CHINESE-AMERICAN
JOINT COMMISSION ON RURAL RECONSTRUCTION

Fisheries Series: No. 6

POND FISH CULTURE AND THE ECONOMY OF INORGANIC FERTILIZER APPLICATION

By

Shu-yen Lin

Taipei, Taiwan, China

June, 1968

CHINESE-AMERICAN
JOINT COMMISSION ON RURAL RECONSTRUCTION

Fisheries Series: No. 6

POND FISH CULTURE AND THE ECONOMY OF INORGANIC FERTILIZER APPLICATION

By

Shu-yen Lin

Taipei, Taiwan, China
June, 1968

Table of Contents

POND FISH CULTURE AND THE ECONOMY OF INORGANIC FERTILIZER APPLICATION

S.Y. Lin

Senior Fisheries Biologist, JCRR

The present dissertation is based on information obtained from experiments and demonstrations conducted by the Taiwan Fisheries Research Institute and the Hsien governments in different parts of Taiwan, with technical and financial assistance from the Joint Commission on Rural Reconstruction in the years 1955—1967. The objective of such experiments and demonstrations was naturally multifold: (1) to convince the fish farmers that inorganic fertilizers are the most economical and efficient stimuli for increasing pond fish production, (2) to find out whether inorganic fertilizers can replace entirely, or at least partly the expensive and unhygienic organic fertilizers so far as silver carp, bighead, goldfish, Crucian carp, mud carp and grey mullet culture in combination is concerned, (3) to determine the optimum dose and the economic dose of each kind of inorganic fertilizer and (4) the last but not the least, to suggest a possible set of criteria for the application of inorganic fertilizers.

For better interpretation of the phenomena and results of the experiments in pond fertilization, a program of basic researches supported by a grant from the Rockefeller Foundation was started in 1966. W.K. Liaw, assistant Professor of National Taiwan University, is the team leader of this program. Since at the beginning the research staff was small and the facilities inadequate, only a few of the basic problems such as the identification of the phyto- and zooplankton in ponds, certain aspects of primary productivity, nutrient dynamics, water and bottom soil quality could be tackled in the past two years. Many other investigations of the ecology and succession of pond plankton, pure culture and physiology of phytoplankton and the feeding ecology of the plankton-feeders will be initiated later when research personnel are available.

In order to show how the inorganic fertilizer experiments were designed and the extension program developed, a short review of the data obtained from research and practical experience would be useful as background information.

Domestic Fishes and Their Feeding Habits

Before starting the discussion on pond fish culture and the economy of inorganic fertilizer application, it would be helpful to identify, first of all, the species of fishes raised in all kinds of ponds. They are:

1. Silver carp (*Hypophthalmichthys molitrix*)—phytoplanktophagic
2. Bighead (*Aristichthys nobilis*)—macroplanktophagic
3. Mud carp (*Cirrhina molitorella*)—phytoplanktophagic, detritophagic
4. Crucian carp (*Carassius carassius*)—planktophagic
5. Goldfish (*Carassius auratus*)—planktophagic
6. Grass carp (*Ctenopharyngodon idella*)—herbivorous
7. Common carp (*Cyprinus carpio*)—omnivorous, benthophagic
8. Black carp (*Mylopharyngodon piceus*)—molluscophagic
9. Eel (*Anguilla japonica*)—carnivorous
10. *Tilapia mossambica*—omnivorous
11. Grey mullet (*Mugil cephalus*)—phytoplanktophagic, detritophagic
12. Catfish (*Parasilurus asotus*)—carnivorous
13. Perch or sea bass (*Lateolabrax japonicus*)—piscivorous
14. Milkfish (*Chanos chanos*)—herbivorous

Whether it is justifiable to classify the Crucian carp and the goldfish as two distinct species is still highly controversial. But as many taxonomists have distinguished the two as separate species, (for example, Hora and Pillay, 1962), and in practical culture the two species are treated differently because of their spawning habits and growth rates, it is deemed convenient and pertinent therefore to discuss them as two separate species or varieties here in this paper. Crucian carp is a species introduced from Japan and goldfish is a native of Taiwan.

Under similar conditions the response of fish yield increase to inorganic fertilizers has a great deal to do with the feeding habits of the fishes concerned. Table 1 shows the percentage increase in weight of the different species of fishes raised in the same pond in response to superphosphate application (Lin and Chen, 1966).

Table 1. Comparison of the production of different species in polyculture in the control and the superphosphate treated ponds

Species	Untreated (kg/ha/year)	Treated (kg/ha/year)	Increase (%)
Silver carp	181	381	110
Bighead	58	155	167
Common carp	18	17	0
Grey mullet	28	55	96
Grass carp	26	26	0
Perch	17	25	47
Others	58	58	0

In examining this table one would wonder why silver carp and bighead were the fishes benefited most by superphosphate, next the grey mullet and lastly the perch, but the common carp and grass carp had no weight increase over the control at all. The explanation for such phenomena can only be found in studying the feeding habits of the fishes, because as superphosphate is the essential nutrient in increasing phytoplankton production, any fish that grazes on phytoplankton will have plenty to eat and grow faster than the others. Silver carp, bighead and grey mullet are well known for their plankton feeding habit; perch feeds on small fishes which in turn devour phyto-and zooplankton constituting a longer trophic chain, therefore less conversion value.

The grass carp depends principally on either land or aquatic weeds for nutrition. Since a pond for intensive culture is always devoid of aquatic weeds, and when no land grass is given, the grass carp has very little food for nourishment and growth. The common carp in such a polyculture ecosystem also suffers from the lack of food, because it is primarily a benthic fauna feeder. As fertilization increases the phytoplankton population, shading is created to cut light penetration to the bottom of the rather deep ponds of the Taoyuan Farm. As a result, little bottom fauna, particularly Chironomid larvae, ***Bosmina***, etc. is available for the common carp to feed on.

In reviewing literature, instances are not uncommon showing that yield increase of phytoplankton feeding fishes responds more markedly to inorganic fertilizer application than that of the carnivores or omnivores. For example, in Wielenbach, Germany, ponds fertilized with superphosphate at 25 to 30 kg/ha/year for 18 years, produced, on the average, 120 kg/ha/year more than the control. The common carp is an omnivore, but it prefers benthic insect larvae, especially the Chironomids, as food. This feeding habit together with the low water temperature in Germany is evidently responsible for the low yield. From Dendy's discussion (in Frey, 1963), it is estimated that when farm ponds in the U.S.A. are stocked with such fishes as ***Micropterus salmoides***, ***Lepomis macrochirus*** and *Ictalurus punctatus* and fertilized with N-P-K-$CaCO_3$ at the rate of roughly 1000-1500 kg/ha/year, the standing crop of plankton (mostly phytoplankton) and fish production would reach 1000-2500 kg/ha (wet weight) and 250-450 kg/ha/year respectively. Again, as all these species are carnivores and the period of favourable temperature for growth (6-8 months) is short, the comparatively low annual fish yield is only natural.

In Malacca, Malaysia, Hickling (1962) applied superphosphate to ponds in which principally ***Tilapia mossambica*** and ***Puntius gonionotus*** were stocked, and found that with P_2O_5 application at the rate of 40 to 120 kg/ha/year, the fish yield increase was in the order of 261 to 1260 kg/ha/year over the control ponds. This remarkable yield increase in response to superphosphate is possible because both ***Tilapia*** and ***Puntius*** are phytoplankton-feeders and they have a full 12 month period of growth.

Tominaga ***et al*** (1964) conducted a very interesting experiment on the effect of N-P fertilizers on the yield increase of silver carp, Crucian carp, common carp and grass carp in polyculture. In this experiment, fertilizers equivalent to N-185 kg/ha and P_2O_5-150 kg/ha were added to the pond for the culture period March to September, and the results are shown in table 2.

This outstandingly high yield of the phytoplankton feeding silver carp, Crucian carp and goldfish entirely in response to N-P application is remarkable. At the same time it shows the indifference of grass carp and common carp to the use of inorganic fertilizers in such an ecosystem of culture.

A project has been initiated at the Chupei Fish Culture Station to study the feeding habits of the silver carp, bighead and mud carp with the objectives to interpret precisely the foregoing phenomena and to improve stocking manipulation in relation to inorganic fertilizer application. The data obtained from this study in February and March, 1968, preliminary as they are, illustrate very significantly the nature of feeding of these three species and their relation to the trophic chain in the two experimental ponds (each 1000 m^2), both of which were fertilized with superphosphate, but to only one, supplementary feeds in the form of rice bran and peanut cake were given.

