilities with upland crops. More maize than normal could be sown and the excess thinned-out for fodder. Fast growing legumes such as soybean, mungbean and pigeon pea could be intercropped with maize and a crop harvested before the maize closed-out the light. There are native species of Southeast Asian legumes with known potential for livestock feed, e.g., *Pueraria* and *Desmodium* but also exotics such as various species of *Stylosanthes* (Schultze-Kraft 1986). It is possible to sow annual *Stylosanthes* on ricefield dikes to provide seed which can be broadcast into the stubble after harvest and grazed with volunteer weeds (Perkins et al. 1986). There is a vast array of trees and shrubs that serve as animal fodder, many of which fix nitrogen; for example *Leucaena leucocephala* (Brewbaker 1986). Tropical forage grasses have been studied for only a few decades but there are many species available (McIvor and Chen 1986).

Livestock Subsystems

The greatest potential for integrated farming systems with fish probably lies with mixed farms having crop and livestock subsystems because livestock manure is a useful pond input. Farms that have only livestock fall into two distinct categories: 1. ranching farming systems in semi-arid and arid areas, with little potential for aquaculture because of water constraints, and 2. feedlots.

Intensive feedlot livestock farming may be conveniently integrated with fish but it is a capital-intensive operation because of the purchase of feed off-farm, usually from agro-industry, and has limited relevance for small-scale farmers.

Recognizing the major use of livestock as draught animals, Javier (1978) posed the question: "with the increasing emphasis on mechanization in agriculture, will this mean that there will be no place for livestock any longer?" However, the place of livestock on small-scale farms is assured, even with the advent of mechanization. It is feasible to grow three to five crops on the same piece of land each year with increasing cropping intensities. Sixty percent of the annual production of digestible feedstuff is not useful directly as human food and livestock are a potentially attractive means of utilizing various kinds of crop residues (Javier 1978). There is a voluminous literature on the subject of nonconventional feed resources for livestock, summarized by Devendra (1985), which can also be referred to in the development of supplementary feeds for fish.

Several reasons have been given for the relative neglect of livestock on small-scale Asian farms; for example, 1. few farmers can spare land to grow fodder because it is needed to grow crops for human food; 2. the tropical climate supports grasses of only poor nutritional value; 3. the tropical climate reduces the growth and fertility of cattle; and 4. the tropical climate causes disease (Grigg 1974). However, these constraints are more apparent than real and can be addressed with the knowledge available today from countries like Australia, which has highly developed livestock farming systems in the subtropical and tropical areas of its landmass.

Most potential feed resources on the farm are in the form of crop residues such as rice straw and maize stover which have low digestibility (Javier 1978). These are probably best fed to ruminants (rather than used directly as fishpond inputs) and the ruminant manure used as a pond input. Livestock can gain weight when fed on low quality crop residues supplemented with concentrates. There is often a seasonal distribution problem with livestock fodder. Rice straw, maize stover and empty legume pods are dry and can be stored relatively easily but green fodder may need to be conserved by drying, ensilage, or composting (Javier 1978).

The highest fish yields from integrated farming systems have been reported from ponds receiving feedlot livestock manure. The livestock had received high quality feed and their manure therefore had a high nutrient content (see below). Since livestock are a key component in a productive integrated farming system with fish, a major research effort is required to develop technology for increasing the quality and quantity of livestock feed produced on small-scale farms so as to increase livestock production directly and fish production indirectly in integrated farming systems.

Ruminants, particularly large ruminants such as cattle and buffalo, have particular relevance for the development of small-scale integrated farms because they are in widespread use in Asia as draught animals. However, many agricultural societies in Africa have yet to introduce the plough and therefore do not keep livestock for draught purposes. Ruminants can process fodder which is indigestible to humans but research is needed to identify strategies to upgrade the quality of their manure as a pond input because ruminants grazed on rough pasture and/or stover have manure with a low nutrient content. Small ruminants (sheep and goats) are normally considered to be animals of arid areas but they are important in certain areas in the humid tropics. Small ruminants are sometimes stall-fed using the "cut and carry" system. Free ranging ruminants, both large and small, are often paddocked at night which also facilitates manure collection as a pond input. The collection of nitrogen-rich urine (as well as manure) as a pond input has important potential. For stall-fed ruminants, this resource is usually wasted, but trials are now beginning on the use of cattle urine as a pond input in India.

Monogastric livestock (pigs and poultry) with dietary requirements more similar to humans than ruminants are often raised in small numbers on small-scale farms as scavengers. The manure of feedlot pigs and poultry raised on commercial formulated feeds is high in nutrients and is a valuable fishpond input. However, research is needed on the on-farm production of nonconventional feeds for pigs and poultry and on the nutrient content of their manure when receiving such feeds.

Fish Subsystems

Strategies for increasing production

Two broad strategies for increasing agricultural production are to increase the farmed area and/or to increase the yield per unit area (Grigg 1980). It is generally considered that there is little potential for increasing the area of arable land, with the exception of Africa. The expansion of the area devoted to aquaculture must therefore be considered as a major strategy because there is relatively little aquaculture in the tropics at present, including Asia, and high yields of fish can be obtained from small areas compared to those required for significant production of most arable crops. Fish culture is a highly attractive option for increasing the production of high quality animal protein.

Increased yields should also be targetted, preferably by the more widespread application of traditional agricultural technology involving pond inputs generated on-farm (integrated farming) as opposed to the adoption of modern agricultural technology with its dependence on agro-industrial inputs.

Extensive, semi-intensive and intensive aquaculture

The degree of intensification of fish farming is defined according to feeding practices because these usually comprise more than 50% of the total operating costs in an intensive system. However, intensification is associated with increasing usage of capital, labor and mechanization. A useful classification is as follows:

1. *Extensive* systems utilize natural feed produced without intentional pond inputs. They are excluded by definition from an integrated crop-livestock-fish farming system with the exception of certain integrated rice-fish farming systems in which fish may derive benefits from inputs added solely for rice cultivation.

2. *Semi-intensive* systems rely on fertilization to produce natural feed and/or supplementary feed (but with a significant amount of the fish diet supplied by natural feed) and are typical components of integrated crop-livestock-fish farming systems.

3. *Intensive* systems have all the fish nutritional requirements provided by a nutritionally complete pelleted feed with little or no nutritional benefits from natural feed produced in the pond. Trash fish, a byproduct of capture fisheries, is also used as feed in certain intensive aquaculture systems. Such intensive aquaculture would normally not occur in a crop-livestock-fish farming system because it is difficult to formulate and produce a nutritionally complete pelleted diet from ingredients produced only on the farm. Most western and Japanese aquaculture systems fall within this category.

Essentially, fish raised with livestock in an integrated farming system feed in the semi-intensive mode. A major part of their nutrition is derived from natural food which develops in the pond due to fertilization of the water by manure and fish feces. However, the relative contribution of natural feed to fish nutrition decreases as the quality and quantity of supplementary feed increases.

Fish yields from aquaculture systems range over three orders of magnitude (Fig. 5):

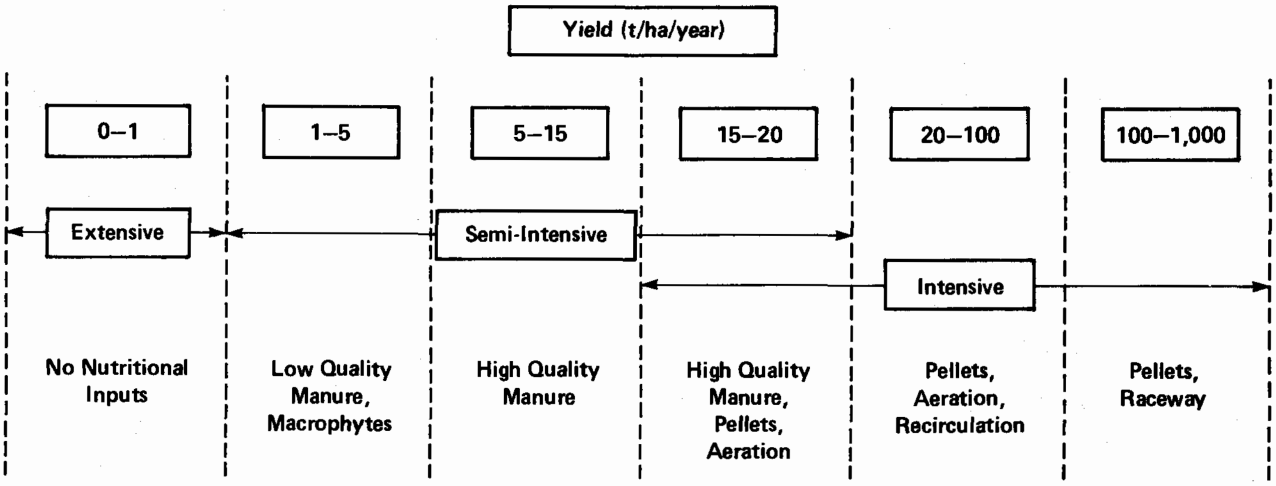

Fig. 5. Intensification of aquaculture systems.

1. 0-1 t/ha/year from extensive systems with no nutritional inputs;

2. 1-5 t/ha/year from semi-intensive systems with low quality manure and/or macrophytes as supplementary feed;

3. 5-15 t/ha/year from semi-intensive systems with a high quality manure input;

4. 15-20 t/ha/year from semi-intensive systems with a high quality manure input and pelleted feed inputs and aeration characteristic of intensive systems;

5. 20-100 t/ha/year from intensive systems with pelleted feeds, aeration and water recirculation; and

6. 100-1,000 t/ha/year from intensive systems with pelleted feeds and running water (ponds or raceways).

The upper fish yield obtained to date in a livestock-fish farming system with high quality manure (duck or pig) as the sole pond input is about 10-12 t/ha/year from both small-scale experimental and larger-scale commercial systems (Oláh 1986; Wohlfarth and Hulata 1987). This is impressive, but the system is essentially a "black box" because pond dynamics - the biological and chemical bases of production - are poorly understood.

It is proposed that an integrated livestock-fish farming system with high quality manure as the only input be used for further basic scientific research to understand how the system functions. The knowledge from such studies could then be used in attempts to increase the fish yield from integrated crop-livestock-fish farming systems in which the pond receive lower quality inputs such as low quality manure and/or macrophytes (vegetation) as supplementary feed.

Interactions in crop-livestock-fish integrated farming systems

Possible on-farm interactions between the various subsystems in a crop-livestock-fish integrated farming system are presented in Fig. 6. The schema excludes products from the various subsystems and merely indicates on-farm linkages. Rice-fish culture is well-established in certain Asian countries (de la Cruz and Carangal, in press) and involves a variety of systems e.g., trenches and ponds, constructed in rice land (Plates 1 and 2). Livestock excreta (manure)

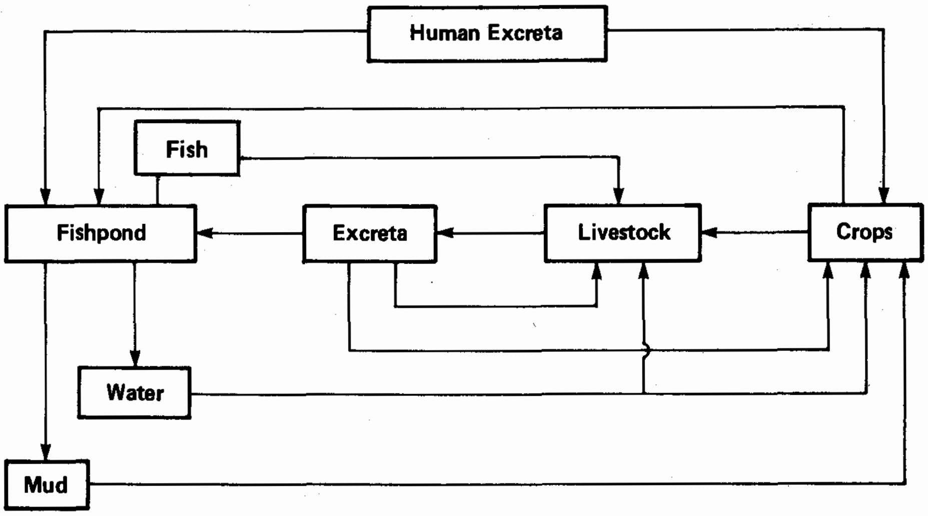

Fig. 6. Schema of possible on-farm interactions between the various subsystems in a crop-livestock-fish integrated farming system.

Plate 1. A peripheral trench surrounding a ricefield in a rice-fish culture system in the Philippines. The aquatic vegetable taro *(Colocasia esculenta)* is also cultivated on the edge of the trench.

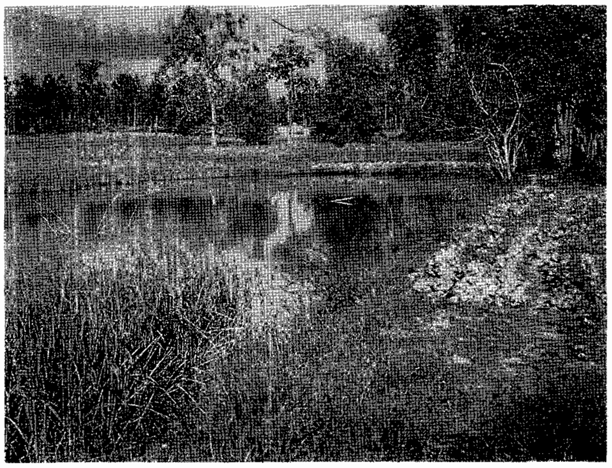

Plate 2. A fishpond constructed within a ricefield in a rainfed area in Northeast Thailand. Pond water is also used to irrigate vegetables cultivated on the dike.

may be used as a fishpond input or to fertilize crops. It is also feasible to incorporate manure into livestock rations. Human excreta may also be used to fertilize the pond or as a crop fertilizer. Crops may be fed to livestock or used as supplementary fish feed. Water from the fishpond may be used to water crops (Plate 3) or as drinking water for livestock (cover plate). Mud removed from the pond may be used to fertilize crops. Fish that are too small to be marketed may be used as a high protein ingredient in livestock or fish feed. The concepts are essentially Chinese in origin and several of the links are supported by a wealth of empirical farmer experience although they have yet to be subjected to the rigor of scientific analysis.

Plate 3. Dry seasonal cultivation of vegetables on a fishpond dike in Northeast Thailand.

Cover plate. Small-scale integrated crop-livestock-fish farming in a rainfed area of Northeast Thailand. This rice farm has a small fishpond that provides fish, permits dry season cultivation of vegetables on the dikes and supplies drinking water for livestock.

