develop hypersensitivity to bacterial parasites and usually die at a pH of 4.5 or lower. In Europe where the soils of the watershed are acid, the lime is added to the soil in the watershed rather than to the water in the lake or pond.

Suggestions for the Effective Use of Commercial Fertilizers in Growing Fish in the South

1. Check the soil in the watershed area. If this soil is very fertile, the water in the pond or lake is apt to contain some nitrogen and potash. Since phosphorus doesn't leach out appreciably, the water may not contain comparable amounts of phosphorus. On the other hand, when the soil in the watershed is sandy or non-productive for other reasons, commercial fertilizers are apt to be needed badly.
2. Don't fertilize overflow bodies of water. There is too much likelihood that the fertilizer will be lost in the overflow water.
3. Don't fertilize in the spring until the water warms up to about 65° F. Fertilization of cold water may stimulate the growth of filamentous algae much more than the phytoplankton.
4. If it is an old lake or pond where considerable amounts of organic matter have accumulated, reduce the first application to one-half rate. Perhaps 50 pounds of 16-16-4 fertilizer per acre could be considered a normal application in this area.
5. Repeat normal application of fertilizer every 10 days until the desired bloom is attained and only as needed to maintain the desired "bloom" thereafter.
6. If the desired "bloom" is not attained in three to five treatments, better stop and find the trouble. Very likely something has gone wrong. It may be that filamentous algae or other plants are present and are eating the plant food. If true, these plants will have to be killed before the phytoplankton can do its job.
7. Apply fertilizer in bags, traps, or baskets submerged in the water, to prevent the phosphorus from coming in contact with the soil and becoming fixed into an unavailable form.

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PHOSPHATE FERTILIZATION OF PONDS

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ABSTRACT

Pond fertilization with N-P-K has been used in the Southeast for the past 20 years to increase fish production and to control aquatic weeds and mosquitoes.

In ponds which had been fertilized previously for a 15-year period with N-P-K, no significant decrease in production resulted from omitting both nitrogen and potassium from the fertilizer mixture during a four-year experimental period. It appeared that adequate nitrogen for plankton production became available from nitrogen fixation by bacteria or algae and from the organic matter and ammonium stored in the bottom muds. Omission of phosphate, however, caused a decrease in

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production during all four years of the experiments. With no fertilization, production decreased during a two-year period; in the third and fourth years, production was approximately the same as in ponds that had never been fertilized.

Phosphate fertilization only was tried in 14 ponds which had been fertilized for three to five years or more with N-P-K, and in which submersed pond weeds were absent. Satisfactory results were in general obtained in plankton production and in weed control. Eight ponds were subsequently drained and found to be supporting crops of fish at approximately the same levels as in previous years with 8-8-2 fertilization. However, in several ponds response to fertilization was delayed for 30 to 60 days, which allowed growth of the branched filamentous alga *Pithophora*. Also in ponds where *Microcystis* scums were a problem with 8-8-2 fertilization, they continued to be a problem with phosphate fertilization.

While pond fertilization was probably first practiced in ancient China using manures and other organic materials, the first systematic investigations were conducted in Germany. Early research in Europe was summarized by Demoll (1925), and more recent summaries have been published by Nees (1949), Mortimer and Hickling (1954), Hickling (1962) and by Schaeperclaus (1962). Earlier European work dealt principally with the use of animal manures, hays and green manures for increasing carp production and later research included the use of inorganic fertilizers.

Schaeperclaus (1962) reported that phosphate was found to be the most effective of the inorganic fertilizer materials, yielding an average of 77 percent increase in production over that in unfertilized ponds. Potassium yielded no increase in fish production in certain ponds, and a considerable increase in others. Nitrogen was considered unnecessary in pond fertilizers as nitrogen fixation by bacteria had been demonstrated to occur in pond bottoms when a suitable substrate of carbohydrates was present to provide the essential energy. Schaeperclaus also cited Wunder as reporting that the average increase in carp production by the use of nitrogen as fertilizer varied from two to 26 percent, with an average of 17 percent over a four-year period.