Table 2. Results of inorganic fertilizer experiment in a 1.49 hectare pond (from Tominaga *et al*, 1964)

Species in polyculture	Stocking No.	Stocking kg/ha	Harvest No.	Harvest kg/ha
Silver carp	1,778	20	1,778	1,123
Crucian carp	75,640	50	26,185	448
Goldfish			10,000	38
Grass carp	20	35	20	52
Common carp	251	23	156	71
Total				1,732

Table 3. Comparison of intestine contents of silver carp, bighead and mud carp from data obtained in February and March, 1968

Kind	Intestine content (% cell/fish)		
	Silver carp	Bighead	Mud carp
Chlorophyta	14.11	15.19	7.11
Bacillariophyta	20.65	17.25	57.59
Cyanophyta	37.70	31.51	10.27
Detritus	25.84	30.63	24.72
Zooplankton	1.70	5.42	0.31
	100.00	100.00	100.00

Table 3 indicates that silver carp is principally a phytoplankton-feeder. Although it appears that silver carp prefers Bacillariophyta and Cyanophyta to other plankton, yet which of the three groups of phytoplankton—Chlorophyta, Bacillariophyta or Cyanophyta—the fish actually prefers, and whether the silver carp is capable of selecting a certain type or types of phytoplankton for ingestion are still matters awaiting determination. There is no doubt that the silver carp possesses the most efficient mechanism—the gill-rakers—for filtering plankton food, for the long gill-rakers are fused to form spongy plates with pores so fine that even Protista (nannoplankton) less than 10 microns in size cannot pass through when the organ is in action. Should this be the actual situation, then it would be logical to infer that the silver carp is capable of filtering and ingesting both macro-and nannophytoplankton, detritus floating on the surface or suspending in water and, even to some extent zooplankton. This hypothesis is partially supported, at least, by the observations that the digestive tract of the silver carp in the pond with supplementary feeding contains 51.8% of detritus, whereas that from the pond without supplementary feeding contains only 3.3% of detritus. The possible reason why zooplankton were rarely found and Protozoa (phytoflagellates) were not found in the digestive tract of the silver carp is that, because of their minute size and delicacy, they might have been disfigured beyond recognition by the preserving fluid or seriously damaged and lost during the process of preparation for examination. Also possible is that the delicate Protozoa (phytoflagellates) and zooplankton might have been crushed by the pharyngeal teeth and digested, so they could not be identified as part of the intestinal contents.

According to the results of the preliminary study as shown in table 3, bighead has a similar feeding habit as the silver carp, except that the former ingests a considerable quantity of macrozooplankton such as *Cyclops*, *Daphnia*, Rotifera (*Keratella* and ***Brachionus***) and Cladocera, whereas very few of these were discovered in the digestive system of the latter. The bighead has long and very closely set gill-rakers which are not fused to form spongy plates as in the case of the silver carp, and this suggests that the bighead is well equipped to filter and ingest macrophytoplankton and macrozooplankton but not the nannoplankton consisting of Protozoa and phytoflagellates. This may be the reason why silver carp is a more efficient plankton-feeder than the bighead, as in the ponds nannoplankton are extremely abundant, and for the same reason all the freshwater ponds, especially the well fertilized ones, can support a silver carp crop 3 to 8 times as large as that of the bighead.

The mud carp is a bottom feeder like the common carp, but it does not suck up the mud to pick out worms and detritus for ingestion. The mud carp, quite unfairly named, is a beautiful fish, not looking nor tasting muddy at all. It lives close to the bottom, lightly picking detritus on the bottom surface and ingesting benthic phytoplankton, especially Bacillariophyta or diatoms, with its inferior toothless mouth. As the gill-rakers of the mud carp are very short and widely set, it is likely that any food entering the mouth will be swallowed directly into the digestive tract and does not need any concentration processing by the gill-rakers. Mud carp eats peanut cake, bean cake and rice bran given to it in an aquarium.

The most common types of phytoplankton found in the digestive tract of the silver carp, bighead and mud carp are (1) Chlorophyta: *Spirogyra*, *Scenedesmus*, *Ankistrodesmus*, *Pediastrum*, *Protococcus*, *Characium*, *Tedraedron*, *Chodatella*, *Cosmarium*, *Dictyosphaerium*, *Chlorella*, *Coelastrum*, *Gloeocystis*, *Crucigenia*, *Strauastrum*, *Ulothrix*, *Oocystis*, *Golenkinia*, *Kirchneriella* and *Selenastrum*; (2) Bacillariophyta: *Navicula*, *Melosira*, *Frustulia*, *Synedra*, *Cyclotella*, *Pinnularia*, *Fragilaria*, *Stephanodiscus*, *Nitzschia*, *Amphora*, *Cymbella*, *Meridion*, *Surirella*, *Achnanthes*, *Cymatopleura*, *Eunotia*, *Diatoma*, *Tabellaria* and *Gyrosigma*; (3) Cyanophyta: *Aphanocapsa*, *Microcystis*, *Anabaena*, *Oscillatoria*, *Phormidium*, *Merismopedia*, *Chroococcus*, *Coelospharium* and *Dactylococcopsis*.

Among the zooplankton and benthic fauna, the following groups are found in the digestive tracts of the bighead, mud carp and silver carp: Copepoda, Cladocera, Rotifera and Euglena.

The grass carp is a well-known herbivore, consuming aquatic and land grass like cattle; it also eats, to a lesser extent, food of animal origin. The young fish prefers duckweed (*Spirodela*) and tender grass. The black carp is a typical mollusc-feeder; it eats snails and mussels small enough to be sucked into the mouth cavity and be crushed between the pharyngeal molar teeth. The common carp is a bottom feeder; it devours benthic insect larvae, detritus and even snails. The Crucian carp and the goldfish are plankton feeders, consuming phytoplankton as well as Cladocera, Copepoda, *Daphnia* and Rotatoria.

Eel is a pure carnivore feeding on fish, Crustacea and insects; its supplementary feed consists of, at least, 50% animal protein (dry weight).

Grey mullet is a phytoplankton and detritus feeder very much like the mud carp, therefore the mud carp and the grey mullet should not be stocked together in the same pond in large numbers. Catfish and perch are piscivores; only a very small number of them, at most 50 to 100 fish per hectare, can be accommodated in the same pond.

The milkfish prefers the soft blue green algae and diatoms growing on the bottom as food, although it would eat the tender green algae such as *Enteromorpha* and decayed *Chaetomorpha* as emergency food; it also eats peanut cake, soybean cake and rice bran when the nourishing blue green algae and diatoms are scarce.

For concise information on the feeding habits of the foregoing species of domestic fishes, the accounts of Nikol'skii (1954) and Hora and Pillay (1962) are helpful references. Lin (S.Y. 1968), however, gives a comprehensive review of the feeding habit of milkfish.

Fish Pond Ecosystems

The ecosystem of individual ponds never remains the same. Because of this, fish production varies to a great extent from year to year and from pond to pond. For example, ponds or reservoirs on the high land in the interior may produce only 100 kg/ha a year whilst those constructed on alluvial soil along the coastal plain would yield more than 500 kg/ha/year without fertilization nor supplementary feeding. A pond under identical treatments yielded 740 kg/ha in 1965, but only 620 kg/ha in 1966, the difference probably attributable to factors beyond control.

For the convenience of experimentation design and comparability of results, the fish ponds in Taiwan can be empirically grouped into four classes on the basis of the species of domesticated fishes, the quality of water and other pertinent ecological factors. The first class comprises the reservoirs of some 6,000 hectares lying at some distance from the coast and at altitudes of from 20 to 500 meters above sea level. They are chiefly for Chinese carp culture.

To the second class belong all the eel ponds, roughly 150 hectares in total in which several kinds of Chinese carps are also stocked. They lie either along the coastal plain or in the interior close to the foot of the hills.

The third group of ponds covering roughly a total area of another 6,000 hectares are those lying on the coastal plain, much richer in mineral nutrients than the reservoirs at higher level in the interior. ***Tilapia mossambica*** constitutes the principal biological unit of the ecosystem of coastal plain ponds. Of course, in the same ponds silver carp, bighead, grass carp, goldfish, common carp, grey mullet, eel and milkfish are also stocked.

The last group includes all the brackish-water ponds of some 16,000 hectares constructed on the tidal land for monoculture of milkfish. They represent an ecosystem which is basically different in all respects from that of the freshwater ponds (Lin, S.Y. 1968).

In the first class of ponds or reservoirs polyculture is practiced and the fishes used for stocking in association are: silver carp, bighead, goldfish, grass carp, mud carp, common carp, black carp, grey mullet, catfish and perch.

Some of the physical, chemical and biological conditions of this group of ponds were investigated by Liaw and Lin (1967). They found that light penetration measured with the Secchi disc was greatly influenced by plankton concentration, especially that of phytoplankton, and that generally speaking, this is again dependent on the availability of mineral nutrients. At the time of examination in February 1967, two ponds rich in plankton had a Secchi disc visibility of 85 cm while the other five bodies of water rather poor in plankton, 108 to 239 cm.