Deriving fish culture practices from natural aquatic ecosystems

There are three fish culture systems that have been derived from natural aquatic ecosystems:

1. Vegetation-fed systems in which terrestrial plants and/or aquatic macrophytes are fed to fish (Plates 4a, 4b, 4c); large amounts of excreta are produced by the inefficient digestive processes of macrophyte herbivorous fish (Edwards 1987). These excreta act as pond fertilizers that produce natural food for plankton/detritus filtering fish (Plate 4d) and carnivorous/detritus benthic feeding fish. Aquatic macrophytes growing in the pond are not part of the system because, in a well-managed system that has adequate inputs to support good fish growth, they are shaded out by phytoplankton.

Plate 4a. Terrestrial vegetation (pumpkin leaves) being chopped-up prior to use as fodder for fish in Northeast Thailand.

Plate 4b. An aquatic macrophyte, duckweed, being used as fodder for fish in Central Thailand.

Plate 4c. Grass carp raised in a macrophyte-fed pond in Central Thailand.

Plate 4d. Nile tilapia raised in a macrophyte-fed pond in Central Thailand.

2. Excreta (manure)-fed systems for plankton/detritus filtering fish and carnivorous/detritivorous benthic feeding fish (Plates 5a, 5b).

3. Trash fish-fed systems for purely carnivorous fish such as the culture of snakehead *(Channa striata)* and walking catfish (*Clarias* spp.) on byproducts from the trawling industry in Thailand.

Plate 5a. Small-scale integrated chicken-fish system in West Java, Indonesia.

Plate 5b. Small-scale integrated pig-fish system in Northeast Thailand.

A simplified diagram of vegetation-fed and excreta (manure)-fed fishpond systems is presented in Fig. 7. System 3 is omitted as it is not a viable option for most integrated farms due to the high cost and limited availability of the feed input. Such farms require more energetically efficient fish that feed lower on the food chain.

Choice of fish species

A total of 31 species is listed in Table 1 as potential candidates for integrated farming systems involving aquaculture in the tropics. All are native to Asia with the exception of the tilapias. The list of predacious species could be expanded to include some African species but predacious fish are really of less interest in integrated farming than those with planktivorous/herbivorous/detritivorous trophic niches. Predacious fish have been used to control the recruitment of tilapia but this role will likely diminish with the introduction of monosex tilapia culture. Sixty-five per cent of the fish listed are native to the tropics; the remaining 35% are native to warm-temperate/subtropical zones but thrive in the tropics.

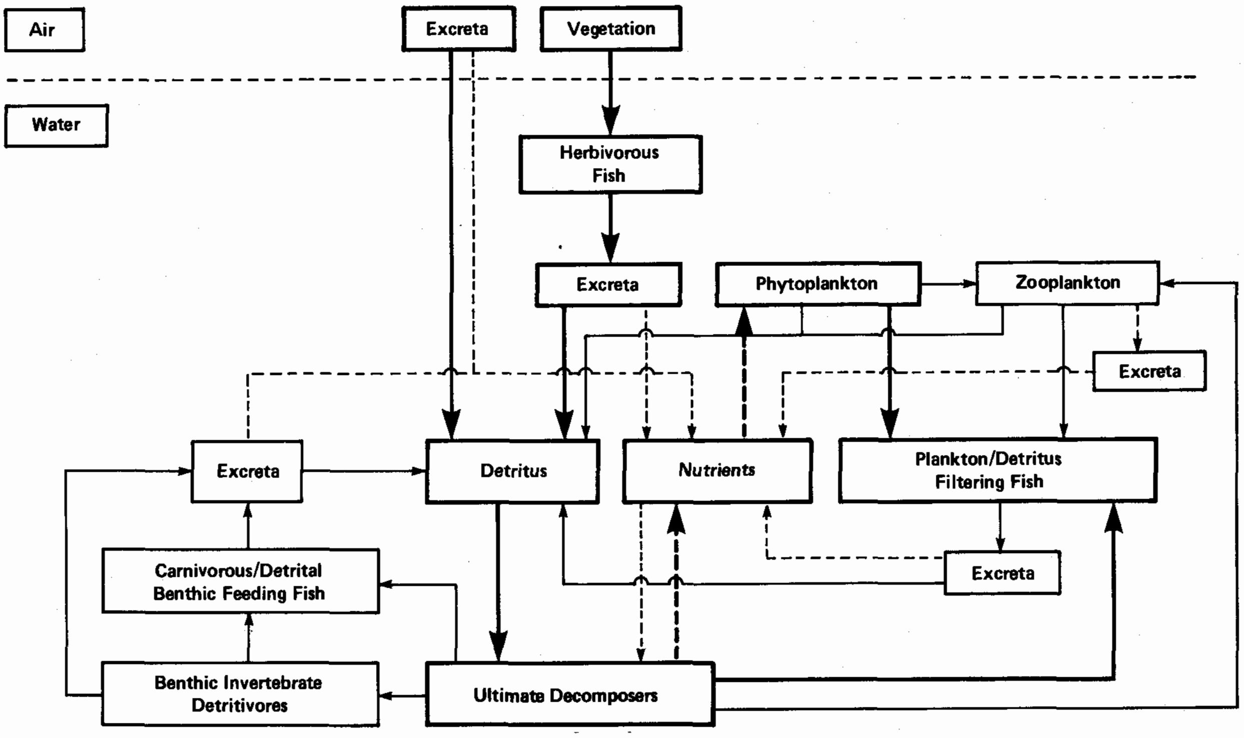

Fig. 7. Food chains in vegetation and excreta (manure) fed fishponds. Solid lines represent pathways of particulate matter and broken lines soluble nutrients from excreta. Major components and pathways are indicated by thicker lines.

Polyculture, the culture of more than one species of fish together in the same pond, has generally been regarded as more productive than raising individual species separately (monoculture). The rationale behind polyculture is that fish have different trophic and spatial niches and that with polyculture a balanced fish population, with different species that complement each other, can occupy all the niches in the pond. However, there is surprisingly little experimental evidence to support the concept of polyculture with the exception of the incorporation of planktivorous fish in the traditional European monoculture of the common carp *(Cyprinus carpio)*, which is a benthic feeder (Opuszynski 1981; Yashouv 1971). Trophic niches of fish overlap to a much greater extent than is generally appreciated and Nile tilapia *(Oreochromis niloticus)*, which occupies several niches, has yet to be evaluated against polycultures under the same set of experimental conditions. *O. niloticus* is an exceptionally versatile feeder. A recent study in the Sudan (Hickley and Bailey 1987) described it as taking phytoplankton in the water column, periphyton and fine particulate organic matter from plant and other surfaces, and benthic organic detritus.

The fish in Table 1 are listed according to major (**) and minor (*) trophic and spatial niches (+). The niches of the various species need to be established under various fertilizer/feeding regimes. The competition index (C) of Reich (1975) could be used to quantify the performance between species in polyculture:

$$C = (A - B)/A \times 100\%$$

where A = yield of a certain species in monoculture;

and B = yield of the same species in polyculture with a second species.

If $B < A$ and C is positive, there is competition between the two species.
If $B > A$ and C is negative, the presence of the second species increases the yield of the first.

Table 1. Fish species as potential candidates for tropical crop/livestock/fish farming systems according to major (**) trophic niches. Minor trophic (*) and spatial (+) niches are also indicated.

Scientific name	Family	Common name	Trophic niche					Spatial niche		
			Filter feeder		Macro-particulate					
			Phytoplankton	Zooplankton	Macrophyte	Detritus/ Invertebrates	Predacious	Surface	Bottom	Column
Helostoma temmincki	Anabantidae	Kissing gourami	**	*						
Trichogaster pectoralis	"	Snakeskin gourami	**	*						
Chanos chanos	Clupeidae	Milkfish	**							
Oreochromis aureus	Cichlidae	Blue tilapia	**	*		*				+
O. mossambicus	"	Mozembique tilapia	**	*		*				+
O. niloticus	"	Nile tilapia	**	*		*				+
Hypophthalmichthys molitrix	Cyprinidae	Silver carp	**	*				+		
Labeo rohita	"	Rohu	**	*						+
Osteochilus hasseltii	"	Nilem	**	*						
Aristichthys nobilis	Cyprinidae	Big head carp	*	**				+		
Carassius carassius	"	Crucian carp	*	**						
Catla catla	"	Catla	*	**				+		
Osphronemus goramy	Anabantidae	Giant gourami			**					
Tilapia rendalli	Cichlidae	—			**					
T. zillii	"	—			**					
Ctenopharyngodon idella	Cyprinidae	Grass carp			**					+
Megalobrama amblycephala	"	Wuchang fish			**					
Parabramis pekinensis	"	Chinese bream			**					
Puntius gonionotus	"	Silver barb	*		**					
Cirrhinus molitorella	Cyprinidae	Mud carp				**			+	
Cirrhinus mrigala	"	Mrigal				**			+	
Cyprinus carpio	"	Common carp		*		**			+	
Mylopharyngodon piceus	"	Black carp				**			+	
Mugil cephalus	Mugilidae	Grey mullet				**			+	
Macrobrachium rosenbergii	Palaemonidae	Giant freshwater prawn				**			+	
Pangasius pangasius	Schilbeidae	Silver striped catfish				**			+	
Channa striata	Channidae	Snakehead					**			
Clarias batrachus	Clariidae	Walking catfish					**			
C. macrocephalus	"	" "					**			
Lateolabrax japonicus	Serranidae	Sea perch					**			
Lates calcarifer	"	Sea bass					**			

There is a near infinite number of potential polyculture systems considering the large number of potential species in Table 1. There are 11 permutations of two species in monoculture and polyculture, with species ratios of 1, 2, 3 and 4 (Table 2). A two species polyculture system involving a plankton/detritus column feeder and a carnivorous/detritus benthic feeder might be appropriate for an excreta (manure)-fed system. There are 91 permutations of three species in monoculture and polyculture with two species, and polyculture with three species, with species ratios of 1, 2, 3 and 4 (Table 3). A three species polyculture system involving a macrophyte herbivorous fish, a plankton/detritus column feeder, and a carnivorous/detritus benthic feeder might be appropriate for either a macrophyte-fed system or a macrophyte and excreta (manure)-fed system. Two species would be required for systems that receive only manure.

Table 2. Number of permutations of two species in monoculture, and in polyculture with four ratios.

Number of species (species ratio)	Species ratios Species 1	 Species 2
(a) Monoculture (2 permutations)		
1(1:0)	1	–
	–	1
(b) Polyculture (11 permutations)		
2(1:1)	1	1
2(2:1)	2	1
	1	2
2(3:1)	3	1
	1	3
2(3:2)	3	2
	2	3
2(4:1)	4	1
	1	4
2(4:3)	4	3
	3	4

The number of permutations soon becomes impossibly large with more than three species in polyculture. To evaluate even a limited number of permutations would clearly need a major research effort with large numbers of experimental ponds, personnel and equipment items. Polycultures of at least six species are common in China and India (Lin 1982; Tripathi and Ranadhir 1982) but there is a dearth of scientific data to support the use of such large numbers of species.

It is recommended that research be conducted initially with polycultures of two species for manured systems and three species for systems in which macrophytes are used as supplementary feed, taking into account the market demand for these species. The versatile plankton/detritus feeding Nile tilapia *(Oreochromis niloticus)* and the versatile bottom feeding common carp *(Cyprinus carpio)* are suggested for both manured and macrophyte-fed systems with the addition of a suitable macrophyte feeding fish for the latter system. The best options for the macrophyte feeding fish are grass carp *(Ctenopharyngodon idella)*, silver barb *(Puntius gonionotus)* and *Tilapia rendalli*, according to local circumstances.

Table 3. Number of permutations of three species, (a) in monoculture, (b) polyculture with two species and (c) polyculture with three species, with four ratios.

(a) Monoculture (3 permutations)

Number of species (species ratio)	Species ratio Species 1	 Species 2	 Species 3
1(1:0)	1	–	–
	–	1	–
	–	–	1

(b) Polyculture with 2 species (33 permutations)

Number of species (species ratio)	Species ratio Species 1	 Species 2	 Species 3
2(1:1)	1	1	–
	1	–	1
	–	1	1
2(2:1)	2	1	–
	2	–	1
	–	2	1
	1	2	–
	1	–	2
	–	1	2
2(3:1)	3	1	–
	3	–	1
	1	3	–
	1	–	3
	–	3	1
	–	1	3
2(3:2)	3	2	–
	3	–	2
	2	3	–
	2	–	3
	–	3	2
	–	2	3
2(4:1)	4	1	–
	4	–	1
	1	4	–
	1	–	4
	–	4	1
	–	1	4
2(4:3)	4	3	–
	4	–	3
	3	4	–
	3	–	4
	–	3	4
	–	4	3

(c) Polyculture with 3 species (55 permutations)

Number of species (species ratio)	Species ratio Species 1	 Species 2	 Species 3
3(1:1:1)	1	1	1
3(2:1:1)	2	1	1
	1	2	1
	1	1	2
3(3:1:1)	3	1	2
	1	3	1
	1	1	3
3(4:1:1)	4	1	1
	1	4	1
	1	1	4
3(2:2:1)	2	2	1
	2	1	2
	1	2	2
3(3:3:1)	3	3	1
	3	1	3
	1	3	3
3(3:3:2)	3	3	2
	3	2	3
	2	3	3
3(3:2:1)	3	2	1
	3	1	2
	2	3	1
	2	1	3
	1	3	2
	1	2	3
3(3:2:2)	3	2	2
	2	3	2
	2	2	3
3(4:2:1)	4	2	1
	4	1	2
	2	4	1
	2	1	4
	1	4	2
	1	2	4
3(4:3:1)	4	3	1
	4	1	3
	3	4	1
	3	1	4
	1	4	3
	1	3	4
3(4:3:2)	4	3	2
	4	2	3
	3	4	2
	3	2	4
	2	4	3
	2	3	4
3(4:3:3)	4	3	3
	3	4	3
	4	4	3
3(4:4:3)	4	4	3
	3	4	4
	4	3	4
3(4:4:1)	4	4	1
	1	4	4
	4	1	4

Fishpond dynamics

The objective in a manured fishpond is to fertilize the water to produce enough natural food for the fish but not an overabundance of plankton, particularly phytoplankton, that can affect fish growth or survival by adverse environmental conditions. Both autotrophic and heterotrophic food chains proceed simultaneously in a manured pond, involving phyto-, zoo-, and bacterioplankton as well as benthic invertebrates and bacteria in the sediments, although the extent to which the various natural food components are exploited by fish depends to some extent on the trophic and spatial niches of the fish community (Colman and Edwards 1987).