In Israel, Hepher (1962) found that ponds fertilized with both phosphate and nitrogen gave uniformly highest yields. However, phosphate was the more important, giving a 333 percent increase in yield of carp while nitrogen added an additional 183 percent. He found that the addition of available nitrogen gave greatest increase in the spring, while in summer it had little effect. He postulated that nitrogen fixation was more effective in warm water than in cold water, and fixation probably furnished adequate amounts of available nitrogen during the summer period.

In Malaya, Hickling (1962) found phosphate to be the most effective inorganic fertilizer; the addition of nitrogen, as nitrate or urea, increased production to a much lesser extent, and was not considered profitable.

In Alabama, work was begun upon pond fertilization in 1934, using both organic and inorganic fertilizer materials (Swingle, 1947). However, organic materials, such as hays and manures, were discarded because relatively large quantities were necessary for relatively moderate increase in fish production and dense growths of filamentous algae often resulted. In a series of experiments, it was next established that fish production was directly related, within limits, to plankton production and that rooted aquatic vegetation was undesirable. Phytoplankton was found to utilize efficiently in vitro inorganic fertilizers with N-P ratios of 2:1. Since, in natural waters, soluble phosphate is rapidly bound by absorption or precipitation, the amount of phosphate was doubled for use in pond water, giving a 4:4.6 N-P_2O_5 ratio. Very small amounts of potassium appeared essential in vitro, and since the mixture was to be widely used, a small amount was included. The result was approximately an 8-8-2 N-P_2O_5-K_2O fertilizer mixture.

Various fertilizer materials were next tested in newly excavated ponds in which the bottom clays contained very little organic matter

(Swingle and Smith, 1939). As in European, Israeli and Malayan experiments, phosphate was the most effective single fertilizer material, yielding 48 percent increase in bluegill production. While nitrogen alone, as sodium nitrate, slightly reduced production, its use together with phosphate raised production by an additional 24 percent. A complete N-P-K fertilizer increased production 177 percent over that with no fertilizer, and the addition of lime to the N-P-K caused an additional 89 percent increase. Ammonium and nitrate were equally effective as sources of nitrogen.

Since at that time insufficient numbers of experimental ponds were available for proper replication, the 8-8-2 fertilizer or its approximate equivalent, was tried in ponds located in the Coastal Plains, the Piedmont, the Upper Coastal Plains and the Black Belt clay soils of Alabama. In all areas, good results were obtained by the use of this fertilizer in fish production as well as plankton production and for control of aquatic weeds and mosquitoes.

In addition to the increase of fish production, there was another consideration which affected the final selection of the pond fertilizer for use in the Southeastern United States. This was that immature forms of the mosquito, *Anopheles quadrimaculatus*, the intermediate host of the malarial parasite, lived among the aquatic weeds in pond waters in this area of the United States. In 1934, when pond research was begun in Alabama, malaria had already become a minor health problem throughout the area due to a combination of measures which included those for control of the anopheline mosquito. The mosquitofish, *Gambusia affinis* was relied upon for biological control, but in addition County Health Officers made monthly inspections of both public and private ponds and lakes. Whenever anopheline larvae were found in a pond or weeds emerged above the water surface in the shallow water, water drawdown or weekly spraying with oil was required. Consequently, it was realized that no pond program was desirable unless management methods could be developed which prevented production of anopheline mosquitoes in the ponds. Early experiments at Auburn demonstrated that mosquitofish were ineffective in control of anopheline mosquitoes where aquatic vegetation reached to or pierced the water surface; when no aquatic weeds were present, biological control by either mosquitofish or bluegills was effective and mosquito larvae were seldom found. This emphasized that a method of pond management must be devised which prevented growth of rooted aquatics (and also of floating plants such as duckweed or bladderwort). N-P-K fertilization proved to be effective in producing a rapid growth of phytoplankton which, by its shading action, prevented growth of most submersed rooted plants. Their control allowed greater wind and wave action, which often was effective in control of both duckweed and bladderwort. Later, N-P-K fertilizer was found to be effective in control of growths of rooted submersed aquatics, when applied in the later winter or early spring. Fertilization during this period stimulated the growth of cold-water species of filamentous algae that grew over and shaded out submersed rooted aquatics; as the water warmed up in the late spring, the winter species of filamentous algae died and were replaced by planktonic algae (Smith and Swingle, 1942).