The pH of all the experimental ponds examined ranges from 7.1 to 8.3 which is favourable for fish growth. Dissolved oxygen content of 7-10 ppm at noon remains adequate for high production; alkalinity as $CaCO_3$ varies from 33 to 132 ppm and hardness (Ca, Mg) 90 to 113 ppm, in the Taoyuan ponds, all high enough for optimum production provided phosphorus and other nutrients are available in balance. The phosphorus content of the unfertilized pond water is 0.044 to 0.05 ppm; but when fertilized with superphosphate or receiving run-off water from watersheds, the phosphorus (PO_4-P) concentration may increase to the level of 0.50 to 1.00 or even higher for a few days. The amount of silica (SiO_2) in freshwater ponds varies from 1.3 to 6.80 depending on the time of day and the phytoplankton population. A highly eutrophic pond contains less soluble silica than the oligotrophic, because the phytoplankton bloom has used up most of the silica available in the water. The same phenomenon is also true of phosphorus and the other essential nutrients for photosynthesis.

Another interesting characteristic of the highly productive ecosystem in the freshwater ponds is the chloride concentration. When Cl^- content is between 14 and 26 ppm as in the Taoyuan ponds Nos. 2012 and 5017, the fish yield comes to 747 kg/ha/year and 1242 kg/ha/year respectively. In three other ponds containing less than 6 ppm of chloride the yield is below 400 kg/ha/year.

The bottom soil of most of the freshwater ponds in Taiwan is rich in organic matter (3 to 4%) and nitrogen (N 1200 to 3298 ppm), fair in available phosphorus (P_2O_5 13 to 46 ppm or 39 to 138 kg/ha) and in Ca and Mg (150 to 960 ppm), but very rich in Fe (12 to 183 ppm) and potassium (K 30 to 110 ppm).

The composition of the plankton biomass varies from pond to pond and on different days and seasons. Some ponds examined in February, 1967, when the temperature remained between 19° and 20°C on the surface, not as yet the season for plankton bloom, had 40 to 78% phytoplankton and 22 to 60% zooplankton. Among the phytoplankton, chlorophyceae (***Pediastrum***, ***Scenedesmus***) were dominant; next came the diatoms.

In reviewing these preliminary water and bottom soil analyses of the freshwater ponds it appears that phosphorus and silicon are the principal limiting factors in primary productivity and consequently fish production. Therefore if these two nutrients are added artificially in adequate quantity, fish production can be greatly enhanced.

The eel ponds (freshwater) represent another class of ecosystem which is characterized by the carnivorous eel as a primary major domesticated species, while the common carp, silver carp, bighead, goldfish, grass carp and Crucian carp are secondary. Another outstanding feature of this class of ponds is the abundance of blue green algae such as ***Microcystis***, ***Spirulina***, ***Anabaena***, ***Chroococcus***, ***Merismopedia***, ***Coelospaerium***, etc. due to the superabundance of nitrogenous organic matter derived from the decomposition of the residual feedstuff given to the eel. In this ecosystem the common carp feed directly on the dispersed parts of the feedstuff of animal origin, the silver carp and goldfish on the phytoplankton, and the bighead on both zooplankton and phytoplankton.

A four hectare eel pond in Hsinchu can be used to illustrate the basic characteristics of this type of pond (reservoir) ecosystem. The pond originally built for irrigation purpose is 1.5 m in average depth (deepest part 4-5 m at the sluice) and the conditions under which the pond stands are very similar to those at the reservoirs in Taoyuan excepting that the discharge of water does not take place so often.

In this four hectare pond 2,400 kg of about 100,000 elvers, each weighing 10-40 g were stocked in 1967 once or twice the year for a culture period of 6 to 12 months during which the stock grew to about 14,000 kg in toto. This means that most of the elvers attained an average weight of 200 g from the original weight of 25 g in 6 to 12 months. Selective fishing was carried out as often as once every day in the cold months to once a week to a month to remove the large eels over 200 g for the market and leave the smaller ones to grow. Besides eel, 6,000 to 8,000 silver carp fingerlings of 10-20 g, 800-1,000 bighead of 10-20 g, 32,000 common carp of 10-20 g, 4,000 to 6,000 grey mullet of 0.5 g and a few hundred goldfish and 2,000 to 4,000 mud carp were also stocked in the same pond as secondary crops for the same culture period.

The breakdown of the harvest is roughly as follows:

Species	Harvest
70,000 Eel (several crops a year)	14,000 kg
4,000 Silver carp	6,000 kg
1,000 Bighead	5,600 kg
8,000 Common carp	4,000 kg
3,000 Grey mullet	800 kg
4,000 Mud carp and grass carp	1,600 kg
Total	32,000 kg

As feedstuff for the eel, fresh trash fish to which 5 to 10% of gas, pure fish meal is added is given, resulting in a conversion rate of about 10:1. This means that only 10% of the feedstuff administered turns into eel meat, with the rest of the 90% dispersed in various forms of gas, soluble substances and particulates in the water, part of which is directly or indirectly utilized by the common carp and the other fishes. To feed the common carp, a few thousand kg of bean cake, silkworm pupae, etc. are given in addition.

The harvest of eel in this ecosystem of large reservoir is comparatively light as compared with that from the intensive culture in the smaller ponds, usually with each unit area not exceeding 5,000 m^2. With aeration by pump and mechanical paddle device in addition to necessary renovation of water and special care in the administration of feeding and "water conditioning", a pond of 5,000 m^2 in area can be managed to yield 10,000 kg of marketable eel from an original stock of 1,500-2,000 kg (elvers). Other small ponds under less favourable conditions yield about half as much.

In 1968 elver stocking is doubled; instead of 2,400 kg of 100,000 elvers, 5,000 kg of 200,000 elver are stocked in the same pond with an estimated crop of 25,000 kg of marketable eel, most of them weighing more than 200 g.

In Taiwan two types of ponds are used for eel culture, the running water and the stagnant water ponds. In the running water ponds there is no problem of oxygen deficiency, but the stagnant water ponds are heavily polluted so oxygen deficiency is bound to occur between the hours 2400 and 0600 or 0700 and it may even turn from bad to worse in abrupt changes of water colour from green to brownish green to yellow, brown or red and then deadly dusky. In the last two or three phases of colour change, dissolved oxygen may be completely depleted for most of the day thus causing drastic kill of fish. This phenomenon is a distinct exhibit of plankton succession possibly attributed to, first, a climax of phytoplankton bloom which uses up most of the available mineral nutrients and consequently gives rise to an enormous amount of extracellular substances in the water. Under the circumstances phytoplankton is naturally diminished, leaving a niche for the Protista, especially bacteria and flagellate protozoa, to develop and become dominant. This succession causes the water to appear yellowish, yellowish-brown, brown or even red depending upon the kind of dominant protozoa in existence, and at last dark when most of the micro animals die and putrefy. In the meantime

Rotifera and Crustacea follow to multiple in close proportion to the availability of feed, a situation in which the macro-phytoplankton have no chance for immediate recovery, and thus for a period of a few days to weeks the biomass of the oxygen-consumers proliferates to play the role of dissolved oxygen depletion in the ponds. As a result the fish either stop growing due to the shortage of oxygen, or suffer immediate death from oxygen exhaustion.

Now it is evident that the problem of "water conditioning" in the stagnant ponds is demanding a solution. To make the water colour good involves the cultivation of the right kinds of phytoplankton and the maintenance of their growth all the time. Experience has shown that by applying inorganic fertilizers in such a manner as to provide adequate nutrients to the phytoplankton, proper green and brownish green colour can be initiated and maintained. Furthermore, by stocking some kind of phytoplankton-feeding fishes to graze on it so as to establish a state of balance between consumers and primary producers, foul water may be prevented. But experiments are needed to determine the kinds and the dosages of the inorganic fertilizers to be used, the species of phytoplankton feeders developed as a consequence, and the many physiological and ecological factors of the ponds influencing the above.

The freshwater ponds on the coastal plain are richer in mineral elements and are generally more productive than those on a higher level in the interior. Many ponds of this class are highly polluted by the city or village sewers. The species of fishes used to stock this class of ponds, particularly in south Taiwan are, in the order of importance in production: ***Tilapia mossambica*** which accounts for more than 50% of the total harvest in many ponds in Tainan and Kaohsiung; silver carp 10%, grey mullet about 12%, and 20 to 32% being common carp, goldfish, bighead, eel and milkfish.

The milkfish ponds are built on the tidal flat for sea-water culture. As the ecosystem of this class of ponds is totally different from that of the freshwater ones, the same principle and practice of fertilization cannot be applied here. It requires special techniques and standards of application which have not as yet been developed.

Lin (S.Y., 1968) has discussed in detail the experiments, results and problems of salt-water pond fertilization, a subject not to be repeated in this paper.

Further Experiments of Superphosphate Application at the Taoyuan Fish Farm and at Liyutan 1966-1967

As explained by Lin and Chen (1966) the Taoyuan Fish Farm manages 120 ponds (or reservoirs) with a total water surface of 854 hectares, principally for the domestication of silver carp, bighead, grass carp, mullet, Crucian carp, mud carp, perch and catfish. Among these 120 ponds, eight of two distinct types in respect of fertility were selected for the 1966 experiments. The four ponds of high fertility yielded an average of 619 kg/ha/year (extremes 442-780) and the other four poor ones 132 kg/ha/year (extremes 113-180). The rich ponds were heavily fertilized with nightsoil and received run-off water rich in nutrients from the surrounding watersheds, while the poor ones received none or very little nightsoil and run-off from the watersheds.