It is desirable to determine not only the biomass or standing crop of the various types of natural food but also their productivities so that their potential relative contributions to fish nutrition can be assessed. Ideally, it would be desirable to isolate the different components of the food web to assess their feed value but this is difficult to do in practice. The maximum sustained rate of phytosynthesis in fishponds in the tropics is about 4 gC/m2/day (8 g of biomass/m2/day) or equivalent to about 30 t dry weight of phytoplankton/ha/year (Colman and Edwards 1987). Assuming a feed conversion ratio (FCR) of 2:1 (dry phytoplankton to wet fish), the maximum fish yield would be about 15 t/ha/year (30 kg/ha/day), which is close to the maximum reported yield from ponds loaded with high quality livestock manure. Research is needed to assess fish growth on different types of phytoplankton because there is convincing evidence that blue-green algae are more digestible (especially by tilapia) than green algae (Colman and Edwards 1987). Methods to introduce and sustain blue-green algae (blooms) require further study, possibly involving seeding. The competitive interactions amongst different types of algae in fishponds should also be studied. Zooplankton are widely acknowledged to be an important natural food for fish, particularly for fry. Bacteria which can be entrapped by mucus secretions of both tilapia and silver carp may be an important source of nutrition. Much more research is warranted on feeding pathways in manured ponds and on the mechanisms by which fish filter and digest plankton and particulate matter.

The nutrient dynamics of fishponds, particularly with respect to C, N and P require elucidation. To maintain a daily photosynthetic rate of 4 gC/m2/day in a 1-m deep fishpond would require minimum daily inputs of 4, 0.8 and 0.08 g C, N and P/m2/day, assuming that the C:N:P ratio of phytoplankton cells in a light-limited pond with excess nutrients for growth is 50:10:1 by weight (Goldman 1979), and assuming 100% transfer efficiency and no nutrient recycling within the system. The latter two assumptions of course are incorrect but tend to cancel each other out. A better knowledge of nutrient dynamics within the pond ecosystem would enable rational decisions to be made concerning the amount and frequency of nutrient loadings and whether these should be constant, increased, or decreased with time during the fish growth cycle.

A major consideration in manured ponds is water quality, particularly dissolved oxygen (DO). There are large diurnal fluctuations in DO in a steady-state manured pond, due largely to the presence of phytoplankton (Fig. 8). However, problems with low DO at dawn occur only if the phytoplankton are not growing because, on a 24-hour basis, they generate more DO than they use in respiration if net photosynthesis is positive (Colman and Edwards 1987). Experiments on the tolerance to low DO of various fish species should be conducted in diurnally fluctuating as

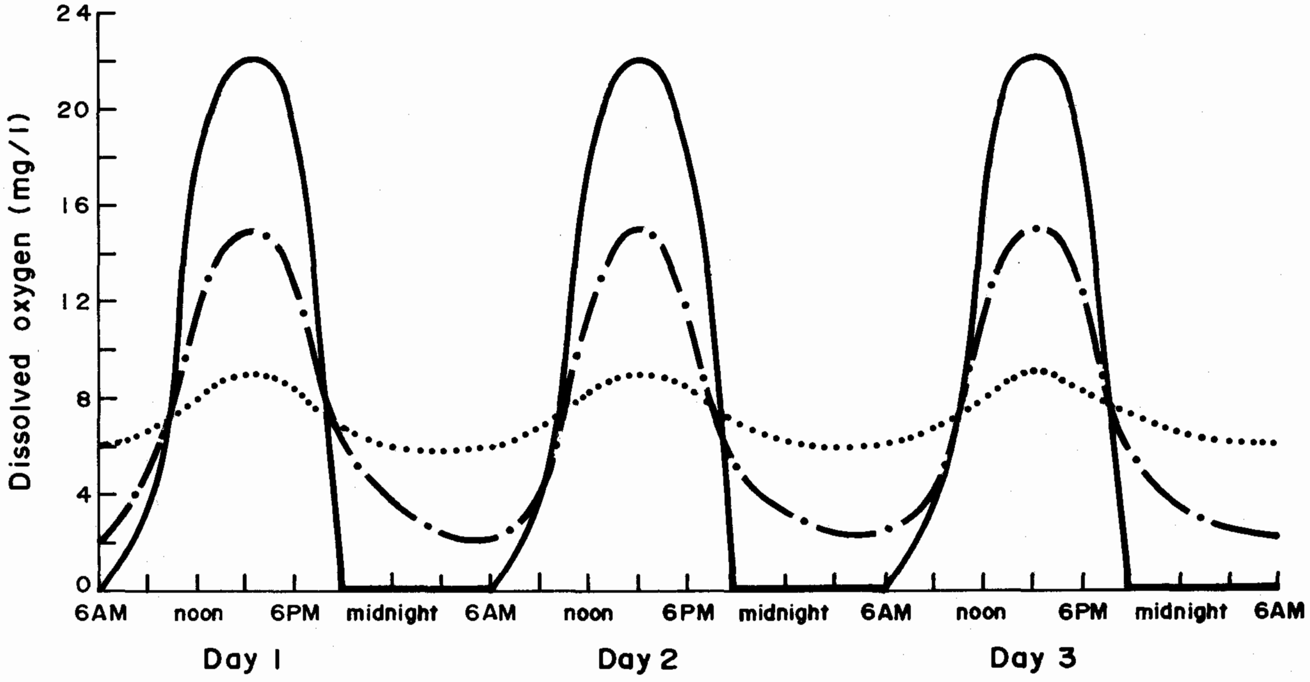

Fig. 8. Diurnal changes in dissolved oxygen (mg/l) in infertile water (dotted line), fertile water (dashed and dotted line) and hyperfertile water (solid line) in the tropics.

opposed to constant DO regimes. Such experiments can be carried out in the laboratory in clear water systems but a more valid assessment needs to be conducted in outdoor systems with changes in DO effected by the phytoplankton. Chronic sublethal effects of low DO, which can lead to reduced fish growth over long periods of time, should be studied in addition to short-term lethal effects.

Toxic products of organic matter degradation, particularly ammonia, nitrite and hydrogen sulphide are probably not a problem in a steady-state manured pond system although catastrophic inputs of organic matter from shock loadings of manure or from the collapse of algal blooms can lead to fish kills.

Types of nutritional inputs to ponds

The major measure of quality for a pond input is its C:N ratio. This applies to feeds as well as to manures because there is a highly significant correlation between the nitrogen content of food and its absorption efficiency by fish (Pandian and Marian 1985). Bomb calorimetry could be used to get a "common currency" for pond inputs and outputs so that meaningful efficiencies of fish productivity could be developed for a wide range of inputs. However, nutrient value must be considered as well as energy. Carbon is the single most important nutrient in biological systems in terms of the quantity incorporated into organisms but nitrogen is usually the first limiting nutrient because of its volatility. C:N ratios are at least two times less in high quality than low quality inputs.

There is a well-known relationship between fish yield and various types of pond nutritional inputs (Hepher 1978; Van der Lingen 1959) (Fig. 9). Fish yield increases with an increase in the status of pond nutrition but to benefit fully from increased food availability it is necessary to increase the density of fish in the pond. Pond experiments should therefore be conducted at a range of stocking densities: experience to date suggests that 0.1, 0.5, 1, 3 and 5 fish/m^2 would be a suitable range.

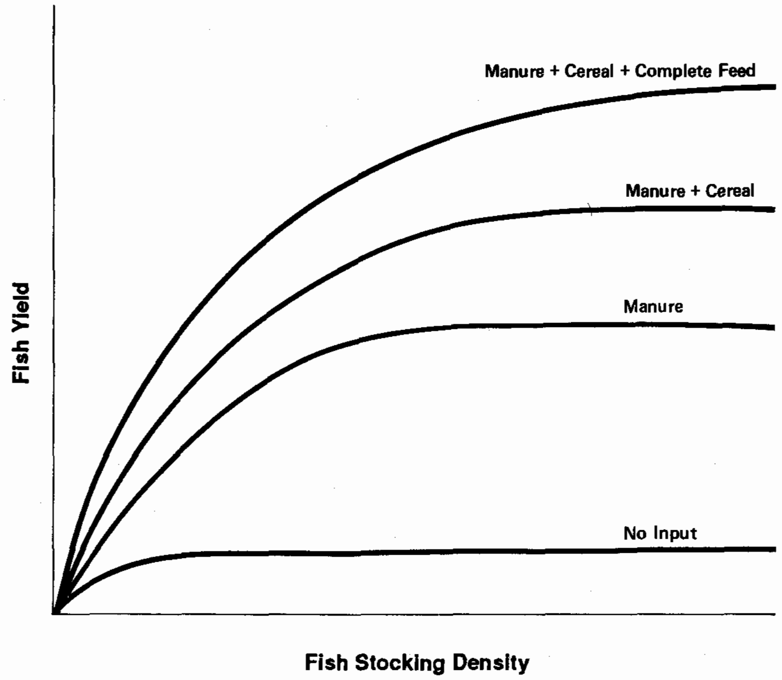

Fig. 9. The relationship between fish stocking density and fish yield as a function of various types of pond nutritional inputs. Modified after Van der Lingen (1959).

Recent studies have demonstrated high yields from ponds loaded with manure from feedlot livestock. Hopkins and Cruz (1982) obtained extrapolated net fish yields of up to 10 t/ha/year from 400-m^2 and 1,000-m^2 ponds in the Philippines, using only pig or poultry manure, *without inorganic fertilizer or supplementary fish feed.* Similar yields were obtained at the Asian Institute of Technology (AIT), Bangkok and in villages (Plate 6) in Central and Northeastern Thailand using duck manure as the sole pond input (Edwards 1983). A mean annual net yield of 175 kg of fish was obtained from a 200-m^2 pond fertilized with the manure of 27 ducks in villages. It was estimated that this could supply almost all the annual animal protein needs of a family of five people.

Plate 6. An AIT adaptive field trial with duck-fish integration in a village in Central Thailand.

However, the effects of the various types of organic manures on fish yields remain to be adequately assessed. In particular, why manure from feedlot livestock gives a much higher yield than manure from grazing ruminants. Although dawn DOs were close to zero in duck-manured ponds in the AIT study, DO concentrations during the afternoon were as high as double supersaturation due to intense phytoplankton photosynthesis. A hypothesis was made that fish productivity is directly proportional to manure N-content and that similar fish yields to those obtained in the duck-manured pond could be obtained by adding buffalo manure to provide the same N-loading rate (Edwards 1983). However, subsequent experimentation gave much lower yields from buffalo- than from duck-manured ponds (AIT 1986). A higher dry matter loading rate of buffalo manure was used to obtain N-loading rates comparable to those for duck manure. This caused an adverse DO regime in the pond. It appeared that the main oxygen demand was from the buffalo manure itself and not from the night-time respiratory demand of phytoplankton. This contrasts with the situation found in ponds fertilized with high quality duck manure.

It is particularly important to investigate the technical feasibility and economic viability of using inorganic fertilizer supplementation to improve grazing ruminant manure from a "low quality" to a "high quality" manure to increase fish yields. Preliminary experimentation at AIT with inorganic fertilizer supplementation of buffalo manure has recently led to a significant increase in fish yield from buffalo-manured ponds with encouraging gross margins for the cost of commercial fertilizer compared to the farmgate price of fish (AIT, unpub. data).

Byproducts such as cereal brans (Plates 7a and 7b) and oil cakes are already known to be good quality supplementary fish feeds but research is required to improve the nutritional value of lower quality feedstuffs, such as crop residues and straw. Essentially, there are three approaches to recycling low quality (high C:N ratio) byproducts in a fishpond:

1. aerobic composting on land;
2. aerobic utilization by broadcasting chopped material over the pond surface so that it can be directly consumed by fish or enter aerobic aquatic decomposition pathways; and
3. anaerobic composting *in situ* by heaping the matter in the pond.

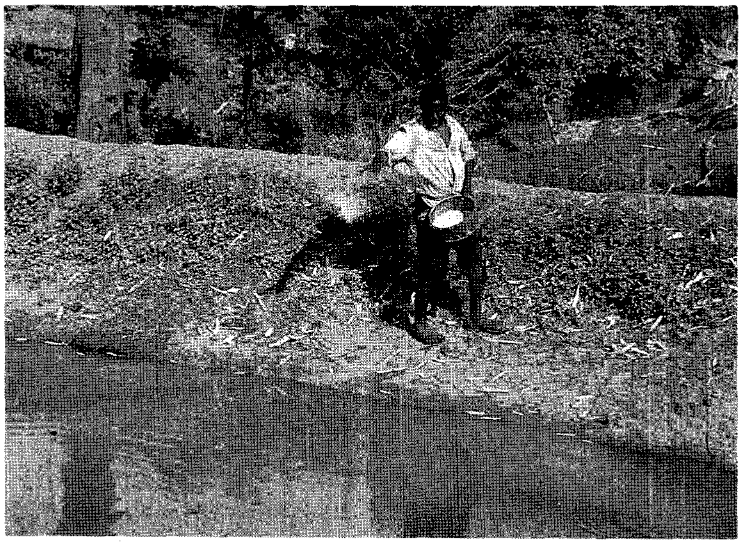

Plate 7a. Maize bran (madeya) used as a supplementary fish feed in Malaŵi.

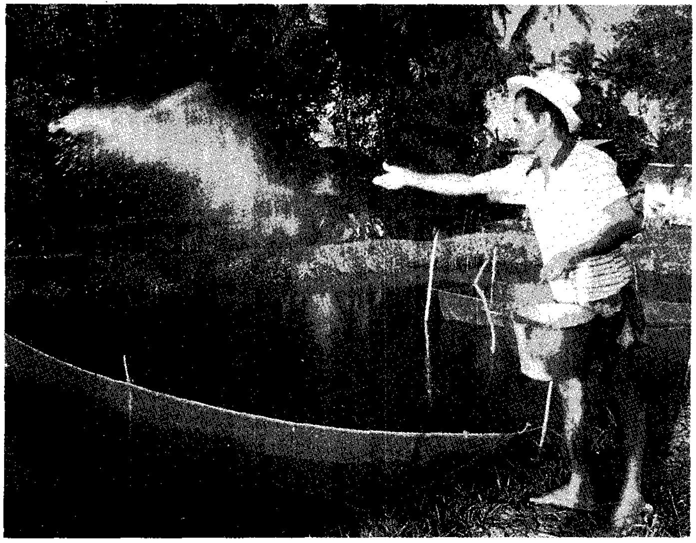

Plate 7b. Rice bran feeding in Laguna, Philippines.

The second strategy would probably be the most efficient - aerobic composting or decomposition in the pond itself - because the loss of nutrients would likely be less by aerobic composting in the pond than on land. However, all three strategies merit further study.

