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ALKALINITY, HARDNESS, AND PRODUCTIVITY OF LIMED PONDS*

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ABSTRACT

The application of 1120 kg of basic slag per ha and 2240 kg of limestone per ha raised the concentrations of calcium, magnesium, carbonates, and bicarbonates, depressed carbon dioxide tension, and elevated pH, but significant treatment effects in the photic zone were sometimes masked by the diel effects of photosynthesis and respiration. In deeper waters below the photic zone, basic slag and limestone clearly elevated pH and concentrations of carbonate and bicarbonate, and initially depressed free carbon dioxide. Limestone and basic slag had dissimilar effects. Neither treatment raised total hardness to the level of hard waters; their only significant effect on pond bottom soil was a slight increase in pH. The biomass of seston and benthos and bluegill production were unaffected by liming. During 6.5 months, the experimental ponds produced 140 to 290 kg of bluegills per ha.

INTRODUCTION

Fish culturists in Europe agree that certain types of muds and waters need to be limed prior to fertilization if the latter treatment is to be of maximum effectiveness. Quicklime (CaO) is applied to ponds to destroy fish parasites and undesirable organisms, to precipitate excessive amounts of organic substances, to flocculate colloids and clear muddy waters (Hess, 1930; Schaeperclaus, 1933; Huet, 1952), but its use is undesirable because of its lethal effect on bottom organisms (Neresheimer, 1911; Demoll, 1925). It is toxic to fish and should be applied 10 to 14 days before stocking (Huet, 1952). Slaked lime, Ca $(OH)_2$, has the same effects as quicklime.

Limestone ($Ca.Mg(CO_3)_2$, quicklime, or slaked lime are used to raise the pH of the water to a slightly alkaline level, to raise the

*Based on a Master's thesis directed by Prof. H. S. Swingle.

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acid-combining value (alkalinity, or alkaline reserve) of the pond water and thus form a carbon dioxide reserve, and to improve the chemical, physical and biological condition of the pond bottom (Schaeperclaus, 1933; Macan, Mortimer, and Worthington, 1942; Neess, 1949; Huet, 1952).

Liming hastens decomposition of organic matter in mud and thereby releases bound nutrients (Schaeperclaus, 1933). When applied before fertilization, lime materials are reported to save phosphorus from precipitation as iron phosphate complexes, presumably because lime removes Fe^{+++} from solution in pond water (Neess, 1949). Wunder (1947) claimed that the fertilizing action of phosphoric acid is heightened by $CaCO_3$. However, quicklime must be added separately from other fertilizer materials to prevent "caking" (Demoll, 1925). Maciolek (1954) recommended that fertilization be done two weeks after liming to avoid binding nutrients in insoluble calcium compounds. Schaeperclaus (1933) thought that liming would lead to favorable base exchanges resulting in the liberation of potash from soil.

Demoll (1925) warned against excessive liming which may lead to the loss of valuable absorptive properties of mud and, in poor peaty mud, an acute lack of other elements. Schaeperclaus advised care in liming ponds with water very poor in lime and carbonic acid; over-liming could raise the pH to dangerously high levels. However, he believed that oftentimes the addition of more lime would do no harm, and it would be well to have a lime reserve when dealing with acid ponds.

European workers differ in their recommendations of amounts of lime materials to be used. Schaeperclaus (1933) gave a dosage scale based on the character of the bottom soil and the acid-combining value of the water. Wunder (1949) recommended a dose of 1120 to 2240 kg/ha of quicklime, or twice this amount of calcium carbonate depending on the pH and alkalinity of the water. In general, more lime is used in heavy soils than in light soils, and the amount increases as the pH of the soil decreases. There are differences in opinion as to whether limestone or quicklime is better, but in general (except for the disinfecting action of quicklime), it is agreed that the overall effects are the same, provided that twice as much limestone as quicklime is used (Schaeperclaus, 1933; Wunder, 1949).

As for the manner of application, either the pond bottom is limed after draining or the pond water is limed, depending on the purpose of liming. For parasite and pest control and bottom improvement, the pond bottom is limed. For other purposes, the method of application is inconsequential.

A few liming experiments in the United States (reviewed by Pamatmat, 1960) have yielded conflicting results and the question of whether liming increases fish production under prevailing conditions of fish culture in this country remains unanswered. Evidently there are factors which mask, modify, or completely negate any beneficial effects of alkalinity on aquatic biological production.