The objectives of these experiments in 1966 were to show (1) to what extent fish yield can be increased in the highly productive ponds through the use of superphosphate, and (2) the effect of superphosphate without nightsoil on fish yield. The results are shown in tables 4 and 5.

Table 4. Superphosphate and nightsoil treatment of the eight experimental ponds of the Taoyuan Fish Farm in 1966

Pond No.	Area (ha)	Mean fish yield (1959-1964) prior to treatment (kg/ha/year)	Treatment		Fish yield	
			$CaH_4(PO_4)_2$* (kg/ha)	Nightsoil (ton/ha)	kg/ha	Increase %
2012	8.9	630	111	100	747	18
2015	11.4	442	222	63	585	32
2105	8.8	626	111	156	739	18
5017	6.3	780	222	205	1245	59
8004	7.8	113	444	13	388	243
8008	9.4	120	444	0	354	200
8019	9.4	115	555	0	323	190
10-6	7.8	180	555	43	480	167
Total	69.8					

* Commercial calcium superphosphate contains 18% P_2O_5, therefore $CaH_4(PO_4)_2$ does not mean chemical purity in this paper.

Table 5. Comparison of fish yield increase by superphosphate treatment alone and by superphosphate plus nightsoil in 1966 and 1967

Pond area (ha)	Mean fish yield (1959-1964) prior to treatment (kg/ha/year)	Mean $CaH_4(PO_4)_2$ (kg/ha/year)	Mean Nightsoil (ton/ha/year)	Mean fish yield	
				kg/ha/year	Increase over years (1959-64) %
18.8 (Taoyuan)	118	499	0	385	226
15.6 (Taoyuan)	147	499	29	504	242
20.0 (Liyutan)	149	450	0	493	231

In 1967 experiments were extended to 16 ponds covering a total water surface 109.4 hectares in Taoyuan. The experimental design and the results in fish production are shown in table 6.

Table 6. Results of superphosphate fertilization in 16 experimental ponds in 1967

Pond No.	Area (ha)	Mean yield (1959-1964) prior to treatment (kg/ha/year)	$CaH_4(PO_4)_2$ (kg/ha)	Fish yield	
				kg/ha	Increase over 1959-64 %
2012	8.9	630	111	1,159	83
2105	8.8	626	111	891	42
6009	4.0	440	222	736	66
8104	7.2	271	222	441	62
2015	11.4	442	222	703	59
5017	6.3	780	222	1,219	56
6006	4.0	379	444	884	133
8103	4.8	364	444	673	82
8004	7.8	113	444	520	360
8008	9.4	120	444	410	241
8019	9.4	115	555	454	294
10-6	7.8	180	555	630	250
5002	4.4	470	666	1,004	113
7009	5.6	191	817	685	260
5003	4.8	355	1,000	1,272	257
8102	4.8	292	1,000	815	178
Total	109.4				
Mean		367	427	750	

One more pond of 20 hectares, the Liyutan of Nantou Hsien was added for comparison. The treatment and the results are shown in table 7.

Table 7. Superphosphate treatment and results of experiment in Liyutan in 1967

Species	Mean yield (1964-1966) (kg/ha/year)	$CaH_4(PO_4)_2$ (kg/ha)	Fish yield		
			No.	kg	kg/ha
Silver carp	34	450	7,909	7,909	395
Bighead	0		640	960	48
Crucian carp	60		3,331	666	33
Mud carp	50		1,032	258	13
Grass carp	1		—	—	—
Others	4			77	4
Total	149	450	12,912	9,870	493

Experiments in Freshwater Ponds of Coastal Plain, 1966-1957

It was the purpose of this experiment to show if inorganic fertilizers, especially the cheap superphosphate alone, could be used as a substitute for, at least, a part of the costly organic manures in order to leave a wider margin of profit and, furthermore, if higher production than the present could still be achieved by the addition of superphosphate to the traditional practice of fertilization with organic manures. In a way it was a replication of the experiments conducted in Taoyuan 1966. Two units of ponds, one of 10 ha and the other 9 ha in Kaohsiung Hsien were selected for experiment. The fish farmer of each pond unit was advised to carry out his traditional practice of fertilization, but in addition he was to add $CaH_4(PO_4)_2$ to his ponds at the rate of 222 kg/ha in a culture period of 10 to 12 months. To save time and for greater efficiency of fertilization, this quantity of 222 kg/ha should be divided into at least 60 portions of about 3.7 kg each for application once every five days. However, the farmer could alter the schedule at his discretion to apply whatever quantity he deemed necessary in maintaining the desirable light brownish green colour of the water to prevent its worsening by turning brown or red. The results of the 1966-1967 experiments are shown in tables 8 and 9.

Similar experiments were also carried out in Chiayi.

Table 8. Results of superphosphate treatment to freshwater ponds of the coastal plain 1966-1967

Year	1st pond unit (10 ha)			2nd pond unit (9 ha)		
	Total yield kg	kg/ha	$CaH_4(PO_4)_2$ kg/ha	Total yield kg	kg/ha	$CaH_4(PO_4)_2$ kg/ha
1965	68,480	6,848	0	63,335	7,039	0
1966	72,420	7,242	235	63,985	7,109	250
1967	81,920	8,192	202	69,216	7,690	250

Table 9. Comparison of organic and inorganic stuff added to the 2 units of ponds as feed and fertilizers (kg/ha)

Organic stuff	1st pond unit (10 ha)			2nd pond unit (9 ha)		
	1965	1966	1967	1965	1966	1967
$CaH_4(PO_4)_2$	0	235	202	0	250	250
Nightsoil	22,370	14,400	20,630	24,800	18,060	20,230
Pig manure	13,300	9,700	12,770	17,000	12,226	10,930
Rice bran	170	296	0	7,444	6,104	1,356
Green grass	2,350	2,197	2,453	12,000	16,600	3,000
Bean cake	0	0	571	5,000	6,240	830
Legume seed cake	700	780	0	532	522	550
Sesame seed cake	2,150	2,214	4,040	0	0	500
Brewery waste		0	0	0	0	3,500

Results and Discussion

The results of the experiments carried out in 1965, 1966 and 1967 show an infallible response of fish yield increase to superphosphate application in all the Taoyuan freshwater ponds. The degree of response, of course, varies with the ecological conditions of the individual ponds and the dosage of superphosphate. Tables 4, 5 and 6 show that, on the one hand, in ponds which are enriched by many allochthonous nutrients, the index of fish increase by superphosphate over the fixed base of production prior to treatment is always low; but, on the other hand, when a poor pond receives little allochthonous nutrients, fish increase by superphosphate application is remarkable.

Similar results are obtained from experiments carried out in the low land area of Chiayi and Kaohsiung Hsien where ponds are built on rich alluvial soil, and the production prior to phosphate treatment ranges over 1,000 kg/ha/year, while the increase through the use of P_2O_5 at 40-80 kg/ha is only from 8 to 32%. In the poor ponds at the Taoyuan Farm producing less than 200 kg/ha/year prior to treatment, the increase in yield through the use of similar dosage of P_2O_5 ranges from 82 to 360% (tables 4, 5, 6 and 8, and figure 1).

The experiments carried out at the Taoyuan Fish Farm in 1966 and at Liyutan in 1967 (tables 5 and 7) suggest that superphosphate alone can take the place of nightsoil in boosting fish production to the level of about 400 kg/ha/year. The dosage of P_2O_5 should be over 80 kg/ha/year, and even application up to 180 kg/ha/year for the first two or three years is still economically effective. In this connection further experiments should be carried out to determine the maximum dosage of superphosphate which would give a profitable increase in fish production and the compensation point where the cost of superphosphate will equalize the value of fish increase.

Figure 1 illustrates a general pattern of linear relationship (regression line from three years' data) between the dosage of superphosphate and fish yield increase notwithstanding the occurrence of irregularities due to such factors as the fertility of the ponds, meteorological changes and the heavy loss of fertilizers through continuous discharge of water. For example, the fish yield increase in the 1965 experiment hints to P_2O_5 at 180 kg/ha/year as the optimum dose, whilst the experiments of 1966 and 1967 suggest that 80 kg/ha/year and 100 kg/ha/year give the highest indices of increase respectively (tables 4 and

6). Strictly speaking this regression line obtained by least square method is misleading in the present case because yield increase is not infinitely proportional to the increase of fertilizer application. Nonetheless the second line connecting the mean percentage increase of fish yield with optimum dose at $CaH_4(PO_4)_2$ 555 kg/ha/year seems more realistic.

As the Taoyuan reservoirs were built primarily for the purpose of irrigation, and fish raising is managed under whatever conditions the irrigation authority permits, the water level of the reservoirs is therefore beyond the control of the fish farmers. On many occasions during the culture period, the water in the reservoirs is heavily drawn to meet the needs of the rice fields. As a result a large part of the superphosphate applied is lost, and the phytoplankton and zooplankton which are important food for the Chinese carps and the grey mullet are mostly gone. For this reason the residual effect of P_2O_5 on fish yield in many ponds is not apparent at all, as shown in table 11. The production of ponds Nos. 8103, 8104, 2015 and 6009, for example, was reduced in 1967 despite the continuous application of P_2O_5 for three years.