Fertilization of ponds in the Southeast was therefore for the purposes of increasing fish production and for the control of aquatic weeds and mosquitoes. It was essential, for the prevention of growth by rooted aquatics, that the plankton algae increase rapidly in the early spring and shade the pond bottom before rooted plants began growth. N-P fertilization did this much more rapidly and effectively than P fertilization alone, a fact also noted by Hepher (1962) in Israel. Phosphate-only fertilization occasionally stimulated the growth of rooted aquatics (Nees, 1949) instead of planktonic algae.

The method of pond management developed at Auburn, using bluegill-bass in fertilized ponds was at first viewed with suspicion by public health officials as it was feared that widespread construction of ponds on farms would cause an increase in anopheline mosquitoes and malarial outbreaks in widespread areas. Fertilization was objected to on the reasoning that if it increased food for any aquatic organism, it would also increase mosquitoes. Careful checks on the abundance of mosquito larvae in new ponds and in old ponds that were receiving fertilization were therefore made by research personnel and by public health officials. It was found that mosquito abundance decreased in old ponds shortly after fertilization was begun, and that they practically disappeared with disappearance of the submersed aquatic weeds. In new ponds, fertilized sufficiently to prevent weed growth, mosquitoes were never a problem except where marginal weeds spread into the shallow water around the pond edges (Swingle and Smith, 1942). Consequently fertilization was made part of the recommendations for mosquito control in ponds by the State Health Department.

For years, in newly constructed ponds throughout Alabama, the amount and frequency of fertilization has been more dependant upon what was required to control underwater weeds than upon how much fertilizer was required to achieve maximum fish production. The recommendation to add more fertilizer whenever pond water cleared sufficiently so that an object could be seen deeper than 12 to 18 inches below the surface was for the prevention of the growth of rooted aquatics and of filamentous algae, which, if they become abundant, not only harboured mosquitoes but also too many small bluegills. In general, fertilization as practiced in the Southeast, along with deepening of the water 18 to 24 inches along the pond margins, has been quite effective in the control of submersed aquatic weeds and in mosquito control in ponds. While submersed aquatics were largely controlled, *Pithophora* and *Microcystis,* became prevalent "weed" plants in fertilized ponds.

Evaluation of Nitrogen in Ponds Fertilized for a 15-year Period

In many ponds which have been fertilized annually over a five-year to 20-year period, rooted aquatics are no longer a problem. With the accumulation of ammonia, organic matter and bound phosphates in the bottom muds, they were no longer the same environments as the original ponds. Consequently, research was begun at Auburn in 1959 to reevaluate the usefulness of nitrogen as a fertilizer (Rabanal, 1960; Gooch, 1962). A series of 12 ponds which had been fertilized with 8-8-2 annually for a 15-year period was stocked with fish and four ponds each received the following N-P_2O_5-K_2O fertilizer treatments: 0-0-0, 0-8-2, 8-8-2. The two latter were at the rate of 100 pounds per acre per application with 10 applications per year. The test fish used were: in 1959, the carp (*Cyprinis carpio*) and the goldfish (*Carassius auratus*); in 1960 the carp; in 1961 and 1962 the channel catfish (*Ictalurus punctatus*). Fish were stocked in February or March and the ponds drained the first of November of each year.

The results (Table I) indicated significant increases in production from the use of either the 0-8-2 or the 8-8-2 over that with no fertilization. While the differences between 0-8-2 and 8-8-2 with carp and goldfish approached significance in 1959, there was no statistically significant difference between the two treatments in any year. This would indicate that the addition of nitrogen was without measurable effect upon fish production in these ponds.

Table 1. Fish production per acre with three fertilizer treatments.

Species	Number stocked	Year	Days in experiment	Average net pounds fish per acre. 0-0-0	0-8-2	8-8-2
Carp [1]	500	1959	225	275.2	312.4	348.8
Goldfish [1]	2,000	1959	225	413.8	615.2	700.6
Carp [2]	1,800	1960	272	125.0	261.2	295.9
Channel catfish [2]	600	1961	233	52.8	203.4	204.2
Channel catfish [2]	2,800	1962	210	53.9	358.7	310.9

1. Averages of 2 replications.
2. Averages of 4 replications.

Chemical analyses indicated sufficient available nitrogen was present in the water of all ponds for good production. The source of this nitrogen was not definitely determined. It could have come from organic N and NH_4 stored in the bottom muds during the preceding 15 years of fertilization, from nitrogen fixation by bacteria present in the bottom soils or the water, from fixation by plankton algae, or most probably from a combination of all these sources. Chemical analyses dealing with this phase of the problem will be presented in another publication by Gooch.

