INTEGRATION OF AQUACULTURE AND IRRIGATION: RATIONALE, PRINCIPLES AND ITS PRACTICE IN ISRAEL.

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Abstract

More than ever before, agriculture must operate according to free market principles. To do this, new concepts, crops and technologies must be introduced, while maintaining low and competitive production costs. One such concept is Integrated Aquaculture and Irrigation (IAI). Fish production is compatible with irrigation in integrated systems, which are based on dual use of the same water, first for fish production and afterward for irrigation. This results in overall reduction of production costs and diversification into a high quality consumer products for the local as well as for export markets. IAI is environmentally friendly.

The three main types of IAI are described, each using different water sources and water distribution systems. Emphasis is placed on the practice in Israel, where IAI is commercially proven, in spite of severe water shortage and climatic constraints, and in combination with advanced irrigation systems. Results of combined yields of fish and land crops are presented for a single farm and on a regional level.

IAI should be considered an integral component of both irrigation planning and rehabilitation of irrigation projects, whether by the public or private sectors, or by individual farmers.

Introduction and Rationale

The inclusion of aquaculture in a conference devoted to irrigation is necessary due to the fundamental global trends that are reshaping the agribusiness environment and in light of the efforts to find appropriate solutions to the threats posed by these changes. Since the subject diverges from mainstream irrigation, a broader introduction is needed.

Governments are engaged in the process of re-deployment of resources and restructuring of their agro-industries, stripping away subsidies and protection policies. Concomitantly, as the traditional role of governments in the agriculture sector is being reduced, privatization, liberalization and fiscal austerity bring about withdrawal of services, such as credit lines for agriculture, which must face the intensely competitive threats of the open market. Private enterprises and the marketplace play an increasing role in a process, leading to market integration and product transformation. The international markets are seeing increased demand for high quality consumer items and processed food at the expense of traditional commodities, whose price decline in real terms. Farmers who fail to make a significant shift from the commodities into higher value products lose world market share. Even in the domestic markets of developing countries, there is a rising level of product transformation to processed food and shifting from carbohydrates to protein rich foods, and from red meat to food considered more nutritious such as fish, fresh vegetables and fruits. The shift is not simply away from commodities, but creates distinctive high quality products to capture consumer interest. The consumer demand is for variety. Responding to regional idiosyncrasies of the local and the export marketplace is becoming an important component of competitiveness and the only path to continued profitability is through innovative production concepts which lower costs and increase demand.

Fundamental changes require fundamental solutions. It is with this in, mind that Israel's experience in integrating aquaculture and irrigation (IAI) is presented.

The recognized promise of IAI is that advanced agriculture should not equate water use solely with irrigation of land crops, but rather with the combined production of fish and land crops. The realization that aquaculture and irrigation are compatible, requires openness on the part of professional irrigation experts, farmers, and agricultural institutions, many of whom are presently convinced that water is meant to be used for irrigation alone.

IAI is not a new concept, it has merely been neglected by modern agriculture. It has been practices on a subsistence level in South East Asia for centuries. During the past two decades, international organization such as the FAO and the UNDP have supported IAI on a low level, mainly in an effort to increase productivity of subsistence farming.

Increased interest in aquaculture stems from the fact that capture ocean fisheries, which even presently practice "hunting and gathering" techniques, have, in the past two decades, caused a depletion of the resource with many of the world's best known edible fish on the verge of extinction. World fisheries have leveled off at about 100 million tons per year, but the harvest of edible whitefish, estimated at around 12 million tons, has been declining at rates of 7-10% per year. This has resulted in the imposition of severe quotas, which further increase the scarcity and prices of fish (Seafood Magazine, 1995). This process is effecting the markets in the developed countries as well as developing countries, since in both there is an apparent increase in demand for fish and fish products, for the reasons mentioned above. The seafood market is characterized by intense competition for quality fish. Developed countries (Japan, USA, EEC) rely on foreign sources of supply and import more than 50% of their supplies, and in the developing countries must spend significant amounts of hard currency on importation of low priced fish for local consumption (New, 1991). This situation is expected to continue and become more acute as world population, world economic restructuring, and the standard of living continue to increase. The apparent difference between the production potential and relative abundance of agricultural products and commodities (production driven), as opposed to the limitation of production and scarcity of seafood (market driven), is noteworthy and provides the basis for IAI.

Major efforts are being made to develop and implement aquaculture, mainly in the marine environment, but the farming community, with access to fresh water and irrigation infrastructure, is in the best position to benefit from these new trends.