However, in those reservoirs where less water is discharged for irrigation because the water supply to the rice fields can be obtained from independent canals other than the reservoirs, fish production is increased through the accumulation of nutrients. This explains part of the reason why only a few of the Taoyuan ponds can be managed to increase fish production to the level above 1000 kg/ha/year, while most of them remain poor despite continuous fertilization.

Table 10. Relationship of superphosphate dosages and fish yield of 16 experimental ponds in 1967

Total area (ha)	Mean yield prior to treatment (kg/ha/year)	P_2O_5	$CaH_4(PO_4)_2$ (kg/ha)	Mean fish yield 1967 (kg/ha/year)	Increase over (1959-1964) %
17.7	628	20	111	1,025	63
28.9	473	40	222	755	60
26.0	207	80	444	565	173
17.2	145	100	555	533	267
4.4	470	120	666	1,004	113
5.6	191	160	888	685	258
9.6	323	180	1,000	1,044	223

Table 11. Fish production and P_2O_5 dosages of the 16 experimental ponds of the Taoyuan Fish Farm, 1965-1967

Pond No.	P_2O_5 dosage (kg/ha)			Fish yield (kg/ha)		
	1965	1966	1967	1965	1966	1967
2012	0	20	20	902	747	1,159
2105	0	20	20	655	739	891
6009	40	40	40	739	640	736
8104	40	40	40	583	401	441
2015	0	40	40	579	585	703
5017	0	40	40	1,293	1,242	1,219
6006	80	80	80	774	618	884
8103	80	80	80	662	498	673
8004	0	80	80	279	388	520
8008	0	80	80	258	353	410
8019	0	100	100	244	323	454
10-6	0	100	100	370	480	630
5002	120	120	120	835	740	1,004
7009	120	120	160	556	564	685
5003	180	180	180	863	902	1,272
8102	180	180	180	653	817	815

Commercial Use of Inorganic Fertilizers in Freshwater Ponds

The history of inorganic fertilizer application to freshwater ponds in Taiwan is short. Before 1964 the use of inorganic fertilizers to boost fish production in freshwater ponds was scarcely known, although experiments have been carried out in brackish-water ponds since 1952, and the agricultural use of inorganic fertilizers has a much longer history. In 1965 the Chupei Fish Culture Station of the Taiwan Fisheries Research Institute, with technical and financial assistance from the Joint Commission on Rural Reconstruction, carried out a series of experiments and demonstrations in 11 freshwater ponds covering a total area of 54 hectares distributed in the counties of Taoyuan and Hsinchu. Table 12 shows part of the striking results obtained (Lin and Chen, 1966). Encouraged by this, the Taoyuan Fish Farm and many other private fish farmers immediately began to use superphosphate on a large scale. Thus in 1966 and 1967 the Taoyuan Fish Farm alone applied 155,070 and 255,804 kg of superphosphate to 549 and 628 hectares respectively, resulting in 53 to 85% increase in fish yield at very low cost over the mean yield of 1959 to 1964 when no inorganic fertilizers were used (table 13). The results of inorganic fertilizer treatment in the three private ponds in Hsinchu with increases over unfertilized yields from 110 to 399% are even more remarkable, most probably attributable to the minimum discharge of water during the culture period. The confidence of the Taoyuan Farm management in the use of inorganic fertilizers is further strengthened by the profits made in 1966 and 1967 (table 14). This together with further efforts made by the Joint Commission on Rural Reconstruction to hold demonstrations in Miaoli, Taichung, Chiayi, Nantou, Tainan and Kaohsiung in addition to Taoyuan and Hsinchu, has constituted effective stimuli towards the extension of inorganic fertilizer application to almost all the 12,000 hectares of freshwater ponds and reservoirs on the island within a short period of three years, although the exact figure of the total quantity of inorganic fertilizers used up to date is not yet available at the moment.

Table 12. Results of superphosphate treatment at the Taoyuan Farm (1965)

Pond No.	Area (ha)	Mean production (1959-1964) prior to treatment (kg/ha/year)	P_2O_5 (kg/ha)	Yield (kg/ha)	Increase %
5002	4.4	470	120	835	77
5003	4.8	355	180	863	143
6006	4.0	379	80	774	104
6009	4.0	440	40	844	91
7009	5.6	191	120	556	191
8102	4.8	292	180	630	116
8103	4.8	364	80	720	97
8104	7.2	271	40	637	135

Table 13. Results of commercial use of superphosphate at the Taoyuan Farm (1966-1967)

Year	Total area (ha)	$CaH_4(PO_4)_2$		Fish yield		Yield increase	
		kg	kg/ha	kg	kg/ha	Fixed base index	Per kg of $CaH_4(PO_4)_2$
Mean (1959-64)	542	0	0	217,142	400	100	0
1965	537	22,666	42	286,829	534	133	3.19
1966	549	155,070	282	336,081	612	153	0.75
1967	628	255,804	407	466,443	741	185	0.83

Table 14. Total production, cost and profit made by the Taoyuan Fish Farm during the period 1962 to 1967

Year	Fish production		Total cost of production (NT$)	Profit (NT$)
	kg	kg/ha		
1962	266,562	469	2,878,050	405,221
1963	283,203	422	3,450,514	107,234
1964	351,226	540	4,547,211	659,229
1965	368,501	535	4,209,951	909,671
1966	464,497	612	5,256,071	1,837,459
1967	489,833	743	7,640,677	3,221,510

Cost of Production and Profit

In order to appreciate the effect and advantages of superphosphate as stimuli for the increase of fish yield, it is necessary to make a close examination of table 14 again for the purpose of explaining the causes of yield increase in years other than 1966 and 1957 and interpreting the relationship between the cost of production and profit.

The increase of production in 1966 and 1967 was doubtless attributable to the use of superphosphate, but the raise of yield and profit level in 1964 over 1962 and 1963 was due to the application of organic fertilizers and the expansion of pond area as shown by the records of the Taoyuan Farm. The slight increase of production in 1965 over 1964 was, however, attributed to superphosphate applications to the eight demonstration ponds, in addition to the improvement of management, more extensive use of organic fertilizers and the more favourable meteorological conditions.

The cost of production at the Taoyuan Farm consisting of 42% labour, 18% fish fingerlings, 21% fertilizers (mostly inorganic) and 19% administration for 1967, varies to a considerable extent from year to year dependent on the price of fish fingerlings for stocking, the cost of inorganic fertilizers and daily commodities. The labour force comes from the 600 ex-servicemen who now turn fish farmers and to whom the daily cost of living, equipment, social, educational and recreational expenses must be advanced by the administration. As this item constitutes the basic activities of the Farm, it heads the list in expenses. The success of induced spawning of the Chinese carps by pituitary hormone injection since 1964 has cut down the cost of fingerlings for stocking, whilst that of using inorganic fertilizers to increase production in ponds has raised the expenditure on fertilizers. Nightsoil and other organic manures are collected by the ex-servicemen themselves without additional cost, but as demonstrations have shown that inorganic fertilizers can be conveniently and economically used to replace organic manures so far as Chinese carp and mullet culture is concerned, the use of the latter is now on the decline. Instances are also known that ponds overdosed with nightsoil have resulted in reduced yield (Lin and Chen, 1966).

The ex-servicemen use their spare time to cut grass to feed the grass carp whose faeces and any grass left over would serve as fertilizers for phytoplankton increase in the ponds.

The profit listed in the last column of table 14 represents whatever is left over after deducting the total cost of production from the gross income derived from the sale of fish. This profit is then distributed to the "fish farmers" in accordance with the amount of work each has contributed to the production during the year of culture.

The advantage of using superphosphate in freshwater ponds to obtain better yield and higher profit of silver carp, bighead, Crucian carp, grey mullet and mud carp is further strikingly illustrated in the 1967 experiment at Liyutan (table 7). For three years (1964-1966) prior to superphosphate treatment, the mean production of this reservoir of 20 hectares was only 2973 kg valued at NT$ 40,256 at the average cost of production at NT$ 78,422 or a loss of NT$ 38,166. After treatment in 1967 the yield increased sharply to 9831 kg in eight months, valued at NT$ 124,402 at the cost of production of NT$ 81,314 to allow a net profit of NT$ 43,088.

The Value of Superphosphate in Pond Nutrition

Experiments and demonstrations have shown that superphosphate effectuates the increase of fish production in several ways: (1) PO_4-P when present in sufficient amount stimulates the bluegreen algae to fix molecular nitrogen into soluble nitrogen compounds, (2) when the nutrient level of PO_4-P and nitrogen compounds is raised, primary productivity is greatly enhanced to give rise to abundant phytoplankton biomass upon which many of the domesticated fishes graze, (3) superphosphate application at regular intervals clarifies the water to permit deeper penetration of light so as to provide more space for photosynthesis (primary production) and to supply more O_2 to the fish, (4) in the longer trophic chain more phytoplankton will benefit the increase of zooplankton and eventually the zooplankton-feeding and carnivorous fishes and (5) since domesticated fishes are so provided with abundant food through PO_4-P fertilization, parasitic infestation and bacterial diseases may be reduced to the minimum.