Microbial preconditioning of plant matter by aerobic composting on land leads to a reduction in the C:N ratio because C is lost and N is conserved. However, the N becomes increasingly refractory with time as composting proceeds. It becomes 'locked up' in compounds that do not break down easily (Pullin 1987). Short-term experiments should be conducted with a compost maturation period of days rather than months to correspond to the thermal maximum of the compost pile. This is when the microbial biomass should also be at its peak.

The efficiency of conversion of farm crop residues into farm produce should be compared between a crop-ruminant system (in which manure is used as a crop fertilizer) and a crop-ruminant-fish system in which manure is used as a pond input. An analogy has been drawn between the rumen and the fishpond: low quality inputs in both are processed into higher quality microbial natural feed for target organisms (Schroeder 1980) although this is a doubtful analogy (see discussion in Moriarty and Pullin 1987). Moreover, it may be more biologically and economically efficient to process low quality vegetation and crop residues (with appropriate pretreatments to improve digestibility) by feeding them to ruminants and then to use their manure as a pond input rather than to utilize these materials directly (with or without pretreatment or nutrient supplementation) as pond inputs.

Vegetation, both terrestrial and aquatic, needs to be assessed as a direct feed for herbivorous fish and as a fertilizer to produce natural food after incomplete digestion by herbivores. The direct-feeding value of aquatic macrophytes in particular might be improved considerably if their moisture content were reduced.

Complete feeds are normally dried and pelleted and are produced by agro-industry. Research should be conducted into the on-farm manufacture of low cost wet or dry pelleted feed using low cost materials and methods of feed storage. A major problem is the replacement of fish meal as the major protein source for commercial diets. Plant protein sources such as soybean can only replace a limited percentage of fish meal. Small fish that are too small to market, harvested from ponds or ricefields, may be a suitable replacement for fish meal. Other sources of animal protein such as snails or tubificid worms need to be assessed as nonconventional animal protein sources of pelleted feed. A well-manured pond usually has abundant high protein natural food so it may be feasible to feed fish with cheaper *energy rich* pellets to complement the natural high protein diet. However, such diets may need to incorporate feeding stimulants to be acceptable to fish (Mackie 1982). Betaine, amino acids, "amino-acid like" substances and inosine and its derivatives have been characterized as feeding stimulants for teleost fish (Carr 1982). Research is required to identify low cost feeding stimulants, particularly those that occur in on-farm products. Studies are also required on low cost methods of on-farm storage of pelleted feeds.

Physical characteristics of the pond

Fish yield may be influenced by the size of the fishpond, irrespective of the rate of fertilizer/feed inputs per unit area. The water quality may be better in a larger than a smaller pond because of the greater wind effect on the surface. Wind induced water movement is a major factor in water circulation in static water ponds. However, large ponds have proportionally less edge/marginal zone (perhaps the most fertile area of a pond) than small ponds. This could adversely affect fish yield. Research is required to determine the optimal size of fishponds for different systems, commensurate with good pond management.

Ponds are commonly only 0.8-1.5 m deep in the tropics although ponds in China are usually 2-3 m deep. The optimal pond depth for the tropics remains to be determined. The effect of pond depth on fish production could be assessed by computing pond inputs on an areal as well as a volume basis for both shallow and deep ponds. A factorial experimental design involving stocking density would need to be incorporated into such studies. Fish productivity might not vary with depth in a manured pond because the productivity of the natural food organisms in the water is a function not only of the nutrients contained in the inputs but also of solar radiation at the surface, which is independent of depth. However, deep ponds may lead to greater fish yields than shallow ponds if significant amounts of supplementary feeds are given. Furthermore, deep ponds may be needed in rainfed areas with seasonal rainfall to store water to permit fish culture during the dry season.

Pond sediments

There is considerable controversy concerning the role of pond sediments in fish production. The water column may have the more important role in productivity in a manured pond because it is three-dimensional compared to the two-dimensional sediment/water interface. Furthermore, the water column contains all the phytoplankton. However, bacterial productivity should be greatest at the sediment/water interface due to bacterial decomposition of sedimented organic matter (Fig. 10). Thus, the sediments could be an even more important site of nutrient regeneration than the water column. It is hard to partition autotrophic and heterotrophic food chains in a pond loaded with significant amounts of manure but experiments should be conducted in which pond sediments are physically separated from the water column. The effects on fish yields of various densities of benthic feeding fish as "bioperturbators" should also be assessed. Mechanical disturbance of the sediments or ‘stirring’ also merits investigation. A total carbon fixation rate of 8 gC/m^2/day has been reported for fishponds with sediments regularly stirred so that sedimented detritus and associated bacteria were resuspended in the highly aerobic water column (Costa-Pierce and Craven 1987). This is a considerably higher carbon fixation rate than those previously obtained from static, unstirred ponds. The strategy of sediment stirring may be the key to elevating the fish productivity in manured ponds. However, it should not be forgotten that the most efficient food chains are aerobic not anaerobic and that photosynthesis by phytoplankton is the major source of dissolved oxygen. A balance would need to be reached between increased bacterial productivity from the resuspension of bacteria-covered detrital particles in the aerobic water column (which would also increase nutrient regeneration and stimulate phytoplankton growth) and reduced photosynthesis due to water turbidity.

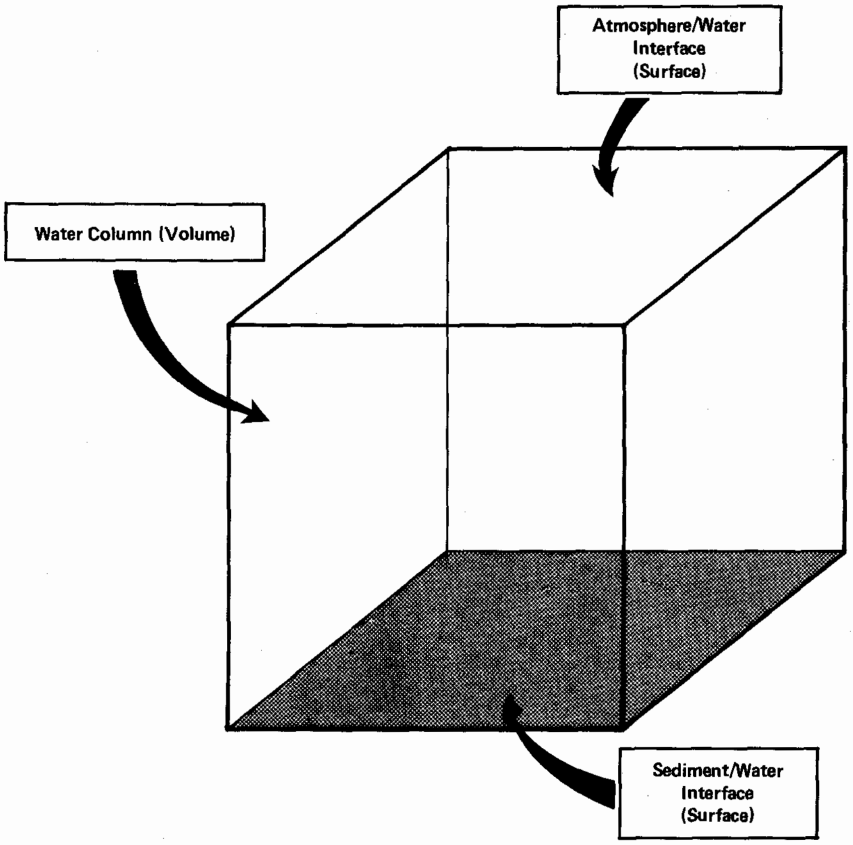

Fig. 10. A three dimensional representation of the fishpond water column.

However, a "sediment-degradation" phenomenon has been reported from Israel (Ram et al. 1982) in which fish growth is inhibited 50-70 days after stocking. This has been attributed to the accumulation of organic matter leading to anaerobic conditions and the production of toxic H_2S. Sediments are usually air-dried when fish are harvested by pond draining before a new cycle is started. This oxidizes the sediments, at least partially. However, there is no information on the effect of varying the drying period on the mineralization of sediments of different depths, nor of the effects of drying on water column productivity when the pond is refilled. In China, excess fishpond sediments are removed and used as crop fertilizers (Plate 8). Studies are also required on the value of fishpond sediments as fertilizers for terrestrial crops.

Plate 8. Fishpond sediments collected during the fish culture cycle fertilize mulberry cultivated on a fishpond dike in Guangdong, South China.

Research is clearly warranted on all aspects of the management of fishpond sediments during the fish culture cycle.

Fish stock management

Most fish culture comprises a single stock-single harvest operation in which fingerlings are stocked at the start of the culture period and are harvested by pond draining for market at the end of the growth cycle (Fig. 11). The increase in weight of the fish in the pond follows a sigmoid curve: slow during the first phase, because the individual weights of fingerlings are small, and more rapid as the fish grow larger. The third phase is one of slow growth because the carrying capacity of the pond is being approached. The carrying capacity may be defined as the total weight of fish in the pond that can be supported by the available feed resources and water quality (Fig. 11).

However, significant increases in fish yield may be obtained by utilizing more fully the spatial and nutritional resources of the pond throughout the culture cycle. A higher weight of fish should be stocked at the outset to eliminate the slow weight increase of phase 1. An intermediate harvest should be carried out at the upper inflection point of the curve at the end of phase 2 when the increase in fish weight slows because the carrying capacity of the pond is being approached. Although there are as yet few experimental data to support this hypothesis, the cumulative harvests from such stock management may be at least double that in a single stock/single harvest cycle. Research on fish stock management could significantly increase the yields from most fish culture operations, not just integrated farming systems. It could also have enormous economic advantages for farmers; for example, a more even supply of produce to market and improved cash flow.

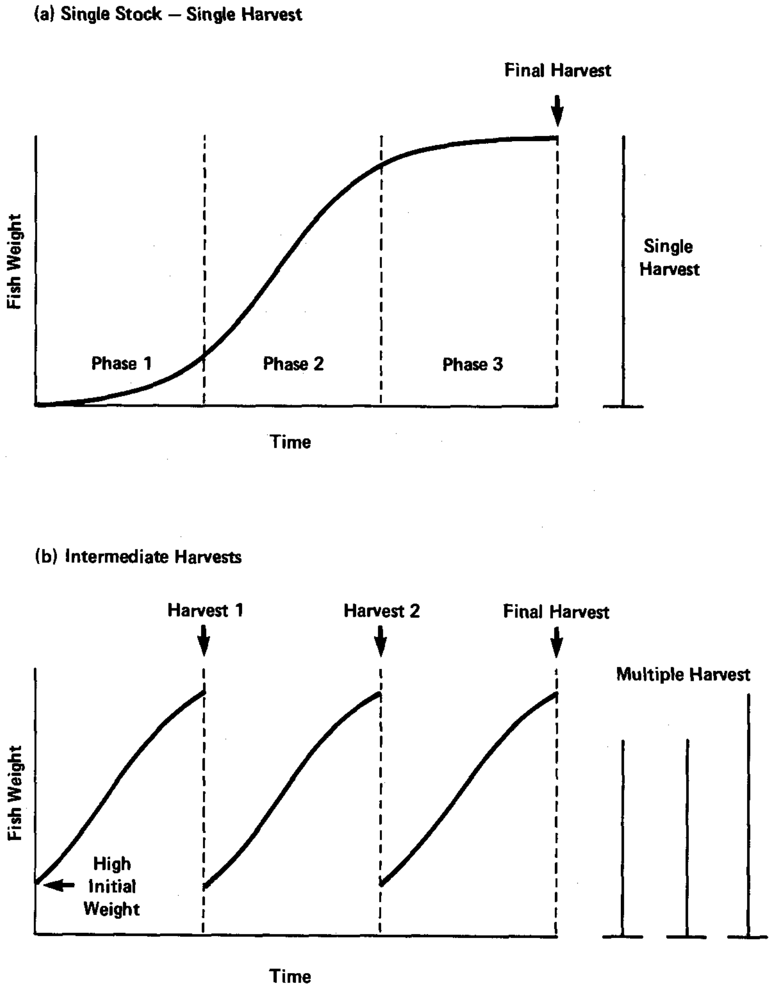

Fig. 11. Fish stock management to increase fish yields.

Systems modelling

Collection and analysis of data from complex aquaculture systems is difficult. However, attempts are now being made to improve the format of data collection from fishponds (e.g., CRSP 1986). Several groups have begun to apply powerful statistical techniques, such as multiple regression and critical path analysis, to data sets from waste-fed fishponds, from on-station experiments and farms (e.g., Milstein et al., in press; Pauly and Hopkins 1983; Prein 1985). Data sets can be analyzed and compared by different working groups anywhere in the world. The key is the collection and formatting of data in an appropriate form and the availability of suitable hardware and software. These techniques hold great promise for the future. A review of the application of systems modelling in aquaculture has been prepared by Cuenco (in press).

Systems modelling is also an important field of future research for integrated agriculture-aquaculture farming systems. Ecosystem modelling techniques have been applied to fishponds by Cuenco et al. (1985a, 1985b, 1985c) and Svirezhev et al. (1984). Modelling techniques have yet to be applied to integrated farms having an aquaculture subsystem but they are powerful tools for elucidating the major factors that control productivity and profitability (the 'bio-economics' of the farm) and hence the choice of management options.

There is a wealth of experience in such data analysis and modelling techniques available from agriculturists, especially farming systems specialists, of which aquatic systems researchers currently know virtually nothing.

Potential health hazards

The introduction of a fishpond as a farm subsystem should not pose any unacceptable risks to public health. There is a possibility that livestock manured ponds may present health problems for humans because some diseases of animals are transmissible to human beings. Although there are few data in the literature on disease transfer through the use of manure as a pond fertilizer, it does appear that the risk of disease transmission via fish grown in such ponds is low. Furthermore, such fish are nutritionally and economically beneficial for farmers and consumers. Fish are not susceptible to most infections of warm blooded animals (livestock and man); they are healthy and demonstrate good growth in well managed manured ponds. The main danger lies in the passive transfer of pathogens, e.g., *Salmonella* but there is a rapid attenuation of enteric microorganisms in manured ponds in the tropics, probably due to high temperature, pH and dissolved oxygen. Fish raised in manured ponds should be washed and cooked well prior to consumption as a final safeguard.

The construction of fishponds may provide breeding sites for insect vectors of disease, particularly mosquitoes that may transmit malaria. However, mosquito breeding in ponds can be largely controlled by good design and management, in particular by preventing vegetation either hanging into or emerging through the surface of the pond (Feachem et al. 1983). Furthermore, the fish themselves may aid mosquito control by the consumption of larvae.

