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Source: *Ambio*, Vol. 22, No. 7, The Royal Colloquium (Nov., 1993), pp. 491-494
Published by: Allen Press on behalf of Royal Swedish Academy of Sciences
Stable URL: http://www.jstor.org/stable/4314132
Accessed: 03/10/2009 11:20

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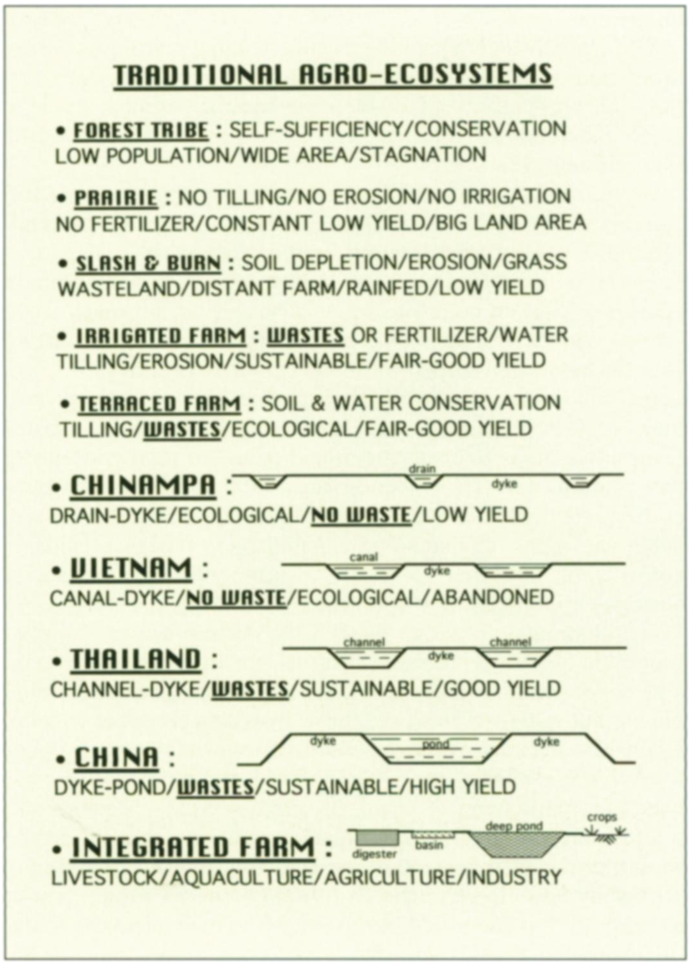
Aquaculture, Ecological Engineering: Lessons from China

Economic development and urbanization worldwide have led to many pollution problems as a result of growing input to the environment of organic wastes and inorganic nutrients. Even the developed countries have not been able to solve this problem satisfactorily. The situation is especially problematical in developing countries where raw wastes are disrupting the coastal ecosystems that are the main source of food protein. This article describes how these problems are addressed in China, using aquaculture and ecological engineering not only to solve waste problems, but also to optimize food and energy production by completely recycling wastes in integrated farming systems.

Figure 1. Various agricultural ecosystems are shown from the simplest traditional ones still existing today to the most sophisticated modern ones using appropriate technology.



INTRODUCTION

Modern urban development has created many pollution problems. These problems are mostly caused by the inability of industrialized peoples to deal properly with the wastes, some of them highly toxic, that are the result of the increasing use of natural resources. Gases are emitted to the air; solids are used in landfills; and wastewaters are flushed into the environment. All these activities contribute to environmental degradation.

Some of the conventional engineering solutions in industrialized society have addressed important issues, such as odor and microorganisms before the residue or effluent is discharged in the environment. However, serious pollution problems remain.

The organic pollutants have been transformed and shifted causing problems elsewhere, e.g. eutrophication in the receiving bodies of water or toxicity in complex food chains.

Most developing countries can not afford what is, obviously, an inefficient and ineffective waste-management strategy, and most urban populations in developing countries live with their wastes and suffer the consequences. In some cases, untreated wastes are just flushed into the river or sea to disrupt the coastal ecosystems from which humans obtain most of their animal food protein.