In addition to superphosphate, other compounds of silicon, calcium, magnesium, manganese, cobalt, zinc, copper, molybdenum, vanadium, etc. are also used in experiments to determine whether their addition to the ponds can further increase fish production, but it will take time to obtain convincing results for practical application.

Lin (C.N., 1968) observes that chlorophyll increase is closely related to the PO_4-P supply, and the up-take of phosphorus, silicon and the other mineral nutrients by the phytoplankton is immediate. Thus through observations in superphosphate application, available phosphate concentration increases to the maximum on the second day and drops to the lowest level on the 5th day. On the contrary chlorophyll concentration rises sharply on the 3rd day and reaches the highest level on the 5th day. In the other ponds, records also reveal that silica concentration is low when phytoplankton biomass is high. These findings hint to the advantages of daily application of inorganic fertilizers or once every two days, but it should never be made less than once every five days.

However effective superphosphate has proved to be the nutrient for fish yield increase, there still remains, from the economic point of view, numerous problems to be solved. The first question concerns the optimum dose of superphosphate to be applied to a certain type of ponds. This is usually determined through well-designed experiments, but a second question arises as to what criteria should be set for the fish farmers to follow in applying the optimum dose. This involves the evaluation of the physical, chemical and biological conditions of a pond for the purpose of proper application of superphosphate, a task requiring such high precision in techniques and so much cost in labour that it is hard to be satisfactorily accomplished. Further difficulties are encountered in the fact that the criteria once set up for the selection of an optimum dose will have to be changed frequently according to the continuous changes of ecological conditions of the ponds.

Generally speaking, for practical purposes the commercial fish farmers are primarily concerned with the economic evaluation of the effects on fish yield through three levels of superphosphate application—underdose, optimum dose and overdose—in the ponds. Such effect should be relevantly interpreted in terms of total profit. For example, when superphosphate is applied at the rate of 100 kg/ha, the effective conversion rate from fertilizer to fish is 1:2.1, whilst at the rate of 500 kg/ha or higher the conversion rate comes only to 0:0.8. But as the total fish yield under different rates of superphosphate application is compared, the former case gives much less profit than the latter. The following text will discuss this aspect of pond fertilization in detail to show that overdosage of phosphate can still be considered as a profitable practice.

Another question that remains to be determined is to what extent should a pond be overdosed with superphosphate and still make a reasonable profit.

Optimum Dose of Superphosphate

By optimum dose is meant, under a special set of pond ecosystem, the dose of superphosphate that will give the highest yield in a culture period of approximately 12 months. As illustrated in figure 1, a general linear relationship between fish yield increase from a fixed base and the dosage of superphosphate persists even up to P_2O_5 180 kg/ha or 1000 kg of superphosphate per hectare. Unfortunately data are not yet available to show the effect of larger dosage than P_2O_5 180 kg/ha on fish production increase under the conditions at the Taoyuan Farm.

Usually for common carp and ***Tilapia*** culture one may find the dosages of P_2O_5 30 kg/ha and 60 kg/ha respectively to be the maximum, after which fish yield increase tends to level off or even decline. But in the present case where silver carp, bighead, grey mullet, Crucian carp and mud carp, all being either pure or partial phytoplankton-feeders, are raised, a much larger dosage is required for maximum production. The loss of nutrients and consequently the phytoplankton population from the continuous discharge of fertilized water may be responsible for the necessity of increasing the dosage of P_2O_5. But it would be of utmost economic importance to carry out further experiments to determine the largest dosage for maximum yield under the existing Taoyuan conditions.

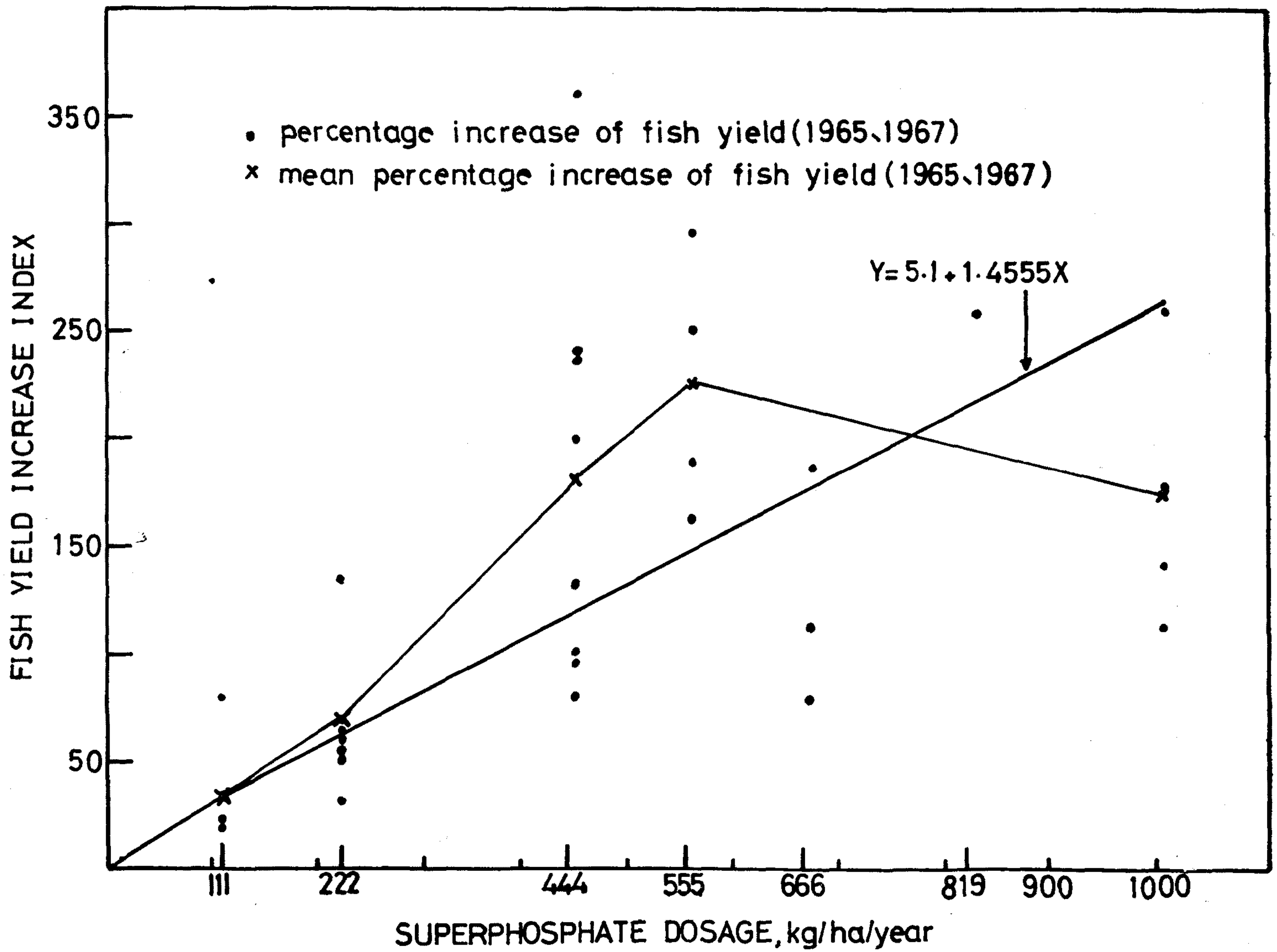

Figure 1. Percentage fish yield increases over fixed base in response to different dosages of superphosphate from experiments carried out in 1965-1967.

Economic Evaluation of Superphosphate Dosage

As discussed in the previous section, the fish yield increase in the semi-flowing reservoirs of Taoyuan follows a linear relationship with the superphosphate dosage up to P_2O_5 180 kg/ha (equivalent to $CaH_2(PO_4)_2$ 1000 kg/ha), but this does not mean that fish yield will be increased infinitely by increasing the dosage of superphosphate. Fish yield increase would stop somewhere when the maximum requirement of phosphate for phytoplankton production has been reached.

Closely related to this relationship between fish yield increase and superphosphate dosage, but different in nature and negative in relationship is the question of how large a dosage should be selected for the highest profit in commercial fish farming.

A possible way to answer this question would be to carry out an extensive series of experiments in order to decide the compensation dosage which represents the point where the value of fish weight increase by one kg of superphosphate will be equal to the cost of the fertilizer. When this compensation level has been experimentally determined, the superphosphate requirement that would lead to financial gain or loss could easily be estimated on the linear scale drawn from the data of the experiments. But, as a long series of experiments would require a large number of ponds, huge quantities of fertilizers and a long period of time, other simpler means can be sought to calculate the optimum dose for high profit and the compensation dose at the same time.