A far greater threat to public health in certain parts of the world is schistosomiasis (bilharzia), an occupational hazard to people who enter fishponds. The disease is caused by *Schistosoma*, a helminth parasite for which the intermediate host is an aquatic snail. Schistosomiasis is a major insanitary disease of man and has increased with the construction of reservoirs and irrigation schemes. Although there are only small foci of infection in Asia, it is most widespread in Africa and northeast South America. Planned epidemiological and ecological studies must be carried out before the implementation of water development schemes in the tropics, including fishponds. A carefully defined package of chemotherapy, health education, sanitation and snail control is required to control the disease (WHO 1980). For most water-borne diseases, the environmental impact of fishpond development is broadly analogous to that of irrigation development, which has been recently reviewed by Verma (1986).

A recent report on the risk of human influenza pandemics from close association of pigs and poultry on Asian farms singled out integrated livestock-*fish* farming as being a potential source of increased pandemics, thereby creating a negative impression of the acceptability of integrated agriculture-aquaculture farming systems in general (Scholtissek and Naylor 1988). They suggested that pigs may be "mixing vessels" in which normally separate avian and human influenza virus reservoirs meet, leading to genetic reassortment and the origin of new human pandemic influenza strains. The promotion of integrated systems in the third world should not create potential human health hazards. However, the inferred link between aquaculture development and human influenza was grossly overstated. Pigs and poultry have been brought together *without fish* on traditional farms in Asia and Europe for centuries. Furthermore, integrated agriculture-aquaculture farming systems involving pigs, poultry and fish are rare and likely to remain so. Such a special case should not hamper the development and expansion of beneficial integrated crop-livestock-fish farming systems. More recent trends in livestock development in both East and West are towards monoculture because of management and marketing considerations and this also apply to the integration of livestock with fish. These points were made in subsequent correspondence (Edwards et al. 1988; Naylor and Scholtissek 1988).

Education

A Systems Approach to Agricultural Development

It is essential to appreciate the concepts that underpin the application of systems thinking to agricultural development before a framework for education to advance the development of integrated farming systems can be constructed. The term education is used here to encompass all levels of 'teaching about agriculture' from extension to farmers to tertiary level studies at universities (FAO 1984).

A systems approach to any activity starts with the concept that everything is connected and a change introduced in one part of the system will induce a change in other parts of the system. Whether this change will cause an unimportant ripple or an irreversible wave is often difficult to determine, particularly in complex systems involving the integrated farming of crops, livestock and fish. This implies that the study of parts of a system in isolation will not be adequate to understand the complete system or to solve problems that stand in the way of its design, construction, repair or improvement.

Modern concepts and techniques for a systems approach were developed by military scientists out of a need to explore the total implications of alternative strategies to achieve specified goals. The value of the approach was soon appreciated in other fields and the techniques have now found their way into many sections of science and industry under one name or another (Dent and Anderson 1971). Definitions and meanings of the words and phrases used are important first steps in systems work (Spedding 1979). So too is defining purpose. This is critical because it sets the framework in which discussion takes place and drives the decisionmaking process in systems operation.

The fact that there is something that can be called "a systems approach" implies that there must be:

- *A philosophical foundation* from which it derives (Popper 1959; Checkland 1984);
- *A body of theory* upon which it rests (Boulding 1956; von Bertalanffy 1968; Campbell 1985);
- *A set of principles* to guide action, the first of which is to identify, classify and describe the systems in which one is interested in order to establish their initial state (Spedding 1979);
- *A way of proceeding*. After it has been decided what system is being considered and how it operates now, if the purpose is to improve it, the prime problem that stands in the way of achieving this improvement must be identified and clearly defined. This is no easy task. In fact, Einstein once said that the definition of the problem is more important than the solution.

The next steps are:

- analyze the problem in relation to the purpose of the system;
- hypothesize a solution;
- synthesize the system under investigation;
- test the solution in the context of the system.

It is possible to proceed in one or more of three ways:

- Accept the hypothesis as a reasonable estimate of the truth and go ahead and test it in an *ad hoc* way;

- Test the hypothesis physically in a controlled, scientific way;
- Test the hypothesis in an abstract way by using computer models in which changes in systems variables can be manipulated.

If the solution is not acceptable to those operating the system then the whole process must be repeated.

A systems approach is highly applicable to the activity of farming systems research and development. It is an extension of a scientific approach (some say a mirror image) which will make traditional studies of agriculture and aquaculture more rewarding. Furthermore, it is evolving as a way of bridging the gap between the generation of knowledge by research and the use of that knowledge to improve the output of products and money from farming systems. The computer may be one of the tools it uses in addition to the backs of envelopes. Modelling and the construction of diagrams may be important techniques to employ while the collection and analysis of data will usually be an essential first step to establish the nature of the system under investigation.

The important point emerging from all these efforts to come to grips with the real forces that underpin agricultural development, and they are not always technical, is that more and more people are beginning to wonder what the world really looks like from a farmer's point of view; in effect it is becoming respectable to stand "in the shoes of a farmer" to find out what his purposes are in order to be able to identify opportunities that could be available to him, to define the problems that block their achievement and to seek acceptable solutions. We need to be able to formulate these problems in such a way that solutions to them are testable before a farmer commits to what might be an inappropriate course of action.

Education Programs

Recent reviews of fisheries education needs and opportunities have been prepared by Chua (1987) and ICLARM (1986). Although education in these publications is considered at all levels, only tertiary education at post-graduate level is dealt with in the present study because this is the level at which research and education are most interdependent and at which education is most urgently needed - to educate future educators. Universities and similar institutions are often thought of as centers of teaching and research. However, they can also be thought of more simply as centers of learning. Teachers, researchers and students are all involved in a learning process.

Tertiary education programs in agricultural/farming systems vary according to country and the circumstances of the institutions involved. However, the purpose of programs based on a systems approach is to produce people who are intelligent rather than informed; primarily biologists, but who are unafraid of either economics or mathematics or getting their hands dirty and who are psychologists and diplomats as well. Such people will be opportunity makers and takers and problem-solvers.

A criticism of a systems approach is exemplified in the statement "systems people know a little bit about everything and not much about anything". This criticism should not be taken any more seriously than the criticism of traditional subject specialists who are said to "know more and more about less and less". Both types of people are necessary; it is how their knowledge is used that is important. Furthermore, the knowledge base for agricultural production is now so great that the mere manipulation of the margin between the costs of inputs and the prices for outputs can produce either huge surpluses of agricultural products (as exemplified by the Common Agricultural Policy of the EEC) or tragic deficits as exemplified by the socially disturbed and overly controlled economies of some countries. What this really means is that the output of agricultural products is powerfully influenced by the *rewards* farmers receive for the *efforts* they make and the *risks* they take. This simple fact is sobering. Professional scientists must keep their feet on the ground and not become unduly impressed with the technical advances that they can achieve. The potential impact of new technology on farming systems is dependent upon a wide range of social and economic factors (Fig. 12).

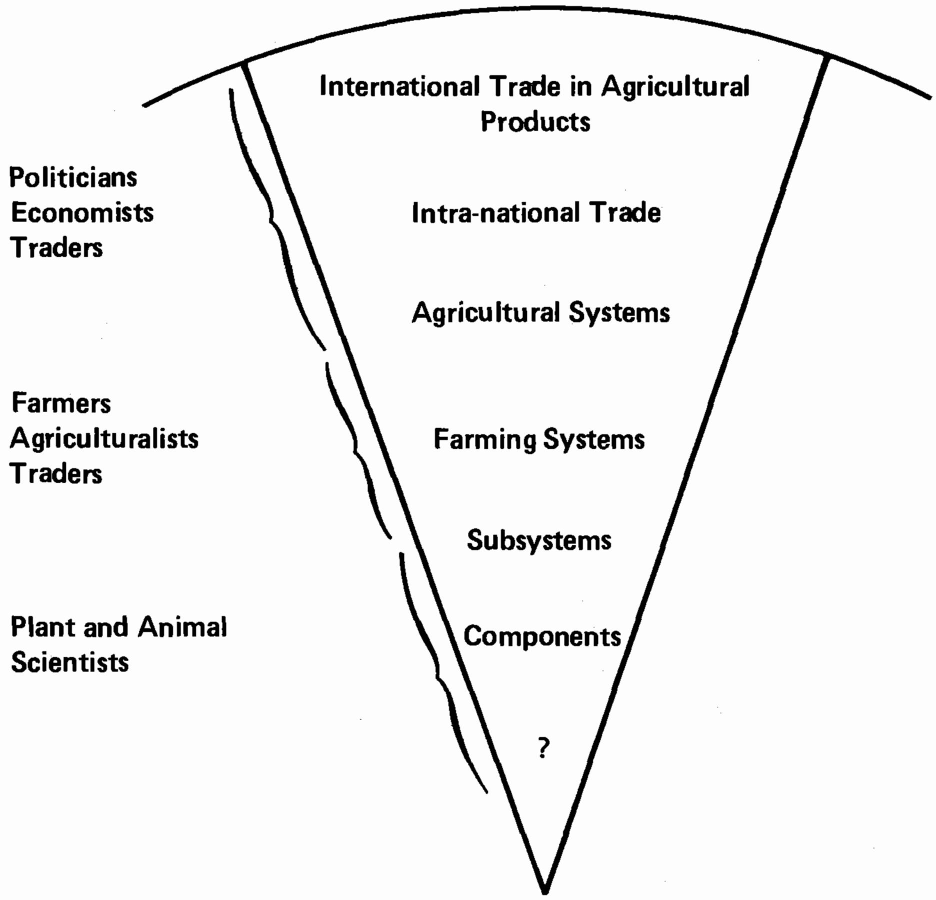

Fig. 12. Levels of focus in agricultural development (from Gartner 1984). Factors in the external environment of a farming system (exogenous factors) may show greater potential for improvement than factors in the internal environment of a farming system (endogenous factors). The term farming systems may then inhibit the teaching and understanding of the wider picture. To overcome this the term agricultural systems is used to encompass the delivery systems for providing essential materials and services to farmers and for getting products to consumers. The question mark indicates further possible levels of focus in this hierarchy of systems.

A systems approach to agricultural development provides a way of examining changes in the components of an agricultural system that will reveal their effects on the system as a whole. Students who develop knowledge, skills and attitudes in this direction should be able to assist in unravelling some of the complex agricultural issues of their time. How this might be achieved can be divided naturally into three teaching activities:

- Teaching what we know (KNOWLEDGE);
- Teaching how to discover what we need to know (RESEARCH); and
- Teaching how to combine both to make improvements in identified agricultural/farming systems (DEVELOPMENT).

Traditionally, teaching what we know provides the bulk of an undergraduate program; it is mostly receptive learning, perhaps with a short-term research project. Teaching how to discover what we need to know is normally confined to post-graduate programs at M.Sc. and Ph.D. levels using the classical methods of science. Teaching how to combine both to make improvements in identified agricultural/farming systems has only begun recently: experiential learning is usually dominant, even at the undergraduate level (Bawden et al. 1984), with receptive learning on the periphery of the education process which takes place within a systems context. Courses on "tools and techniques" are taken as required.

What constitutes an improvement is, of course, always open to debate, which relates back to the all important question "from whose point of view?" - government, researcher, farmer, trader, consumer? The likelihood of improvements being made can often be traced back to who holds the balance of power amongst these and other participants in the operation of an agricultural system. Therefore, an educational program should be heavily oriented towards practice so that the students at some time during their training "stand in the shoes" of a farmer, an extension worker, a researcher, a trader, a banker and a policymaker.

The Need for Research in Association with Tertiary Education

An active, visible research program is an essential component of the overall education process in a systems approach to agricultural development. Highly focused student thesis research on problems involved in the improvement of identified farming systems can certainly contribute to knowledge, but students come and go. A professional research program on the opportunities and problems within an institution's area of influence is needed to complete the structure of an educational program. Student research then takes place in the context of an on-going program, not in isolation, but in the greatest tradition of learning with the student working with and beside the teacher. Furthermore, the cooperation of farmers in this activity is essential. Without an understanding of their point of view, and continuity of contact, they are not likely to be interested in cooperating in the teaching program or in applying the results of the research work.

An Example of a Systems Approach to Education in Integrated Farming

Background and relation to national programs and other institutions

The work being done at the Asian Institute of Technology (AIT) is used as an example for the development of post-graduate programs in agricultural/farming systems. Full details are given in AIT (1988). This work is part of a larger regional program in education to develop systems thinking in key universities and institutes, the purpose of which is to link centers of learning and research to the centers of production. Students come from professional and farming communities, drawing upon each other's knowledge and skills in interlocking activities. The program, initially organized as a UNDP/FAO Regional Project, established post-graduate Diploma and M.Sc. courses in Farming Systems at the following universities: Khon Kaen University, Khon Kaen, Thailand; Zhejiang Agricultural University, Hangzhou, China; University of Peradeniya, Kandy, Sri Lanka; University of the Philippines at Los Baños, Los Baños, Philippines; Institut Pertanian Bogor, Bogor, Indonesia; National Institute of Agricultural Science, Hanoi, Vietnam. The national institutions were faced with the same questions that faced AIT: should programs have systems thinking and methods as the core of their activities with subject matter on the periphery *or* should traditional subjects and disciplines in agricultural/aquaculture science be supplemented by course work on a systems approach to agricultural development?

These questions have led to national programs that vary in style, content and delivery. Khon Kaen University, for example, has a farming systems research group. Members of this group contribute to teaching farming systems as a subject at undergraduate and post-graduate levels. The post-graduate Diploma program includes farming systems as core subject matter for the first time.

All programs share the common themes of trying to present subject knowledge in a systems context and to involve farmers (as well as other participants in agricultural systems) very early on as partners in the educational process.

Other tertiary educational institutions in the Asia-Pacific region have established substantive programs in Agricultural/Farming Systems, each with their own style and emphasis. Among these are: Hawkesbury Agricultural College, Richmond, Australia; Chiangmai University, Chiangmai, Thailand; and the South China Agricultural University, Guangzhou, China.

A key difference between AIT and the national institutions is that the latter can zero in on national issues relating to Farming Systems Development. However, AIT plays a vital complementary role with its international program by bringing together students from different countries. This drives home the point that agricultural development issues at the international level can dramatically affect those at the national level (Fig. 12).

The M.Sc. program in agricultural systems at AIT

General principles

The principle of delivery at AIT is based on the Chinese proverb:

> What we hear, we forget.
> What we see, we remember.
> What we do, we understand.

Any debate on improving the efficiency of small-scale farming systems in Asia should also include fish, the major traditional source of animal protein in many areas. Integrating fish with crop and livestock production adds to the complexity of the competition for the resources of labor and capital but opens up considerable possibilities for increasing the output of food and cash from the resources of land and water under a farmer's control. Therefore, practical work in farming systems development is focused on integrated farming systems involving crops, livestock and fish. The interrelationships in time and space between the components and resources of these farming systems are highly complex. Furthermore, the program concentrates on rainfed farming systems because these are widespread in Asia and have been neglected in development studies. It is believed that if students can be taught within the framework of these systems, they should develop the confidence to tackle any problem situation in agricultural or aquaculture development with imagination and ingenuity.