To add to this problem, local and foreign industries have been allowed to add raw and often toxic wastes to this already critical situation. These problems will increase as urban populations grow, and as Third World countries imitate developed countries in their consumption of more resources, while producing more wastes without adequate means to handle them.

Among the more serious, but avoidable, problems are the increasing flows of organic wastes and inorganic nutrients, to land and water, from chemical farming and the emissions of greenhouse gases from indiscriminate utilization of fossil fuels while destroying the forests which can act as efficient carbon sinks.

Historically, China and Asia have always treated wastes as valuable resources. In a variety of ecological engineering systems, wastes have been returned to the environment to replenish earlier removal.

ECOLOGICAL ENGINEERING AND INTEGRATED FARMING

Ecological engineering involves the design of human activities using locally-available natural resources in ecologically-balanced systems. It began as an art many centuries ago in parts of Asia, Africa, America and even Europe, when humans improved their traditional agro-ecosystems (Fig. 1) by modifying the physical environment in riverine and coastal areas into a system of deepened ponds for aquaculture and elevated dykes for agriculture. They used empirical but proven techniques as well as time-tested management practices to increase food production in order to meet the demands of the increasing population.

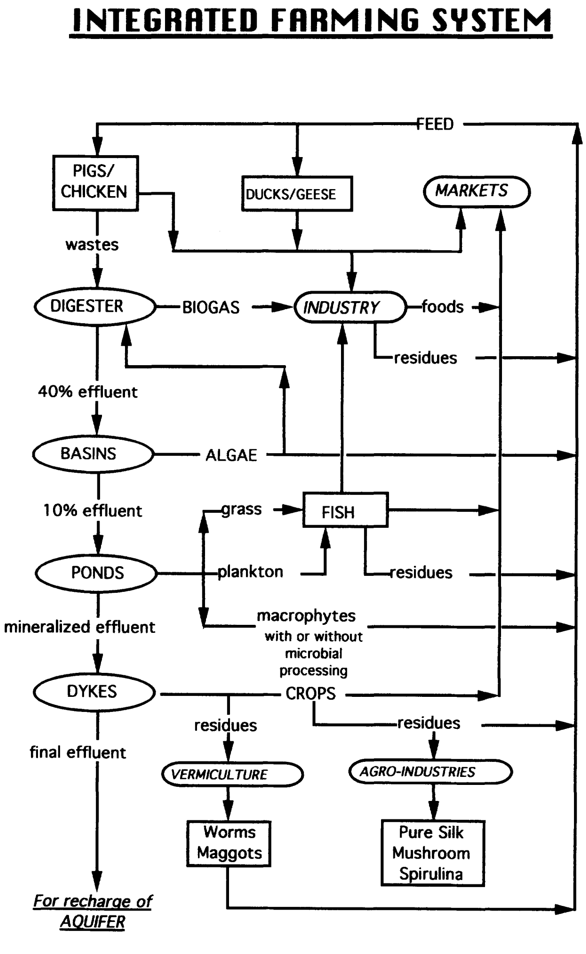
However, this culturing technique has more or less stagnated or entirely disappeared,except in a few countries in Asia. Nowhere has it developed so significantly as in China during the past four or five centuries. Even by current standards, the Chinese development can be called highly sophisticated (1). It is widely used on a large scale, in many parts of China, and was the subject of a special study by the Tokyo branch of the United Nations University in 1980–1983 (2).

It was only three decades ago that ecological engineering was advocated in the West (3), but not actually practiced except in few experimental farms (4) or pilot waste-treatment plants (5). During the same period, the traditional systems in China were studied scientifically (6, 7), and their production processes enhanced with modern technologies (8) into the Integrated Farming System (IFS). In China, many forms of ecological engineering are widely practiced on multi-purpose farms in order to optimize productivity at lowest costs.

In several countries such as Denmark, Sweden, Spain, Hungary, USA, Brazil, Colombia, India, Thailand, Philippines and Vietnam, the IFS is being established, using natural processes involving natural organisms under the most favorable conditions for optimum yields without excessive use of fossil fuels and environmental degradation.