This optimum dose of superphosphate for the highest profit can be conveniently called the "economic dose" in order to differentiate it from the term "optimum dose" of superphosphate for maximum fish yield increase. As has been explained previously, there exists a linear relationship between superphosphate dosage and fish yield increase; but under a certain set of ecological conditions, a maximum fish yield will be reached at a dosage over and above which fish yield will not increase any further. This defines the term "optimum dose" of superphosphate used in the discussion of this paper.

In expressing the fish yield increase by the optimum dose of superphosphate, the index or percentage over a fixed base system is used, because, as the conditions of the individual reservoirs vary to a great extent, it is found simpler and yet sufficiently relevant to use the increase of fish production by superphosphate over the mean yield prior to treatment as the fixed base for comparison.

However, to determine the economic dose, this index system of expressing yield increase by superphosphate is no longer relevant, for by economic dose it is meant that the amount of superphosphate so applied will leave the widest margin of profit. An optimum dose concerns the nutritional and trophic possibility that permits the highest dose of superphosphate to give rise to maximum fish yield, therefore it may not be economical. But, on the other hand, an economic dose is strictly a financial concern. When an economic dose has been fixed and applied, there would be no squandering of funds in fertilization to cut down profit.

In extrapolating the data obtained from the experiments carried out in 1965-1967, the economic dose can be estimated in several ways, three of which are adopted for calculation in the present paper. As shown in figure 2, the first method is to calculate the least square regression line A from data obtained in 1965-1967 experiments. This line gives a negative, straight slope which does not appear to agree with the actual findings, because (1) it is unlikely that fish yield would drop to the level of 0.1 kg per kg of $CaH_4(PO_4)_2$ immediately after the dosage of 1200 kg/ha and (2) the relationship between $CaH_4(PO_4)_2$ and fish yield increase per kg of $CaH_4(PO_4)_2$ is not straight linear at all.

The second method is to take the mean values of the yield increase in kg per kg of superphosphate at different rates of application. The mean values are indicated as Xs in figure 2, which look quite close to reality and yet are not theoretically adequate.

The third way is to calculate a curvilinear regression, $Y=a+b \log X$, so that line B is obtained (figure 2). Perhaps this line represents a relationship which is the closest to the real situation. However, further experiments have to be carried out to verify at least two points. The first is how different are both the optimum and the economic doses for the highly productive and the poor ponds. Secondly, could the economic dosage estimated from extrapolation of the available data stand true for the Taoyuan reservoirs? Meanwhile investigations are being made to determine all the factors that would influence primary productivity and consequently fish yield.

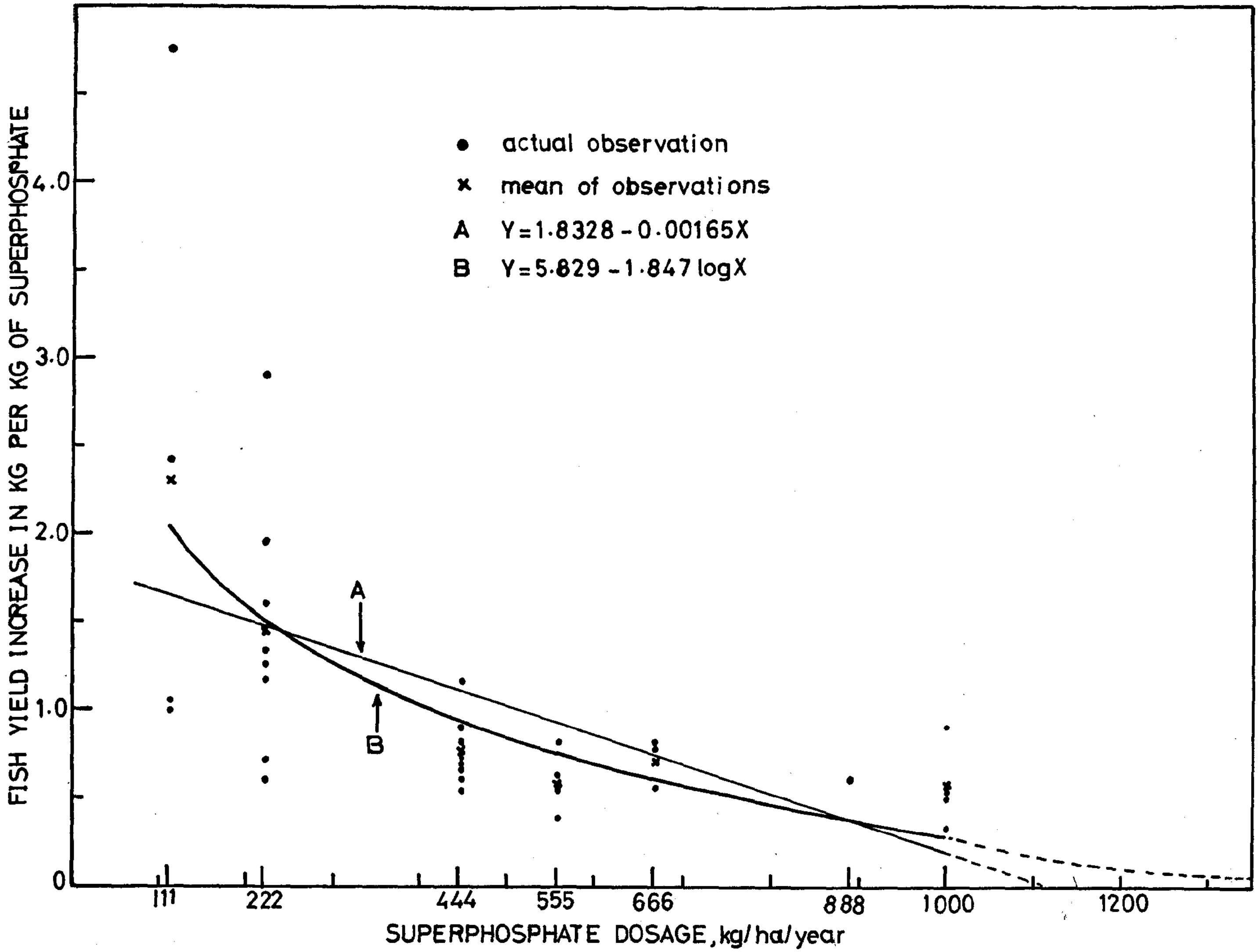

Figure 2. Response of fish yield to superphosphate application extrapolated from data of 1965-1967 experiments in 16 ponds to fixed base index by using the mean yield of 1959-1964 prior to superphosphate treatment as base and to yield increase per kg of fertilizer.

From the curvilinear regression as shown in figure 2, the fish yield increase per kg of superphosphate corresponding to the different rates of superphosphate application can be read. Now suppose the market price of the domesticated fish amounts to NT$ 20 per kg on the average and the cost of superphosphate is NT$ 1.70 per kg. On the basis of these, the economic dose is found somewhere between $CaH_4(PO_4)_2$ 444 kg/ha and 666 kg/ha as shown in table 15. The compensation dosage is then obtained by projecting the curvilinear slope further downward to the abscissa until a point is reached where the fish yield increase is exactly 0.085 kg per kg of $CaH_4(PO_4)_2$ corresponding to a dose of $CaH_4(PO_4)_2$ 1289.5 kg/ha which actually represents $Y=5.829-1.847\times3.11044=0.085$. At this compensation point of coordinates, the value of fish is equal to the cost of fertilizer or fertilizers.

Table 15. Extrapolation of superphosphate dosages for the highest profit based on data from experiments carried out in 1965-1967

$CaH_4(PO_4)_2$		Fish increase per kg of $CaH_4(PO_4)_2$		Total value of fish increase per ha (NT$)	Profit (NT$)
kg/ha	NT$	kg	NT$		
111	189	2.10	42.00	4,662	4,473
222	377	1.50	30.00	6,660	6,283
444	755	0.94	18.80	8,347	7,592
555	944	0.75	15.00	8,325	7,381
666	1,132	0.62	12.40	8,258	7,126
888	1,510	0.38	7.60	6,749	5,238
1,000	1,700	0.30	6.00	6,000	4,300

The Possibility of Silica as Secondary Macronutrient

To three of the 16 experimental ponds of the Taoyuan Farm, zeolite containing SiO_2 72.95%, Ca 3.27%, Mg trace, K_2O 0.13%, Al 9.92%, Fe 4.95%, Na 4.98% and H_2O 3.80%, was added for comparison. Table 16 shows the zeolite treatments and the results in the 1966 and 1967 experiments. With the application of zeolite in 1967, all the three ponds yielded from 18 to 40% more over that of 1966 when one pond alone received zeolite at the rate of 11 kg/ha. It seems likely that zeolite constitutes an effective factor for the increase of fish production, but there might have been other factors involved. As the Taoyuan Farm is expanding the program of zeolite experiment in 1968, more data will be obtained to verify the points in question.