The principles of IAI

In an irrigation system comprising of a water source, a water distribution system, and the irrigated field IAI is achieved by installing or constructing the aquaculture facility near the water source, or between the water source and the irrigated field. In this way, the water is used twice, first for fish production and then for irrigation. Any water source could be used, including underground, river, or impounding reservoir, and any water supply system including gravitational, pumping, or a combination of both.

The use of water in the IAI system is determined by the maximum profitability that can be derived from the combined production of fish and land crops. On one extreme, irrigation takes priority and aquaculture production is conducted according to irrigation schedules. In the other extreme, the aquaculture requirements are considered first and determine the irrigation schedules and the amounts of water to be made available for irrigation. The proportions, however, may vary year by year, according to the relative cost of production of each crop (e.g. fish feed, seeds), on the selling prices of the planned crops, on market demand, and on seasonal changes in climate. A well designed IAI system allows the farmer to respond to such changes on a seasonal basis and modify his production plans accordingly, thus improving his competitive ability.

IAI can be divided into various cases, according to the water source.

a) Impounding reservoirs: These are regional or private reservoirs constructed for irrigation purposes by damming a stream or river basin, and collecting water from its catchments area. Water is supplied by gravity through a network of principal and secondary canals. Aquaculture can be established in any, or a combination of the following ways. In floating cages, in the reservoirs and/or by diverting some of the water from the canal to fish ponds, and returning the water to a lower secondary canal (Fig. 1 a) or to the same canal, at a lower elevation (Fig. 1 b). The scale and output of the aquaculture facilities are designed according to water availability so as to cause no interference in the irrigation schedule. By producing both fish and land crops, the investment in the water facilities is shared by the two crops.

b) Wells or perennial source: Water is pumped from wells, river, or other continuously abundant source, directly into the irrigation network. Pumping is done according to irrigation schedules. Aquaculture can be established in ponds constructed between the pumping station and the irrigated field. The total amount of water is unchanged but pumping costs are shared by land and water crops (Fig. 2). This is especially significant in cases when the pumping cost is high due to the high head. Supplementary water for aquaculture, above the quantities required for irrigation, could be pumped.

c) Seasonal non-perennial source: In areas with seasonally fluctuating water source, the amount of water available in the dry season determines the cultivated area which can be irrigated. In order to increase the irrigated area, or lengthen the irrigation season, it is necessary to construct a reservoir to collect water during the rainy season, for use during the dry season. This is often referred to as a ‘water harvesting structure’. Fish production is accomplished in the irrigation reservoir itself, and/or in intensive ponds (Fig. 3). The intensive ponds are constructed around the reservoir, and ‘borrow’ its water, by circulation. The reservoir becomes a **dual purpose** source of water for both fish production and irrigation. Unless IAI is practiced, the investment in construction and operation the reservoir must be returned solely by the irrigated crops. By producing fish and land crops, the investment and some of the operating costs are shared, increasing the rate of return of investment. In some cases, the construction of a reservoir can be economically justified by the fish production alone, hence the creation of the new water source for dry season irrigation is a contribution of the fish.

The advantages of IAI over an irrigation project producing only land crops are:

* Increase in over all product output, without reducing output of irrigated crops.
* Diversification into high value consumer food items
* Exportation of highly demanded products

* Production of an import substitute, thus reducing hard currency expenditure
* Overall reduction in production cost by sharing
* Increase in rate of return on investments in the water supply and distribution

The first two cases (a and b, above) operate under conditions of year round water availability, and fish are produced without reducing the output of land crops. Case (c) is different in that it operates with a limited water supply, creating a competition between aquaculture crops and land crops. As such, it is more complex to apply, and therefore merits detailed demonstration. It is also the one mostly practiced in Israel, in combination with advanced drip and sprinkler irrigation.

Practice of IAI in Israel

Israel is a semi arid country with subtropical climate. Rains fall during a mild winter of 4-5 months. Annual precipitation is 200-600 mm in most agricultural areas, whereas most of the crops grown in Israel require 400 to 1000 mm, for field crops and fruit plantation, respectively. The 7-months summer is hot and completely dry and every 2-3 years there is a drought.

Year-round irrigation is conducted by constructing reservoirs to collect water during the rainy season for irrigation during the dry season. There are approximately 300 reservoirs with a total volume of 130 million cubic meters. The water sources are mainly flood and drainage capture and underground. The reservoirs belong to water associations, private farms and communal farms. The reservoirs vary in size (from 3-15 ha), in depth (3-12 m), in location of the outlet opening, and in the type of monk (outlet) system used (a net box is attached to the bottom outlet pipe, either floating at a fixed level or floating at a flexible level). Fish are stocked for biological control purposes and/or for commercial purposes (Shisha, 1993). When sensitive irrigation systems are applied (drippers, mini-sprinklers and sprayers), appropriate filters are installed at the outlet, which require cleaning (Sagi, 1993).