Structure

In setting up a study program to achieve these purposes, one is faced with existing institutional constraints. An exception to this is where one begins at the outset with a "Statement of Intent" to establish an institution based on a systems approach, such as was done for the International Livestock Centre for Africa (ILCA 1980).

Within an existing institution the options are:

a) create a revolution, which can have negative consequences;

b) slowly merge the new program with existing programs until an identifiable whole emerges, composed of teaching in terms of systems, components and techniques.

The choice depends on circumstances and people. AIT is proceeding with the latter option. The major problem faced, which is typical of systems work, is what to include in the program and what to leave out, in order to fit within the constraints of the academic requirements of the institution. These include: time allocated to complete the M.Sc. degree program; residential requirements; the minimum number of units required in terms of formal lectures and practical classes and thesis regulations.

Practical classes are most demanding but they are useful for introducing material that cannot be presented in lectures; in fact they generate a demand for relevant knowledge and information which assists with the choice of material to be included in lectures.

The AIT Masters program specifies a total of five terms (semesters), each of about 12 weeks, spread over 20 months. A minimum of 30 units of lectures and practicals are taken over three terms and a research thesis for 25 units of credit must be presented. A high staff student ratio is required because of the number of contact hours demanded by practicals: one full time professional (with appropriate technical assistance back-up) to six students. Three full time professionals with systems training are required to deliver an effective program in association with other faculty.

The core of the program consists of lectures and practicals on agricultural systems. The lectures:

- introduce systems concepts which provide the framework wherein course material delivered on soil, water, plants, animals, men, money, machines and markets can be applied in real life situations;
- expose the methodology of farming systems research and development;
- look at the wider issues involved in farming systems development in order to balance attention to the farmer on his farm with attention to government policy, market forces, input supply and consumer habits;
- establish an understanding of the need to reconcile many different points of view in the process of decisionmaking for agricultural development.

The practicals:

- give students experience in the recognition of opportunities for improving agricultural systems, in the identification of problems that stand in the way of their realization and in the finding of solutions to those problems;
- involve students in the development and continued improvement of an on-campus teaching farm of 2.5 ha involving the integration of crops (rice, maize, fruit and vegetables), livestock (buffalo) and fish (tilapia and carps);
- associate students with component research on an area of 2.5 ha adjoining the teaching farm on problems identified during its design, construction and operation;
- take students off-campus onto farms and into industry and government to investigate production problems, the supply of inputs, the marketing of outputs, the availability of credit and the formulation of policy.

Additional courses are given on: Crop Production Systems; Livestock Production Systems and Aquaculture Systems. These involve the essential biology involved in the "breeding, feeding, health and husbandry" of crops, livestock and fish, and their temporal and spatial requirements, all set within a systems context. The link to capital and labor is provided by another course, Farm Management Economics. The final recommended course is Integrated Farming and Waste Recycling in order to tie the above courses together and establish the links and energy flows in the food chain.

Elective courses to satisfy degree requirements can be taken in related subjects, such as agricultural engineering, rural development and computer science.

Important areas of concern

The program pays attention to two areas of major concern - water availability and pre- and post-harvest losses.

Rainfed farming is of great importance throughout the third world. Water is the key resource and this is brought home to students in the operation of the integrated farm under rainfed conditions. No irrigation water is allowed. Therefore, topics such as rainfall probabilities, soil moisture management and on-farm water harvesting, storage and distribution are of great importance and are highlighted in the practicals. Water is of course essential for fish. Here attention is given to its quality as well as its availability throughout the cycle of the seasons.

Efficiency in agricultural systems can be improved by increasing absolute output per unit of some resource, but a most neglected area for achieving it is in the reduction of losses of what has been produced. A substantive way to bring students' attention to this as well as to the enhancement of product marketability is considered essential.

Some problems

The educational process in agricultural systems requires working at "right angles" to conventional subject knowledge and research. Instead of attempting to reduce areas of ignorance in a particular subject by delving more deeply into it, it is necessary to probe available knowledge in many subjects and disciplines for the facts required to develop a view of a whole agricultural system (Fig. 13). This view needs to be focused at a sufficient level of resolution (Fig. 12) to determine the consequences of different policies and decisions that affect production and profit and other system properties.

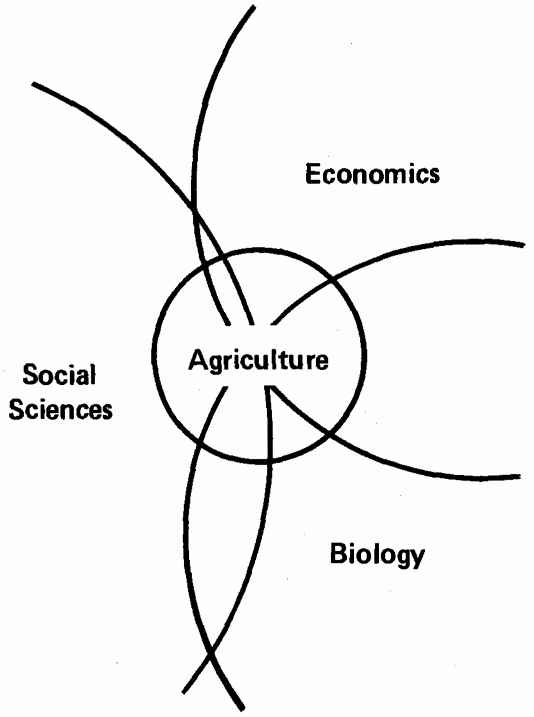

Fig. 13. Diagrammatic representation of agriculture as a subject with some of the overlapping disciplines involved (from Spedding 1979).

A problem with this type of work is that in attempting to build bridges among education, research, extension and practice, one can be uncomfortably isolated at times from the security of the foundations on which these recognized activities rest. Students may suffer this discomfort very early on in their course work. They may feel unable to compete with other students in subjects that are new to them, which affects their self-esteem. However, they slowly realize that they are becoming experts in their own right in viewing systems as a whole rather than as separate parts and that they can absorb relevant subject knowledge more effectively. Then comes an understanding of how the manifestation of a problem (opportunity) in a system is often a long way from the cause (stimulus). Finally comes the perception of system dynamics involving rates, levels and interactions.

A second problem confronting students is the difficulty of accepting the concept of a hierarchy of systems and that a component of one system could be a system itself with its own boundary and properties. Once this is accepted, component study and research becomes just as valid and important as whole systems research; so long as the problem is generated by the system to which the solution will apply.

The third problem and the most difficult in systems work is "how to start?" The need at times for great feats of imagination and ingenuity was mentioned earlier, but some simple advice to students is "start!" by asking the questions: what do I want? what do I have? what do I need?

Another problem common to international institutions like AIT is language. First, there is the difficulty of translating between cultures, particularly when it comes to abstract concepts. Second, there is the more practical difficulty of language when students carry out off-campus/on-farm field work in Thailand. This has necessitated additional Thai staff and places what must be construed as a helpful burden on Thai students. The problem disappears with the establishment of national education programs in agricultural/farming systems development, such as those that have been established through the regional program.

Employment Opportunities

How will the graduates of such educational programs with a systems perspective be employed? A logical place for a graduate with interdisciplinary training is in agricultural extension because farmers must integrate their activities daily, seasonally and annually. However, some problems affecting the performance of farming systems are quite complex and may not be resolved in the day-to-day activities of an extension officer. Farming Systems Institutes are being formed to tackle complex problems and to bridge the gap between subject- and commodity-oriented research and extension services to multicultural small-scale farming systems. Such institutes will require graduates with a systems perspective. However, it is still not enough just to produce people with a systems perspective; job titles, conditions of employment, promotional prospects and career ranges will have to be established. This does not preclude the wide variety of jobs in private industry concerned with agriculture which are appropriate for a person trained as an opportunity maker and taker and as a problem solver.

Points of Vulnerability

The approach to tertiary education in agricultural systems outlined here is somewhat revolutionary, especially as far as the integration of teaching and research on aquaculture within the context of agricultural systems is concerned. Aquaculture educators have yet to get involved in the mainstream of agricultural research and education. The approach, like all new approaches has a number of points of vulnerability. These include:

A. What happens if the demand for tertiary educational programs in farming systems development outstrips the rate at which qualified, experienced teachers can be developed?

The conservative answer is to make haste slowly. It would be better to have a few carefully thought-out programs - properly staffed, adequately funded and producing skilled people - than the opposite. Still, there is no better way to learn how to set up a program than "to have a go"; failure is often a very fast way of learning! In fact, success is generally the outcome of a long history of overcoming difficulties, if not failures.

B. Students may be discouraged when they re-enter the working environment if their superiors do not appreciate their newly acquired skills and fail to utilize them effectively.

C. Post-graduate students seeking to pursue theses in systems work may be penalized because their work does not fit the existing academic requirements of some institutions. Applicants for post-graduate programs may be rejected because their background and qualifications do not fit the requirements of traditional departments. These difficulties are especially likely in institutions which attempt to offer new programs in farming systems and which face a transitional period from their former traditional approach.

D. It will be essential to have international and national lead centers of excellence from which institutions new to a systems approach can draw support and guidance.

E. Specialists in agricultural/farming systems will need to meet regularly to discuss the way in which the subject matter is or should be developing; otherwise it will remain static and unresponsive to the changing needs of agriculture and aquaculture.

Despite these points of vulnerability, it is apparent already that this interdisciplinary approach to education for farming systems development will expand to involve institutions throughout the third world.

An Institutional Framework

General Considerations

Geographical/climatic

Where can research and education for the development of integrated farming systems in the tropics and appropriate subtropical regions best be conducted? The rational answer is undoubtedly in or close to the farming areas where the results will be utilized or in a comparable environment, rather than in artificial 'laboratory' conditions elsewhere. Unfortunately, most research and teaching institutions in the humid tropics and subtropics, where integrated farming has most promise, require considerable strengthening to carry out successful programs. This applies particularly to those in Africa. Therefore the experience of the few strong institutions investigating the development of integrated agriculture-aquaculture systems located in the tropics is invaluable.

These institutions are in Asia: AIT, ICLARM and its cooperators, and some institutions within the ADCP/FAO Network of Aquaculture Centres in Asia (NACA). They constitute vital assets for the future development of tropical integrated farming and merit strong support to sustain their programs and to expand their activities to help others. International cooperation between such established groups and emergent groups in other regions across the tropical belt is likely to be more attractive to donors and more valuable to the researchers concerned than isolated efforts or the more familiar North-South linkages. In particular, the concept of integrated farming research cooperation, educational linkages and technology transfer in a South-South mode from Asia to Africa and other regions has great appeal. Some of the most productive Asian aquaculture systems are based on African fish (tilapias) whereas the potential of tilapia culture in Africa remains unrealized because of a variety of technical, socioeconomic and institutional constraints. This applies especially to small- and medium-scale aquaculture and integrated farming. The need for increased interregional cooperation amongst tropical institutions in research and education for the development of integrated farming is clear.

There is still of course an important role for nontropical institutions, including developed-country universities, in such research and education. Basic laboratory research - for example, on the physiology and biochemistry of pond biota - can be performed wherever good laboratory facilities exist. Many of the more expensive and sophisticated items of analytical and measuring equipment needed for such studies are difficult and expensive to maintain in the humid tropics; it makes little sense to install them in third-world institutions that have chronic recurrent funding problems. However, there is no substitute for performing tropical farming research and education *in the tropics* in projects *involving the study of systems that are interactive with the natural environment*. This applies to studies on fish (individuals, populations and communities), nutritional and environmental physiology, control of reproduction, parasites and diseases and above all to integrated farming systems that have crop and livestock subsystems in addition to fish, and to the highly location-specific factors involved in certain aspects of social science analysis.

Institutions located in the subtropics can perform useful work for application under their local conditions but cannot be effective leaders of a program targeted mainly on the tropics. For example, in Israel there has been a highly productive research effort on the application to fishponds of livestock wastes supplemented with inorganic fertilizers and feeds. Israeli summer temperatures are tropical, but winter temperatures prevent the growth and reproduction of fish.

Israeli research has therefore been directed towards improving Israeli technology and management practices, including overwintering of tilapias with production cycles much longer than would apply to tilapia culture in the tropics, intensive hatchery systems and large production ponds, all under unique socioeconomic conditions. Similar considerations apply to the research programs of some temperate European countries.

In the People's Republic of China, the 'ancestral home' of integrated farming, the climate is not like those of tropical third-world countries. The ADCP/NACA Regional Lead Centre in China is at the Freshwater Fisheries Centre, Wuxi, Jiangsu, where winter temperatures fall to 5°C. This is below the lower thermal tolerance limit for tilapias, which must therefore be held in greenhouses from November to May (FAO 1983). The species that survive there, principally carps, have limited appeal in many other countries (Pullin 1986). No systems can be studied at Wuxi which require an uninterrupted growth phase of more than eight months. This center concentrates on integrated farming research and education on Chinese systems. It is not well-sited, however, to play a major role in a program focused on the tropics. The same applies to the ADCP interregional center in Hungary. Research and education for the development of tropical aquaculture cannot be realistically performed outside the tropics. Considerable contributions have been made by Chinese, European and Israeli researchers to the advancement of aquaculture but systems developed in these areas and the research data that support them cannot be transferred directly to tropical third-world countries. Experts from nontropical institutions can therefore best participate in future programs by contributing their knowledge to activities *located in the tropics*.

Academic

It makes no sense to separate the study and implementation of inland aquaculture from agriculture in third-world countries. Crop and livestock farmers will be the fish farmers of the future. The challenge is to integrate aquaculture into existing farming systems as a profitable subsystem, thereby improving the productivity and profitability of farms.

To accomplish the research and educational activities outlined in this framework will require the cooperation of researchers from different disciplines - aquaculturists, agronomists, biologists (principally fish physiologists, microbial ecologists and other specialists on pond biota) engineers, farming systems specialists, livestock specialists, economists and other social scientists. It cannot be done by biologically oriented aquaculturists alone. Thus, a program that is truly interdisciplinary is needed. Aquaculture research must be brought into the mainstream of agricultural research. This requires a new approach because aquaculture research to date has been largely the province of fish biologists. They and their donors have rarely recognized that aquaculture must be seen in the broader context of other food producing systems, principally agriculture and capture fisheries. Indeed, aquaculture in this context will use many of the same resources and marketing channels.