The main objective is to enhance nutrient cycling and energy flow in ecosystems most efficiently, in order to obtain maximum benefits in food and fiber and to recycle the residues completely and economically. The necessary infrastructure of resource management, whether government or private, should not be costly but should involve people at the grassroots level without government interference, except for technical help if necessary.

Figure 2. The integration of livestock, aquaculture and industry in an ecologically-balanced system, with all the residues recycled to produce the fuel, fertilizer, feed, foods and goods without environmental degradation.



This is best obtained by the IFS which combines livestock, aquaculture, agriculture and agroindustry on every farm, large or small, and reinforces the microbial and symbiotic interaction by using the residues of a biological or biochemical process as input for subsequent ones. This is what ecological engineering is all about.

STRATEGY AND DESIGN

The following strategies and designs are based on the lessons learnt by the author in Asia, especially China, where he lived between 1985 and 1990. For ecological engineering to be effectively applied, an IFS should be considered as a whole and a change in any component should be carefully monitored to avoid any adverse impact on the other components. As a rule, no new material or process should be added to an integrated farm if it generates a residual pollutant that cannot be recycled or that can adversely affect any of its components. It is up to the designer to establish the critera.

The IFS is designed to produce solid wastes that can be totally absorbed within the ecosystem, eliminating the problems of solid-waste disposal and its instantaneous combustion or leachate byproduct, thus, removing the risks of contamination to air and groundwater. The problems of acid (NO_x or SO_x) or greenhouse gases (CH_4 or CO_2) are also eliminated because only solar, wind and biogas energy will be used; there will be mostly monogastric livestock, and very few ruminants to emit methane; paddy rice will be grown with Azolla, a small floating fern containing a nitrogen fixing alga, for the same reason; and the carbon dioxide produced from burning of methane will be absorbed by algae and plants grown on both the dyke and pond surfaces.

The IFS can then be used for treatment of the wastewaters containing the human and livestock wastes. Decomposition takes place in four stages including: (a) simple digesters; (b) shallow algae basins; (c) deep fish ponds; and (d) various planting media.

The critical stage where the treatment can go wrong is during liquid treatment, (b) and (c), and the test for success is shown by the high productivity of wholesome aquatic products such as algae, macrophytes, and fish with almost purified water as the final effluent (Fig. 2).

Obviously, aquaculture plays a very important role in the IFS and it is indeed incredible that this subject has been so much neglected or even totally ignored by government as well as academic establishments in both industrialized and developing countries. Certain countries in Asia have aquaculture to solve farming and environmental problems, and substantial and lasting benefits have been reaped for many centuries (Photo 1).

It is also ironic that in the industrialized countries huge volumes of water are used every day to transport human wastes from urban areas to costly treatment plants to treat wastewater that contains only 1% objectionable organic pollutant; the mineralized effluent then goes to waste. The aquacultural potential, using vast areas of abandoned marshlands or other wetlands, is considerable and can solve the insurmountable problems of eutrophication in the rich countries.

As mentioned above, in the IFS the organic wastes undergo four main treatment processes. This treatment is not for aesthetic and noneconomic values as is often the case in conventional plants, but rather to conserve the valuable byproducts of food, fertilizers, and fuel which are essential for all developing countries. These countries must feed their growing populations and need to import chemical fertilizers and fossil fuels. Besides taking full advantage of warm climatic conditions, the IFS design should provide the best environmental conditions for maximum efficiency and effectiveness in food and energy production to avoid pollution and allied problems. More than adequate scientific knowledge and traditional experience is available for the

A view of the 500-year old Dyke-Pond region covering 80 000 ha of low-lying land in the Pearl River Delta of Guangdong province in Southern China. Both aquaculture in the deep ponds and agriculture on the elevated dykes are highly productive without any external input of fuel, fertilizer or feed in an ecologically-balanced system. Photo: G.L. Chan.

open-minded designer to pick and choose from to develop an optimal IFS for any given situation.