Although the ponds had received phosphate fertilization annually also over the preceding 15 years, phospate was a limiting factor during the first year of its omission (0-0-0 treatment). However, some residual overall effect upon production from the previous fertilization was evident for a two-year period, and only in 1961 and 1962 was production as low as in ponds which had never been fertilized.

The results with channel catfish (Table 1) in 1961-62 illustrates the very important effect of numbers of fish per acre upon net pounds of fish produced. Increasing the stocking from 600 to 2,800 channel catfish per acre increased production in the 0-0-0 treatment by 1.1 pound, in the 0-8-2 treatment by 155.3 pounds and in the 8-8-2 ponds by 106.7 pounds fish per acre in approximately a seven-month period. This is due to the more efficient harvest of available fish-food organisms by the higher number of fish.

Tests With Phosphate Fertilization

The experiments reported above indicated that nitrogen fertilization could be omitted in certain ponds. Consequently 14 ponds, which had been fertilized for a three- to five-year period or longer and in which rooted aquatics had not reappeared for several years, were selected for the use of phosphate fertilization alone in 1962-63. Potash was not used since analyses indicated that none was needed. Experience has indicated that after several years of fertilization with potash, there is no longer need for its addition.

The source of phosphate was triple superphosphate, which was placed on platforms one foot under water to be distributed by wind and wave action. In general, satisfactory results were obtained. In some ponds plankton developed promptly in response to fertilization, while in others response was delayed from 30 to 60 days. Eight ponds were subsequently drained and found to be supporting crops of fish at approximately the same levels as in previous years with 8-8-2 fertilization.

In ponds where *Microcystis* blooms were a problem under N-P-K fertilization, they remained a problem when phosphate only was used. This was contrary to the findings of Prowse (1961) that phosphate fertilization produced diatoms, *Anabaenopsis* and *Oedogonium*, while manures produced *Microcystis* and *Anabaena*. *Anabaena* was dominant in several ponds in Alabama receiving phosphate fertilization only.

Also, *Pithophora* became dominant in two out of four ponds receiving 0-8-2 fertilizer, while it did not appear in four companion ponds receiving 8-8-2. This was probably due to the more rapid production of phytoplankton by N-P-K fertilizer with consequent earlier shading of the pond bottom which prevented growth of filamentous algae.

Conclusions

In most ponds, fertilization with phosphate only was satisfactory both from the standpoint of weed control and fish production. Consequently it would appear desirable for more extensive testing of phosphate—only fertilization in ponds in various soil types throughout the Southeast. It may prove desirable to use N-P-K fertilization once or twice in the early spring to encourage early plankton production, followed by phosphate fertilization the rest of the year.

The use of phosphate-only as a fertilizer will reduce the cost of fertilization by approximately 65 per cent below that required for 8-8-2 fertilization. It is suggested that ponds in which phosphate fertilization is most likely to be successful should be those in which rooted aquatics have been eliminated by fertilization over a period of three to five years and in which the bottom muds contain considerable organic matter. It would also appear that its use may be successful in ponds following the killing of underwater weeds by herbicides, as these dead plants should furnish the required carbohydrate basis for nitrogen fixation.

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OBSERVATIONS ON THE FACTORS INVOLVED WITH FISH MORTALITY AS THE RESULT OF DINOFLAGELLATE "BLOOM" IN A FRESHWATER LAKE

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ABSTRACT

Complete fish mortality associated with the development of high populations of dinoflagellates (*Gymnodinium* spp.) was observed in 1960 in a 9.5 acre fresh-water lake at Baton Rouge, Louisiana. Toxicity of the water samples containing the algae appeared to be related to the increased pH, length of exposure to sunlight and concentration of algal cells. Filtration with activated carbon removed the toxic effects. Laboratory tests offered data to explain the course of the fish mortality in the lake.