We still need to know in what way the addition of lime materials makes any type of water more productive of fish. Natural fish production is a long and complex process which is vulnerable at every stage to limiting or controlling factors. We may never ascertain how liming will ultimately affect fish production unless we investigate how liming affects those factors that could limit production.

The factors most likely influenced by lime materials are pH, free dissolved carbon dioxide, carbonate, bicarbonate, total hardness, calcium, magnesium, organic matter, and the different phosphorus fractions of the pond bottom soils. Experiments were conducted in ponds to determine the effects of basic slag and agricultural limestone on these factors. Standing crops of plankton and bottom organisms, and fish production were measured.

METHODS

Liming and fertilization

Six 1000 m^2 ponds, 1.5 to 1.8 m deep at one end and 0.6 to 0.9 m deep at the other end, were filled with water on 1 April and the lime materials were added on 6 April. Two ponds, F-5 and F-8, were treated with basic slag at the rate of 1,120 kg/ha. F-7 and F-1 were limed with agricultural limestone (2,240 kg/ha). F-6 and F-12 served as controls. The basic slag had the following assay: 8 per cent P_2O_5, 40 per cent CaO, 4 per cent MgO, and 2 per cent MnO. The agricultural limestone used was 67 per cent $CaCO_3$, 20 per cent $MgCO_3$, 8 per cent calcium in forms other than carbonate, and 2 per cent impurities.

One week after liming, fertilizer (ammonium nitrate, triple superphosphate, and muriate of potash) was added to all six ponds at the same rate of 9.0 kg nitrogen, 9.0 kg P_2O_5, and 2.2 kg K_2O per ha. Bi-weekly applications were made in the spring, every 3 weeks at the beginning of summer, and at 4 week intervals in late summer and early fall, a total of 9 applications.

Water sampling and analyses

Water was sampled with a bottle-train sampler (Swingle and Johnson, 1953). Samples were taken at both ends of the ponds, at 15 cm below the surface and 15 cm from the pond bottom.

Samples were taken in the afternoons a week after liming and every 2 weeks thereafter for 5 samplings. Later samples were taken at dawn and at less regular intervals.

The water was analyzed for pH, free carbon dioxide, carbonates, bicarbonates, total hardness, calcium, magnesium, and inorganic phosphorus (American Public Health Association, 1955). The pH analysis was done immediately in the laboratory; this took 30 minutes for each batch of samples. Free carbon dioxide, carbonate, and bicarbonate were analyzed immediately after finishing with the pH determination, and this took 1.5 hr. Determinations for total hardness, calcium, and inorganic phosphorus were finished within 18 hours after collection.

Soil Analyses

Composite soil samples were dried at 40 C and analyzed for dilute acid-soluble phosphorus, neutral ammonium fluoride-soluble phosphorus, acid ammonium fluoride-soluble phosphorus, calcium, and magnesium according to procedures of Swingle (1969). A Beckman pH electrode was used to measure the pH of 20 g of dried soil mixed with 20 ml of distilled water.

Fish stocking and harvesting

The ponds were stocked with bluegill sunfish (*Lepomis macrochirus* L.) at the rate of 3700 per ha 10 days after initial fertilization. The fish were not of uniform size but were predominantly 5 cm total length.

At the end of 6.5 months the ponds were drained and the fish were counted and weighed.

RESULTS

Calcium and magnesium of pond waters

No significant difference existed in calcium and magnesium concentrations between surface and bottom waters of the six ponds although bottom waters had higher average concentrations of both than surface waters.

Analysis of variance of the data summarized in Fig. 1 and 2 showed significant effects of basic slag and limestone treatment on calcium and magnesium concentration of the pond waters. Subsequent orthogonal comparisons between treatment means showed that the effect of 2240 kg/ha of agricultural limestone was different from the effect of 1120 kg/ha of basic slag.

Differences between grand means indicate that 1120 kg of basic slag per ha (81 kg of calcium carbonate per pond) raised the calcium content of the water by 14 mg/liter of calcium carbonate, while 2240 kg/ha of limestone (152 kg calcium carbonate per pond) raised it by only 6 mg/liter. This means that only about 17 kg calcium carbonate dissolved out of the 81 kg added to each pond with the basic slag, and only 7 kg of calcium carbonate out of the 152 kg added with the limestone.