Table 16. Response of fish production increase to the application of zeolite in the Taoyuan (freshwater) ponds

Year	Zeolite application and fish production in ponds.					
	6006 (4 ha)		8008 (9.4 ha)		8019 (9.4 ha)	
	Zeolite (kg/ha)	Fish (kg/ha)	Zeolite (kg/ha)	Fish (kg/ha)	Zeolite (kg/ha)	Fish (kg/ha)
1966	0	698	11	348	0	323
1967	87	884	100	410	200	454
Fish production increase		27%		18%		40%

Criteria for the Administration of Inorganic Fertilizers

Numerous criteria can be set for the administration of inorganic fertilizers, but so far none of them can be considered as definite and positive. However, as they are useful references and represent subjects of profound interest for further researches in order to improve pond fertilization, a brief discussion of them would not be out of place here.

State of Water in Ponds

High efficiency of fertilization in the stagnant water ponds can be easily achieved. But more fertilizers are required for the ponds with some degree of flowing, and if the water is running to the degree of complete renovation in 24 hours in these ponds, fertilization may become a complete loss.

Temperature

When temperature drops below 16°C in the winter, primary productivity is reduced in varying degrees and the growth of many domesticated fishes may be slow or even stop. Under the circumstances fertilization usually becomes superfluous. In late spring when the temperature rises above 20°C fertilization should begin and the amount of fertilizers be increased to double in summer when the temperature goes above 26°C. However, the situation may arise when the water becomes too rich and the population of the blue green algae has reached the maximum, fertilization should then be stopped for a while. Otherwise, the sudden mortality of the phytoplankton may cause the water colour to turn yellow or brown, resulting in oxygen depletion which is dangerous to fish life.

Transparency

Water transparency is measured by the Secchi disc the visibility of which in centimeters is the parameter in this test. The transparency of water is influenced by the concentration of phytoplankton, mud, colloidal material, soluble organic substances and suspended particulates. If the other factors remain minimum, the phytoplankton concentration measured by the Secchi disc reading is sometimes used as criteria for fertilization. Usually a 25 to 50 cm visibility of Secchi disc shows adequate concentration of phytoplankton which should be maintained by adding inorganic fertilizers from time to time. But, it is important that the pond under examination should not receive any muddy or polluted inflow and that *Microcystis*, *Chlorella* and *Anabaena* are not dominant in the phytoplankton bloom, for the surface scum formed by them may reduce the visibility of the Secchi disc. Besides, they are not so nutritious to the fish as the diatoms and *Scenedesmus* which, though equally abundant, do allow deeper penetration of light. However, as to the correlation of concentrations of the various important types of phytoplankton to Secchi disc reading and the effect of fertilization on the phytoplankton concentrations under different ecological conditions, little information is available.

Chemical Quality of Water and Bottom Soil

pH

A complete analysis of the water and bottom soil is a task not easily accomplished, but it should be made as far as possible to provide the basis for the determination of types and dosages of fertilizers to be used. Usually a pH range from 6.5 to 8.5 is considered suitable for fish culture, but in brackish-water ponds the pH may reach 9.5 or 10 at noon and still be healthy for milkfish. For the freshwater pond it is always beneficial to carry out liming periodically for the sake of its buffering effect and to supply Ca as essential nutrient to both phytoplankton and fish life.

Dissolved Oxygen

An adequate amount of dissolved O_2 is essential for fish growth. At 0500-0600 hours the dissolved oxygen content should not be less than 2 ppm. If it drops below 1 ppm drastic kill of fish is bound to happen, and if dissolved oxygen remains below 3 ppm for a long time at night especially between the hours 2300 and 0600, fish will not grow and may even be killed.

It is, therefore, necessary to condition the water by fertilization to make it suitable for fish life. But how this can be achieved is an extremely complex problem. Oxygen deficiency is usually due to the abundant growth of Protista, Rotatoria and Crustacea, consequently to the shortage of phytoplankton as primary producers. To prevent this, fertilization must be made at the beginning of phytoplankton population decline which means the start of colour change from green to yellow or brown, and yet it is the cause of this change of colour that is hard to determine with certainty. However, the general practice is to apply 50 to 200 kg of superphosphate per hectare depending on the speed and condition of response and sometimes in addition, other fertilizers that contain NH_3, SiO_2, Mg, Mn, Fe, Mo, etc. are added in order to maintain the desirable green or brownish green colour.

Phosphorus

Most natural waters contain very little soluble phosphorus, ranging from 0.003 to 0.030. In fish ponds constantly fertilized with inorganic and organic manures, the PO_4-P is comparatively high. By adding about 10 to 20 kg of calcium superphosphate per hectare once every five days the phosphorus content of the fish ponds can be maintained at 0.05 to 0.19 ppm. The highest PO_4-P content turns up, of course, on the first and the following day after superphosphate application and drops gradually to 0.06 and 0.05 ppm on the fourth and fifth day respectively (Lin C.N., 1968).

It appears likely that a phosphorus concentration of approximately 0.2 ppm should be maintained for optimum production of phytoplankton and domesticated fish. But, what will happen if the PO_4-P is maintained at 0.50 or 1.00 ppm? Will phytoplankton and consequently fish production be increased proportionally? In this respect more study and experiments are needed.

Biological Assays

Phytoplankton Standing Crops

By periodic sampling to estimate phytoplankton standing crops in the ponds, one can link up fertilization and consequently fish crop with phytoplankton production. On the basis of such relationship, fertilizer application can be so adjusted as to bring about the best fish crop and profit. Unfortunately information along this line is not yet available in Taiwan.

Chlorophyll Method

Among all the methods employed in the study of primary productivity, such as light and dark bottles, radioactive isotopes of carbon and phosphorus, chlorophyll concentration, uptake of carbon dioxide and mineral nutrients etc., the chlorophyll method can serve as a convenient criterion for inorganic fertilizer application. For example, Lin (C.N., 1968) studied the phosphorus dynamics in fertilized ponds and found that the amount of chlorophyll from phytoplankton is closely related to the concentration of PO_4-P. Before superphosphate was applied, PO_4-P was naturally low while chlorophyll concentration also dropped to the minimum. But immediately after fertilization, the chlorophyll content increased from 0.057 mg/l to a maximum of 0.153mg/l on the fourth day, meanwhile PO_4-P dropped to the lowest 0.051 ppm on the same day.

The foregoing study proves beyond doubt the applicability of the chlorophyll method for use as guide in superphosphate application. Provided that repeated tests agree with the results described above, a chlorophyll concentration of roughly 0.15 mg/l should be maintained by superphosphate application.

Acknowledgement

Thanks are due to C.F. Mao, Technical Manager of the Taoyuan Farm, C.K. Liu and S.F. Wu, Director and Specialist of the Chupei Fish Culture Station, T. T. Huang, H. T. Chen and M. T. Sun, Fisheries Officers of Nantou, Chiayi and Kaohsiung Hsien Governments for faithfully carrying out the inorganic fertilizer experiments and demonstrations in their respective districts. In carrying out the experiment on the feeding habits of the Chinese carps designed by the writer, F.C. Wang and C.N. Lin were responsible for the examination of the stomach contents of the three Chinese carps and the identification of the phytoplankton and zooplankton in both the digestive tracts and the ponds, to whom credits are gratefully acknowledged. The writer also wishes to thank Ruth Lee, Secretary and Assistant to the administration of the Rockefeller Foundation Grant Fund for her efficient and valuable assistance in the preparation of the manuscript.

Literature Cited

Frey, D.G., 1963. Limnology in North America. 734 pages. The University of Wisconsin Press, Madison.

Hickling, C.F., 1962. Fish culture. 295 pages. Faber and Faber, London.

Hora, S.L. and Pillay, T.V.R., 1962. Handbook on fish culture in the Indo-Pacific region. FAO Fisheries Biology Technical Paper No. 14, 204 pages. Rome.

Liaw, W.K. and Lin, C.N., 1967. Chemical and biological studies of fertilized and unfertilized ponds and lakes. China Fisheries, No. 174, p. 3-9.

Lin, C.N., 1968. Phosphorus dynamics in fertilized ponds. China Fisheries, No. 181, p. 5-9.

Lin, S.Y., 1968. Milkfish farming in Taiwan (A review of practice and problems). Fish Culture Report No. 3, 63 pages. Taiwan Fisheries Research Institute.

Lin, S.Y. and Chen, T.P., 1966. Increase of production in freshwater fish ponds by use of inorganic fertilizers. Proceedings of the World Symposium on Warm-water Pond Fish Culture, FAO Fisheries Report No. 44, 3:210-225. Rome.

Nickol'skii, G.V., 1954. Special ichthyology. Translated by J.I. Lengy and Z. Krauthamer, 1961. 538 pages. National Science Foundation, Washington, D.C.

Tominaga, M. *et al*, 1964. A study on the improvement of pond productivity by fertilization. Report Freshwater Research Institute, Ueda Station, 1963, 19 pages.

Wu, S.F., 1967. Preliminary report on the use of zeolite in freshwater ponds. China Fisheries, No. 174, p. 18-19.