THE IFS PROCESS

The main natural processes are important. (a) Inside a digester, the organic solids are liquified by enzymes of the natural bacteria found in the wastes. Subsequent anaerobic digestion occurs over a hydraulic retention period of five to six days for maximum biogas production, with a reduction in biochemical oxygen demand (BOD) of up to 60%. The biogas contains two-thirds methane and one-third carbon dioxide and can be used for domestic, agricultural and industrial purposes. Biogas production can be increased by mixing different kinds of livestock wastes to obtain optimum carbon/nitrogen ratio, adding more digestible biomass such as algae to the digester, and increasing the temperature of the substrate with a solar panel heat exchanger.

The function of the digester is to retain the wastewater in a watertight container for a few days, and in a new farm it can be as simple as a long plastic cylindrical bag with a similar bag for gas storage. More permanent material can be used when it is economically feasible for the farmer, but the digester should not become a piece of sophisticated equipment.

(b) In the shallow algae basin, the digester effluent is oxidized reducing BOD by a further 30% while natural algae grow prolifically by fixing carbon dioxide from both air and water, and releasing oxygen in the basin. The algae can be used as high-protein feed for livestock or as highly-digestible feedstock in the digester to increase biogas production. This is a neglected resource in the tropics where the conditions for photosynthesis are favorable for their growth which can reach 20 g dry weight per m^2 per day.

As a result of decomposition of organic matter in (a) and (b), the livestock in the system can be increased many times without causing organic-pollutant problems, while the production of valuable energy and fertilizer is also increased. The designer can manipulate the number of livestock required to meet the energy and fertilizer needs of the farm in accordance with the requirements of the farmers.

(c) The effluent from the algae basin is mostly mineralized when it enters the fish pond and is a substantial source of nutrients for growth of plankton and other autotrophic organisms as fish feed in the top part of the pond. These organisms require solar energy and atmospheric carbon dioxide for photosynthesis, and these are the reasons why fish ponds all over the world have remained shallow (1–1.5 m), and why their fish yields are generally low.

In China, fish ponds are 2.5–3m deep, and the fish yield is five to six times higher than yields in other countries. The main reason being the abundance of benthos and other heterotrophic organisms in the lower part of the pond where they do not need sunlight or carbon dioxide for growth, and their energy and carbon come from organic wastes producing high-protein feeds.

The suggestion that the Chinese farmers are feeding their fish with organic wastes which are very low in metabolizable protein, requiring 20 to 25 kg of wastes to produce 1 kg of fish, is not true. The organic wastes also serve as substrate for various kinds of bacteria which are also a source of high-protein feed. The adequate stocking of the right kinds of fish to consume all available high-protein feed is the secret of the high productivity in the deep ponds. Another very important factor is the additional space in a deep pond for the various plankton and bacteria to grow, and for various species of fish to feed in their different niches without the stress experienced in an overcrowded shallow pond.

With an abundant supply of biogas, supplemented by photovoltaic and solar energy, it is possible to aerate the deep pond to prevent formation of methane and nitrite at the pond bottom, and to reduce the stress on the fish allowing them to grow better. On farms where arable land is limited, as is the case in many developing countries, the pond surface can also be reduced for dissolved oxygen from the atmosphere, so part of the surface can be used for culture of aquatic food plants or other crops in aquaponic towers.

In some coastal areas, the fish ponds of the IFS can be built in the shallow sea and special crops such as *Spartina anglica* can be grown on tidal flats. Some algae, e.g. *Spirulina* and other edible plants also grow well in seawater.

(d) The fish pond is also a huge reservoir for irrigation water. This is particularly important in times of drought when other farms may remain idle. The IFS can, thus, operate year-round under tropical climate conditions. Another big advantage is that no routine watering of the crops is necessary, except at the seedling stage, because the plant roots can find their water and nutrients from the pond water which is not far below the dyke surface. Thus, the farmer does not have to visit his farm every day which saves a considerable amount of work and time otherwise lost in travelling to and from the farms, which are relatively far from the residential villages and can only be reached by boat on the network of canals between the ponds.