The addition of 1120 kg/ha of basic slag, equivalent to 10 kg of magnesium carbonate per pond, raised the magnesium concentration of the water by 1.3 mg/liter magnesium carbonate, while 2240 kg/ha of limestone (44 kg of magnesium carbonate per pond) raised the magnesium concentration 3.9 mg/liter above that of the control ponds. Magnesium equivalent to about 1.8 kg magnesium carbonate dissolved out of the 10 kg added to each pond with the basic slag, and 5 out of 44 kg added with the limestone. The apparent difference in solubility between basic slag and limestone may be the result of different chemical composition.

Analysis of variance showed a significant change in calcium and magnesium concentration with time. Calcium concentration increased through May and declined until the end of the experiment. Part of this decline in calcium concentration would be accounted for by the utilization by both plants and animals in the pond, precipitation of calcium carbonate as a result of photosynthetic activity of plants (Hutchinson, 1957), and precipitation as phosphate salts and other complex salts. Magnesium increased during the first 3 months and, thereafter, fluctuated at a level much above the concentration at the beginning of the experiment.

Magnesium concentration, in general, continued to increase at the time when calcium concentration was decreasing; the continued increase occurred during the summer when fluctuation in the water level of the

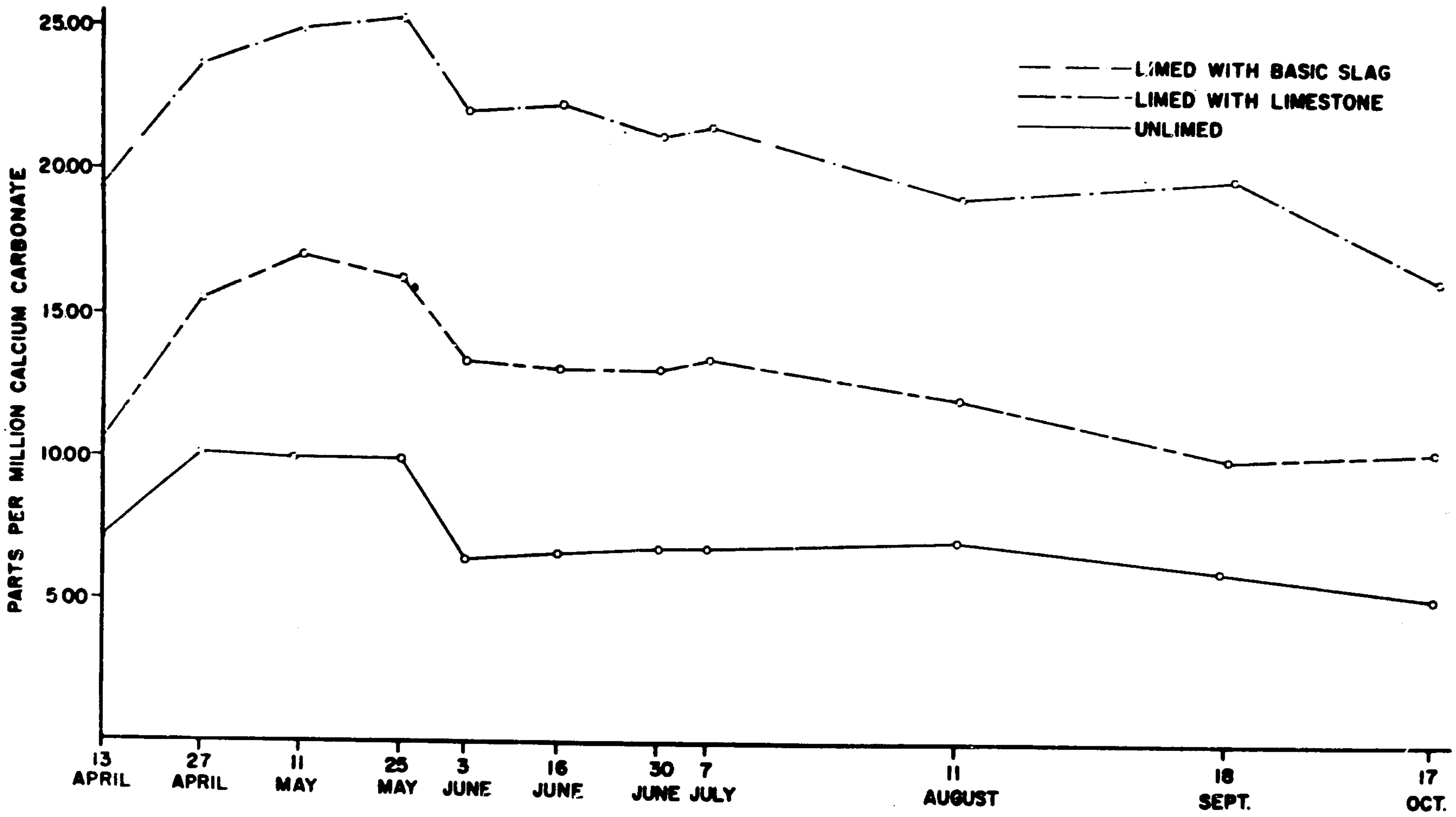

Figure 1. Changes with time in calcium concentration of water in limed and unlimed ponds.