A new research initiative is required. A twofold program is desirable: genetic improvement of appropriate cultured species and interdisciplinary (biotechnical and socioeconomic) research to improve culture systems (ICLARM 1988, Fig. 14). These two components must be interactive and complementary and focus on small- and medium-scale farms. This concept may be challenged by those who prefer separate discipline-specific programs in diseases, engineering, nutrition, reproduction, economics and sociology. However, the advantage of a simpler twofold framework is that research expertise in these and other disciplines can be co-opted to assist the main research thrust as and when required.

Tilapia has the widest acceptance and best prospects for international programs (Pullin 1985). The Second International Symposium on Tilapia in Aquaculture, held in Bangkok, 16-20 March 1987 drew 258 participants from 40 countries (Pullin et al., in press). The largest scientific sessions were on genetics/reproduction and culture systems/management. Carps are also important, particularly in some Asian countries, e.g., Bangladesh, China, India, Indonesia, Pakistan, Nepal, but carp culture has far less scope for growth worldwide than tilapia culture because of market acceptance problems (bony flesh and poor keeping qualities) and the relatively sophisticated hatchery technology required for some species (Pullin 1986). Tilapia is

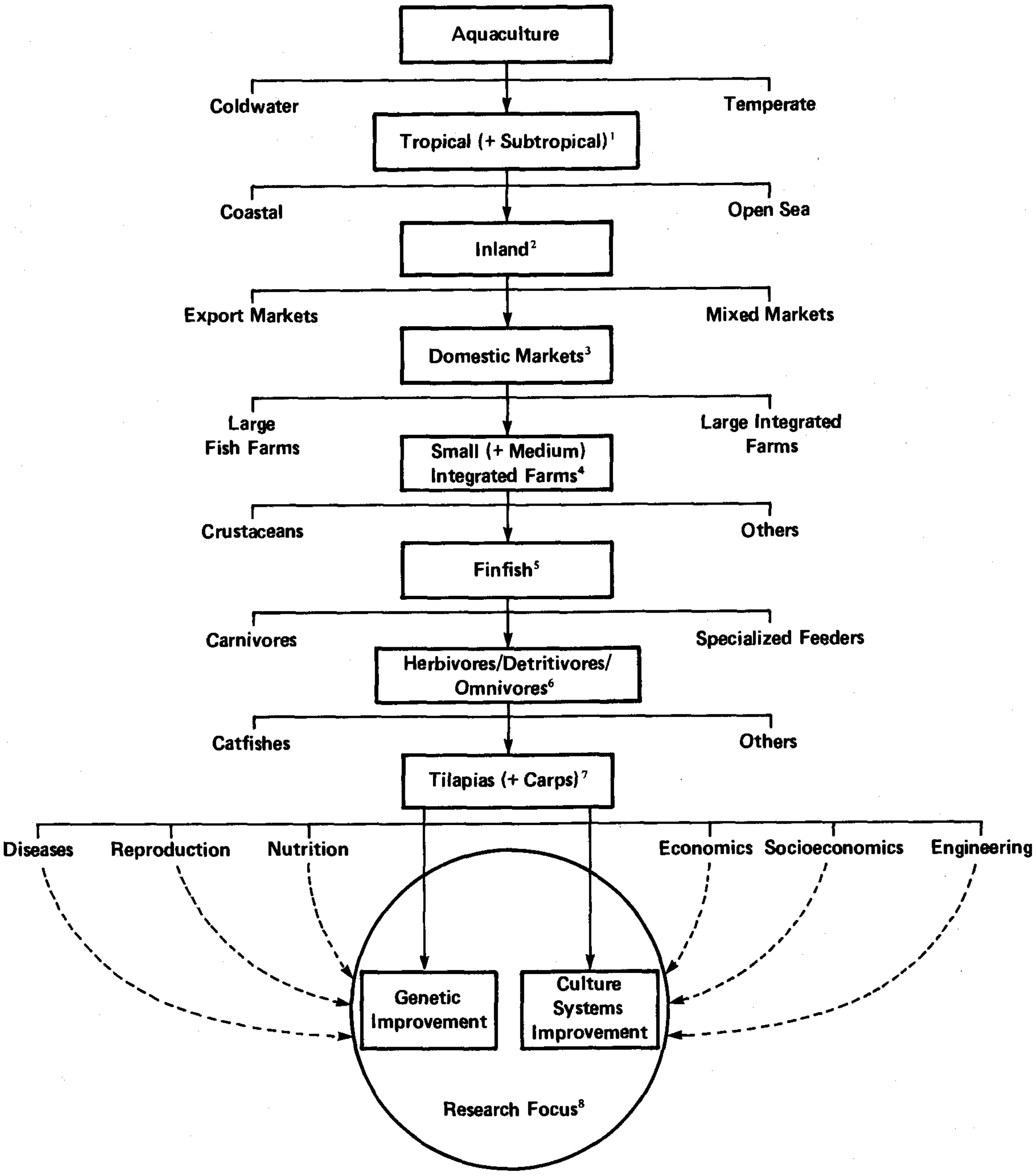

Fig. 14. Focus for a proposed new initiative in aquaculture research. The central boxed categories represent the choice of research themes. The dotted lines indicate inputs from research in other disciplines as and when required.

Explanatory notes: 1. *Climate.* Aquaculture has most scope for growth in the humid tropics (and parts of the subtropics). 2. *Sector.* Inland aquaculture has the most potential. Open sea and coastal aquaculture have greater environmental constraints. Farmers are better suited to fish husbandry than fishermen. 3. *Markets.* Exports earn foreign exchange but markets may be short-lived and benefits limited to the wealthy. By concentrating on domestic markets, rural farmers can improve their own livelihood and produce fish at prices affordable by the rural and urban poor. 4. *Farming system/scale.* Aquaculture is most attractive as a subsystem, integrated into small- (and medium-) scale farming systems. Such integration can be applied in rainfed and irrigated systems. 5. *Target group.* The finfish offer better prospects for sustainable livelihood improvement than the crustaceans and other groups. 6. *Feeding habits.* Herbivorous/detritivorous/omnivorous fishes are better for culture in integrated farming systems than carnivores or specialized feeders. Crop byproducts and livestock excreta can be used as fish feeds and pond fertilizers. 7. *Species focus.* The tilapias (and carps) are the best species to use. The catfishes (some of which are carnivorous) are less suited to integrated farming. They require intensive feeding. 8. *Research focus.* Genetic improvement of tropical finfish can make a major impact on fish production similar to those achieved for crops and livestock. It has not yet been attempted through a well-focused program. It must be interactive with culture systems improvement research, concentrated on integrated agriculture-aquaculture farming systems.

probably the easiest fish in the world to breed and to grow in a wide range of systems. There have been market swings towards tilapia and away from milkfish in the Philippines and Taiwan. Even in China and the Indian subcontinent, which have traditionally preferred carps, interest in tilapia culture is increasing rapidly although experience is very limited. However, carps are included in the research focus defined here because some can be grown in productive polyculture with tilapia and have greater tolerance to the seasonally cool temperatures of the subtropics.

Institutional

Unfortunately, many existing aquaculture research facilities in the tropics and subtropics are badly sited and/or poorly supported. To lead research and education activities, an institution must fulfill similar criteria to those that have ensured the success of the international agricultural research centers: availability of land and water, good communications, schooling, housing, transportation links and security. Without these it is exceedingly difficult to attract and retain the services of high quality staff and to conduct sustained research and educational programs.

A *core program* is essential to provide strong leadership and coordination for the research and educational framework defined here. This must be a program of active research and education, not just a secretariat and information base.

The core program should be independent to insulate it from the frequent shifts in objectives, policy and funding support that are so characteristic of national agencies and governments and which consequently affect the programs of institutions dependent upon their recurrent support. A core program needs sustained objectives and sustained funding.

The involvement of international, regional and national institutions and researchers outside the core program should be sought by means of a network, led and coordinated from the core. This is how interregional cooperation can best be achieved. Research advances and technology development by the core and by relatively strong Asian institutions participating in the network can thereby be shared with institutions in Africa and other regions.

The benefits and cost-effectiveness of networks are described by Plucknett and Smith (1984, 1986). They point out that many of the International Agricultural Research Centers (IARCs) contract out basic research to "avoid duplication of effort and to keep in touch with upstream developments". They give as an example the cooperation of "botanists, taxonomists, cytologists, geneticists, ecologists, biochemists and plant breeders" in crop development research. It obviously makes sense to tap the expertise of strong university departments and research institutions from all over the world for such interdisciplinary work. The same applies to research and education in integrated farming. Here the expertise and participation of the crop and livestock IARCs and other centers (such as Winrock International for livestock) would be of great value.

ICLARM coordinates the Asian Fisheries Social Science Research Network (AFSSRN): a network of institutions, the work of which encompasses aquaculture and fisheries (Maclean and Dizon 1987). The AFSSRN is planning increasing activities in integrated agriculture-aquaculture in Southeast Asia and thus could potentially provide some of the social science expertise required.

A list of some institutions with ongoing or potential interests in integrated farming (i.e., possible participants in a global network) is given in Table 4. This is not an exhaustive list and could be supplemented with many more institutions, particularly agricultural institutions.

However, the temptation to involve from the outset as many institutions as possible in a network should be avoided. It may create a good political impression but has pitfalls. The efforts required for liaison activities for large complex institutional networks and the thin spreading of funds can prejudice the goals of making rapid research and educational advances. Therefore, it is argued here that it is better to concentrate on a well defined core program and a network of a small number of strong institutions with proven ability to advance research and educational goals. It would be the responsibility of each of these institutions to expand the network further. There is also scope for development of a larger network of individual researchers, the main

Table 4. Some institutions with current or potential interest in research and education for the development of integrated agriculture-aquaculture systems. This is not an exhaustive list and there are many other institutions that can contribute to integrated farming research and education, particularly if the sectoral barriers between agriculture and aquaculture are lowered.

A. Suggested Core Program and Network Coordination

Asian Institute of Technology, Bangkok, Thailand
International Center for Living Aquatic Resources Management, Manila, Philippines

B. Potential Network Participants in Asia, Africa and Some of the Developed Countries

1. *Asia*

Bangladesh	Bangladesh Agricultural Research Council, Bangladesh Agricultural University, Mymensingh; Fisheries Research Institute, Mymensingh
China	South China Agricultural University, Guangzshou; Pearl River Fisheries Institute, Guangzshou; Freshwater Fisheries Centre (NACA Regional Lead Centre), Wuxi, Jiangsu; Zhejiang Agricultural University, Hangzhou, Zhejiang
India	International Crops Research Institute for the Semi-Arid Tropics, Hyderabad; Central Institute of Freshwater Aquaculture (NACA Regional Lead Centre), Dhauli, Bhubaneshwar; Tamil Nadu Agricultural University, Coimbatore
Indonesia	Agency for Agricultural Research and Development; Directorate General of Fisheries; Institut Pertanian Bogor, Bogor
Malaysia	Universiti Pertanian Malaysia, Serdang, Selangor
Nepal	National Aquaculture Centre for Training and Allied Research, Janakpur and Integrated Farming Lead Station, Hetauda
Philippines	Central Luzon State University, Muñoz; International Rice Research Institute, Los Baños and its Asian Rice Farming System Network; University of the Philippines at Los Baños; University of the Philippines in the Visayas
Taiwan	Asian Vegetable Research and Development Center, Tainan
Thailand	Khon Kaen University; National Inland Fisheries Institute (NACA Regional Lead Centre), Bangkok
Sri Lanka	University of Peradeniya; Ruhuna University, Matara

2. *Africa*

Cameroon	Institut de Recherches Zootechniques, Yaoundé; FAO/UNDP projects
Ethiopia	International Livestock Centre for Africa, Addis Ababa
Ghana	Institute of Aquatic Biology, Achimota, Accra
Côte d'Ivoire	Centre de Recherches Océanologiques, Abidjan; Institut des Savanes, Bouaké; West African Rice Development Association, Bouaké
Malaŵi	ICLARM/Malaŵi Department of Fisheries, Lilongwe; Bunda College of Agriculture, Lilongwe and Chancellor College, Zomba; University of Malaŵi, International Crops Research Institute for the Semi-Arid Tropics/Chitedze Agricultural College, Chitedze
Nigeria	International Institute for Tropical Agriculture, Ibadan; University of Lagos; Rivers State University, University of Calabar
Rwanda	Université Nacional, Rwanda
Zambia	Department of Fisheries/FAO/UNDP Project, Chilanga
Zimbabwe	Department of Agriculture, University of Zimbabwe, Harare

Continued

Table 4. (continued)

3. *Developed Countries*

Australia	Department of Primary Industries, Brisbane; Hawkesbury Agricultural College, Richmond
France	Centre Technique Forestier Tropical, Nogent-sur-Marne, Ecole Normal Supérieure Agronomique, Toulouse; Institut National de la Recherche Agronomique, Jouy-en-Josas
Israel	Agricultural Research Organisation, Bet Dagan and its Fish Culture Station, Dor, Hof Hacarmel
Japan	Asian Productivity Organisation, Tokyo; United Nations University, Tokyo
Netherlands	Agricultural University, Wageningen
Norway	Agricultural University, Ås.
United Kingdom	Institute of Aquaculture, University of Stirling, Stirling; University of Reading, Reading
United States of America	Auburn University, Auburn, Alabama; Oregon State University and associated US universities within the Consortium for International Fisheries and Aquaculture Development; Winrock International

C. Potential Future Network Participants in the Caribbean and Latin America

1. *Caribbean*

Jamaica	Aquaculture Program, Department of Zoology, University of the West Indies, Kingston
Puerto Rico	University of Puerto Rico, Mayaguez
US Virgin Islands	Aquaculture Program, College of the Virgin Islands, Kingshill, St. Croix

2. *Latin America*

Colombia	Centro Internacional de Agricultura Tropical, Cali
Mexico	Instituto de Investigaciones sobre Recursos Bioticos, Xalapa, Vera Cruz; Centro Internacional de Mejoriamento Maiz y Trigo, Mexico City
Panama	Direccion Nacional de Acuicultura, Ministerio de Desarrollo Agropecuario, Panama City
Peru	Universidad Nacional Agraria, La Molina, Lima; Centro International de la Papa, Lima

functions of which are provision and exchange of information and results between members. ICLARM, for example, operates a highly successful network of this type in fisheries science: the ICLARM Network of Tropical Fisheries Scientists with about 700 members in 80 countries (Munro and Pauly 1982). ICLARM launched a sister Network of Tropical Aquaculture Scientists (NTAS) in mid-1987. The NTAS has integrated agriculture-aquaculture research as one of its major themes (Pullin and Paguio 1987), and its membership currently exceeds 200 individuals.