ROLE OF AQUACULTURE IN ECOLOGICAL ENGINEERING

The IFS has shown how ecological engineering can be applied to various ecosystems in a large region of the Pearl River Delta for the benefit of humans while enhancing the natural processes for sustainable rural development. There are hundreds of such regions in other parts of China where the introduction of aquaculture has made a huge difference to agricultural productivity, as well as providing large stabilization ponds to treat organic wastes effectively instead of leaving them to pollute the environment as is the case in most developing countries.

The basic difference between the stabilization ponds in the West and those of Asia is that the objectives are at opposite ends of the spectrum:

- The emphasis in the West is specifically on total conversion of organic wastes into minerals before disposal even if this causes eutrophication somewhere else, using the natural algae and other autotrophic organisms to produce oxygen by photosynthetic fixation of carbon dioxide from the atmosphere during the day. The usual problem with pond failure is that the prolific organisms die, accumulate at the shallow pond bottom, consume oxygen constantly instead of at night-time only. Finally, the pond becomes septic and eventually breaks down leaving one large mess that is unpleasant to rectify. Ecological engineering fails here because the ecosystem is unbalanced and is left to function ineffectively by itself.
- The emphasis in the Asian case is always for food production, converting the organic wastes into nutrients for autotrophic organisms or using the organic wastes for heterotrophic organisms to grow (as explained above) as feed for 6 or more compatible kinds of fish to consume at different trophic levels.

It is important that every peasant know his pond and stock it with the right kinds of fish, in adequate numbers of each kind, so they can consume as much of the available feed as possible so that the pond remains healthy. Any feed that is not consumed accumulates at the bottom and becomes a potential oxygen consuming pollutant. Every winter the pond is cleaned and the pond mud is removed to fertilize the soil on the dykes.

Aquaculture in China has always been motivated by the necessity to find ways of using marshy or low-lying lands to support a large population. The water in these marginal lands is too shallow for fish culture, and the soil is easily flooded if the rains come before crops can be harvested with total loss of the crop. Instead of draining the land for development, as it is done elsewhere, the shallow ponds are deepened to allow proper fish culture and the excavated soil is used to build up the dykes above flood level for use as agricultural and livestock land.

All the hard work needed to develop the pond-dyke systems was done by hand on a mutual aid basis, this working system has been operating in Chinese villages for many years and is largely responsible for the continued existence of Chinese culture over the past 1000 years at least. The initiative came from the peasants themselves, who were forced to find a means of survival. The development was not connected to government departments or academic institutions. The peasants show much ingenuity in operating their ponds, which have become the center of their farming activities. They have gradually learnt how to limit the number of animals and birds to avoid large amounts of organic waste which would upset the equilibrium in the pond. This can also occur if the nutrients in the pond are not removed fast enough by aquatic or terrestrial plants.

Different kinds of edible aquatic plants such as lotus and water chestnuts have been grown in over-fertilized ponds unfit for fish culture.

The problem of excess fertilizer emerges every now and then. This is surprising because it is usually lacking in most developing countries which have to import chemical fertiizers. Multicropping and rotation of crops have been practiced for many centuries, with valuable products such as mulberry leaves for silk culture, fruits such as litchi and longan, and various mushrooms for export.

Other benefits have accrued from this practice. The extensive system of dykes and ponds has always protected the whole region from flooding, and no crops have ever been lost on the elevated dykes. There is no soil erosion because soil washed down by rain only goes into the pond, and the rich pond mud is removed yearly and spread on the dykes, so no agrochemicals are necessary. There is no seawater intrusion problem, even though the region was formerly low-lying, because the watertable has gradually risen above mean sea level as the elevated dykes became watertight.

All these benefits have accrued during the past few centuries and the whole region has remained highly productive and has never suffered from famine or drought. The prosperity of the region is well recognized in China. The IFS should serve as a model for economic as well as ecological development for the rest of China and many other parts of the world. Unfortunately, this is not the case.

MODERN DEVELOPMENT?

China has recently started a very ambitious modernization program based on the development patterns of Hong Kong, Taiwan and Republic of Korea. This choice is unfortunate, because development in these countries is not sustainable, and the environmental problems are not being seriously addressed. China should emulate the proven and time-tested, environmentally-sound and economically-viable examples of sustainable development that can be modernized with appropriate technologies and that are already in operation in the country itself.

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