Aquaculture in irrigation reservoirs

The use of reservoirs for commercial scale IAI is increasing in Israel. In 1994, IAI was conducted in 1319 ha of reservoir water area, representing 48% of the area devoted to commercial aquaculture in Israel. The total aquaculture output in 1994 was 14,772 tons from 2,746 ha (Sarig, 1995). The increase in IAI activities in Israel occurs in spite of the apparent difficulty imposed by the water limitation: As the dry season progresses, water must be withdrawn from the reservoirs for irrigation at pre-planned schedules. At the same time fish biomass increases in the reservoir, resulting in increased concentration of nitrogenous compounds from fish excretion. This, in turn, may cause increased algal growth and problems both for irrigation (e.g. clogging of filters) and for the fish (growth inhibition due to anoxic conditions). Thus, in addition to carefully planning the withdrawal of water f from the reservoir, the aquaculture production strategy must also be planned (Liberman et al. 1989, Milstein et al., 1989, Zoran, 1993).

Fish fry are stocked in October when rain water begins to accumulate in the reservoir (Fig. 4 a). Several species of fish are stocked together in a reservoir (polyculture), each occupying its own ecological niche. These species include common carp, silver carp, grass carp, red and silver tilapia hybrids, mullet, freshwater prawns and, to a limited extent, catfish. The proportion and average size of each species depends on the niche the species occupies, fry availability, and market demand.

At the beginning of the season, the fish are small and the small amount of water in the reservoir is sufficient for them. As the fish grow and require more space, the rainy season continues and the amount of water in the reservoir rise; an ideal situation. Irrigation begins to draw from the filled reservoir in June, just as the first fish reach market size and are harvested (Fig. 4. b). Thereinafter, selective harvesting of market size fish gradually reduces the number of fish in the reservoir in a manner corresponding to, and coordinated with, the withdrawal of water for irrigation (Fig. 4 c). By the end of the summer, when water in the reservoir is low or depleted, all the fish have reached market size. Market size fish are moved to storage ponds to achieve year round marketing, in spite of climatic constraints and chronic shortage of water.

The fish yield from such a reservoir can reach 15 tons per ha per cycle without causing loss of water and with a low feed-conversion ratio, often as low as 0.8:1.0 (0.8 kg of feed produce 1 kg of fish). While the reservoir can produce higher output, logistic problems (e.g. harvesting) prevent higher stocking.

Super-intensive (S/I) ponds associated with an irrigation reservoir

In addition to stocking reservoirs, and in order to increase the output, fish can be stocked in specially built concrete or plastic-lined earthen fish ponds (100 to 1000 cubic meters), adjacent to the reservoir. Water circulates continuously between the fish ponds and the reservoir (Amit, 1990, Diab et. al., 1991). The S/I ponds are used mainly for the production of export quality fish. The fish are stocked at extremely high densities, hence the term ‘super-intensive’, and the yields obtained are high, reaching, at optimal water temperatures, 60 kg per m3 per cycle, equivalent to 600 tons per ha. Effective fish growth requires input of oxygen, removal of wastes, and elimination of ammonia excreted by the fish.

Environmental aspects

The waste produced by the fish in the reservoir and the S/I ponds is highly digestible particulate matter, dissolved nitrogenous compounds and minute additions of phosphorus derived from fish excrements and decomposed feed. Treatment is accomplished by the action of the natural populations of bacteria and algae, which thrive in the reservoir. These carry out heterotrophic decomposition of the organic waste, followed by nitrification, de-nitrification by various bacterial species, and by assimilation of nitrogenous compounds by the alge (Diab aett al 1991). The reservoir acts as a ‘sun-lit rumen’, and is referred to as a ‘green lung’, converting the organic wastes into single cell protein. In the process, day time oxygen level in the water increases due to photosynthetic primary productivity (Avnimelerch, 1989). The water, thus treated, is beneficial both to fish and land crops: algae produced in the process enter the food web, encouraging secondary productivity (e.g. zooplankton), which supplements the diet of the fish; fish wastes become fertilizers for the irrigated crops. In short, the reservoir serves as a natural biological filter, at no cost to the grower.

The number of S/I ponds associated with a particular reservoir, and the number of fish stocked in the combined system of reservoir and its S/I ponds, take into consideration the amount of wastes produced and the ability of the water system to treat these wastes. Hence, an ecologically balanced system is established and the process, as a whole, is environmentally friendly.