On-farm activities

In tropical third-world countries, there are many experimental aquaculture stations which function poorly. Most were built with no clear objectives other than broad ideas to develop and demonstrate aquaculture. Most lack realistic recurrent funding. A further common fault is that their ponds are often too few in number to permit adequate replication of treatments and/or too large to manage adequately. The most valuable on-station research results in tropical Asia have come from ponds in the range of 200 to 1,000 m^2, particularly 200 to 400 m^2.

There are also large, so-called demonstration facilities. In reality, these have little to demonstrate other than attempts to increase their on-site production year-by-year by what is really guesswork: changing various inputs simultaneously, e.g., species combinations, stocking densities and management practices. This has been a feature of much on-station 'research' in both Africa and Asia and is still widely practised. The fish yields achieved may impress politicians and funding agencies but rarely give insights into the underlying basis of aquaculture production in a form relevant to small-scale farmers who are seeking to adopt or improve systems based on their own limited resources. Moreover, the financial analysis of on-station/demonstration farms are usually very special cases even though it is often presented as representative of industry economics which it is not.

Some researchers have worked successfully with farmer cooperators but the concept of investigative on-farm research in integrated farming (involving cooperation between farmers, researchers and extension workers from conceptualization through experimentation to analysis, publication, dissemination and implementation of results) remains poorly developed. Where there are potential farmer cooperators, and particularly where these have close working relationships with extension services, such activities can generate important data and direct benefits to farmers. Moreover, the compilation of databases from working farms can give valuable insights into the most important factors affecting the productivity of a given system and can be a valuable addition to databases obtained from on-station research. This is of course only possible where a significant number of farmer cooperators can be easily reached and are willing to cooperate with researchers and extension workers.

Johnson and Claar (1986) argue for stronger linkages between farmers and researchers to emphasize research under farm conditions. They report that farming systems research in Zambia and its relationship with extension have been improved by the creation of posts for Research Extension Liaison Officers. This facilitates the development of a research-extension continuum. Phiri (1986) has surveyed the "institutional environment" for agricultural development in Malaŵi and concludes that there is a lack of coordination between researchers from different institutions, extension workers, planners and policymakers. He argues strongly for "multi-disciplinary on-farm research coupled with 'bottom-up' (rather than 'top down') planning ...". Lightfoot (1987) stated that farmer participation in farming systems research is vital. He reviews 'indigenous research' by farmers and confirms that many farmers understand well the concepts of experimentation and controlled input-output trials. However, he also points out that such indigenous research is slow; that farmers' knowledge is hard to elicit and that there are problems in implementing on-farm research that require the researcher to share risk with the farmer and to replicate trials across farms for "quicker definitive answers". Despite these difficulties it is clear that "indigenous research" by farmers and formal experimentation can both generate important data.

It is concluded that on-farm research, which is perhaps better termed 'adaptive field trials', can be exceedingly valuable, particularly in the tropics where on-station experimental pond and farm facilities are in short supply. It facilitates the generation of data and its use in technology development directly with farmer cooperators. Therefore, a program of research and education in integrated farming should involve on-farm trials and educational activities as well as on-station activities for two main reasons: (i) it will increase the availability of experimental facilities and (given adequate safeguards and supervision) the flow of results; (ii) it will allow the testing of systems under 'real world' conditions.

An Institutional Framework

A core program for research and education in tropical crop-livestock-fish integrated farming should undoubtedly be located in tropical Asia. Its potential for development in other regions (for example in Africa, see Preface) is less certain and leadership from Asia is vital. Then it can best serve the established and expanding integrated farming systems in this region through on-station and on-farm research and can educate students from other regions in the factors that are making Asian systems successful. It should be located in the tropics where tilapias and some carps can be bred and grown year-round. Moreover, it should be located in one or more countries in which these groups are accepted as farmed fish. Only from such an environment can research advances and educational activities progress to serve a wide clientele. The clearest candidate countries are the Philippines and Thailand. These countries have access to all the required fish species and practice a wide range of farming systems. ICLARM and AIT and their cooperators in the Philippines and Thailand are major institutions for integrated agriculture-aquaculture research and education in tropical Asia. The NACA Regional Lead Centre in India at Dhauli, Bhubaneshwar, focuses on the development of Indian major carp composite fish culture. The National Inland Fisheries Institute, Bangkok, part of the Thai Department of Fisheries, is another tropical NACA Regional Lead Centre. The NACA Lead Centre at Wuxi, China, is outside the tropics but could be a valuable network participant for research on Chinese integrated farming systems. The Aquaculture Department of Southeast Asian Fisheries Development Center (SEAFDEC), Philippines (which is also a NACA Regional Lead Centre), has not yet been a major player in integrated farming research and education and does not yet have the facilities for such research. Moreover, as NACA changes from a UNDP project to an intergovernmental organization (NACA 1986), some of its member institutions in other Asian countries, e.g., Bangladesh, Indonesia, Nepal and Sri Lanka, may increase their interests in integrated farming.

Turning beyond the core program and potential Asian network members to Africa and other regions, here it is difficult to make firm recommendations. The African Regional Aquaculture Centre (ARAC), Nigeria (part of FAO/ADCP) has achieved little research progress in integrated farming, but has included this topic in some of its training programs. The strong groups in integrated farming involving fish subsystems in Africa tend to be project teams rather than institutions. Good examples are a UNDP aquaculture project at Bouaké, Côte d'Ivoire (Nugent 1987) and an FAO/UNDP project at Chilanga, Zambia (Gopalakrishnan 1987).

The advent in 1986 of an ICLARM base in Malaŵi, with its initial activities tightly focused on an integrated farming research and educational project - Research for the Development of Tropical Aquaculture Technology Appropriate for Implementation in Rural Africa, funded by the Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ), GmbH - should help to strengthen institutional capabilities in southern Africa in the future. ICLARM has begun a program of interdisciplinary research on small-scale integrated farming in Malaŵi (in cooperation with the Malaŵi Department of Fisheries and Chancellor College, University of Malaŵi) and has established linkages to help with orientation on tropical integrated farming systems for African researchers and culturists in Cameroun, Côte d'Ivoire, Ghana, Rwanda and Zimbabwe (Paguio 1987).

For Latin America and other regions (Caribbean and Pacific), the picture is similar. There are a few research and development groups with strong interests in integrated farming, principally in Mexico, Panama and Peru, but the overall capabilities of these regions in integrated farming research and education are limited. Moreover, the scope for growth of freshwater aquaculture in these regions is less certain than for Asia and Africa.

Therefore, the institutional framework recommended here is a strong core program at the center of a network of a few strong institutions in Asia, with linkages to: 1) integrated farming groups and institutions in Africa to foster Asia-Africa interregional cooperation and 2) linkages to strong research groups worldwide for supportive research and educational expertise (especially universities). Further linkages to Latin America and other developing regions are recommended if strong interest, institutional capabilities and development potential can be demonstrated. On a wider front, the ICLARM NTAS is expected to fulfill the task of linking and providing information to individual researchers worldwide. Its members with integrated farming interests will clearly benefit from contact with the institutional framework proposed here and can feed in their own information to help research and education activities. The institutional framework envisaged in general terms is depicted in Fig. 15. It is clearly necessary to survey the capabilities and interests of potential network participants. However, lists of potential network participants have been prepared (Table 4) based on information presented at the ICLARM/UNDP Workshop, "Towards a Research Framework for Tropical Integrated Agriculture-Aquaculture Farming Systems", 15-17 October 1986 (see Appendix I).

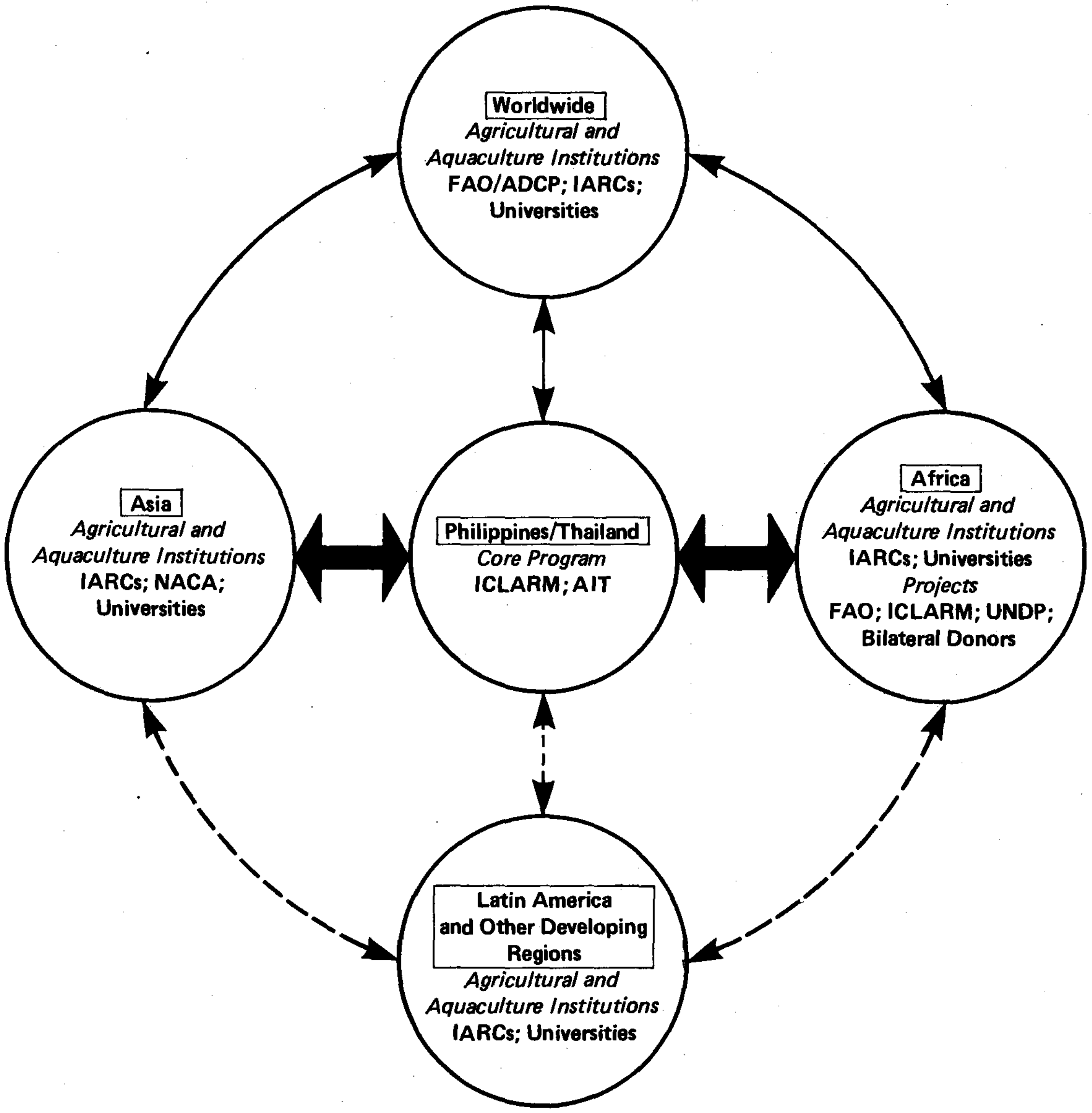

Fig. 15. A suggested framework for an international program of cooperation in research and education for the development of integrated agriculture-aquaculture. The ICLARM/AIT core program has responsibility for research and educational leadership and coordination of a worldwide network of institutions, to be selected according to their expertise and interests. The broad arrows (◀━━▶) indicate the major network linkages between the core, Africa and Asia. The narrow arrows (◀——▶) indicate additional linkages to other strong research and teaching groups. The dotted arrows (◀– – –▶) indicate possible future linkages to institutions in other developing regions (see text). Acronyms are: ADCP, Aquaculture Coordination and Development Programme; AIT, Asian Institute of Technology; FAO, Food and Agriculture Organization of the United Nations; IARCs, International Agricultural Research Centers; ICLARM, International Center for Living Aquatic Resources Management; NACA Network of Aquaculture Centers in Asia; UNDP, United Nations Development Programme.

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APPENDIX I

WORKSHOP - TOWARDS A RESEARCH FRAMEWORK FOR TROPICAL INTEGRATED AGRICULTURE-AQUACULTURE FARMING SYSTEMS

15-17 October 1986, Manila, Philippines

A workshop was convened by ICLARM as part of the information-gathering process from which this study was produced. The workshop was supported entirely by UNDP and ICLARM and was held at ICLARM Headquarters, Manila.

The following papers were presented. Copies of the papers and a summary report may be obtained from Dr. R.S.V. Pullin, ICLARM.

International Research Cooperation in Wastefed Aquaculture and Integrated Farming	**Dr. Roger S.V. Pullin**
Research Methodologies for the Development of Tropical Integrated Farming and Wastefed Aquaculture Systems	**Dr. Kevin D. Hopkins**
A Farming Systems Research Approach to Integrated Agriculture-Aquaculture	**Dr. Joseph A. Gartner**
Social Science and Economics Research Needs for the Development of Wastefed Aquaculture and Integrated Farming	**Dr. Ian R. Smith**
Research for Training Needs for Wastefed Aquaculture and Integrated Farming	**Dr. Peter Edwards**
The Research-Development Interface in Integrated Farming with Special Reference to Africa	**Dr. M.N. Kutty**
Information Flow and Extension in Integrated Farming Systems Research and Development	**Mr. Jay L. Maclean**
Research Priorities for the Development of Rural Aquaculture in Africa	**Dr. John D. Balarin**
The Current Status and Future Potential of Tropical Integrated Farming Systems in Asia	**Dr. V.R.P. Sinha**
Sociocultural Aspects of Integrated Farming Technology Transfer from Asia to Africa	**Dr. Kenneth Ruddle**

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INTERNATIONAL CENTER FOR LIVING AQUATIC RESOURCES MANAGEMENT

The International Center for Living Aquatic Resources Management (ICLARM) is an autonomous, nonprofit, international scientific and technical center which has been organized to conduct, stimulate and accelerate research on all aspects of fisheries and other living aquatic resources.

The Center was incorporated in Manila on 20 January 1977 and its operational base was established in Manila in March 1977. The interests of ICLARM are primarily in tropical, developing countries worldwide.

ICLARM is an operational organization, not a granting or funding entity. Its program of work is aimed to resolve critical technical and socioeconomic constraints to increased production, improved resource management and equitable distribution of benefits in economically developing countries. It pursues these objectives in the fields of aquaculture, resource assessment and management, education and training and information through cooperative research with institutions in developing and developed countries.

The ICLARM core staff consists of internationally recruited scientists drawn from diverse disciplines in the biological and social sciences. In addition, provision is made for trainees, consultants and visiting scientists, contributing to breadth of competence and flexibility.

The core program and core staff are supported by private foundations and governments.