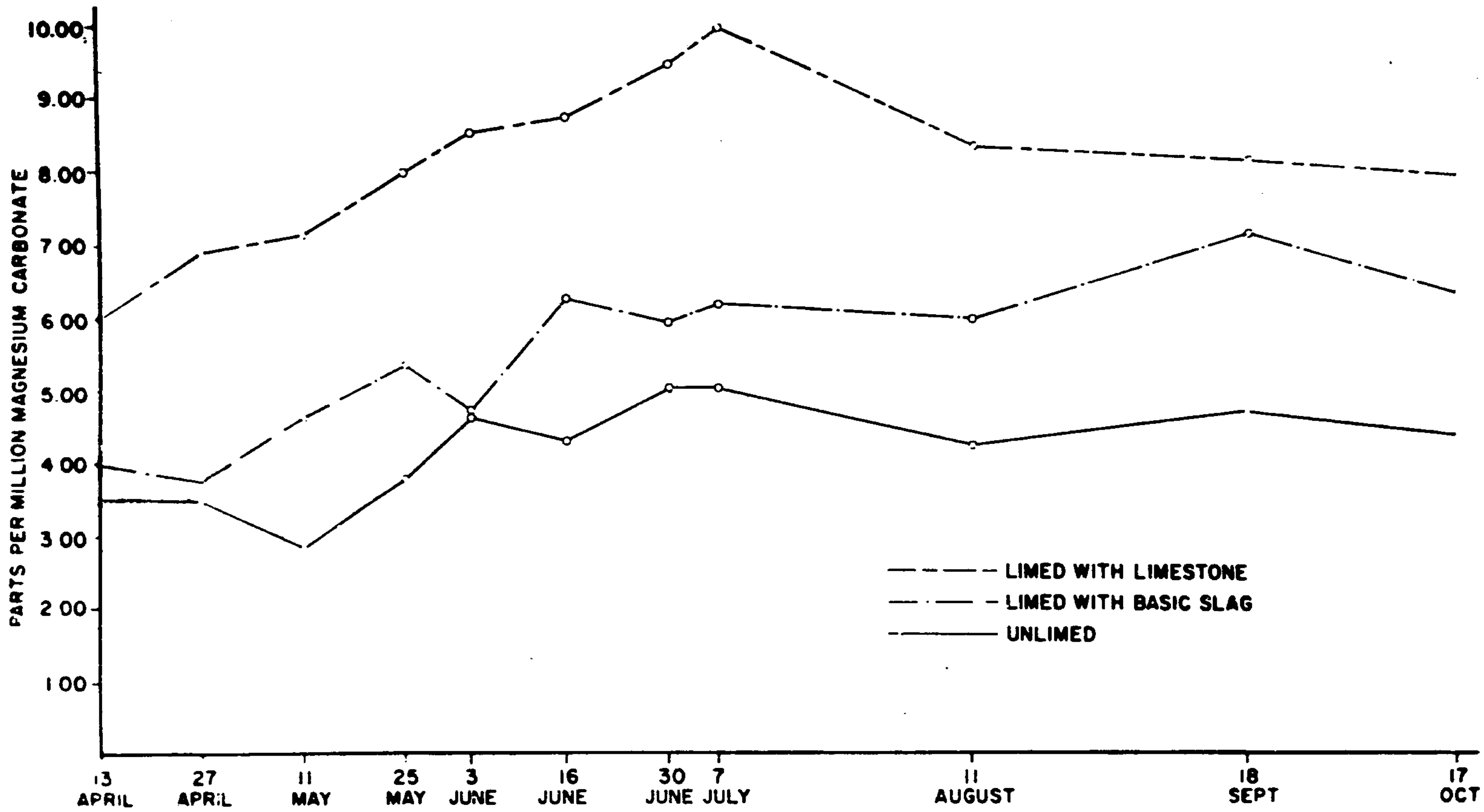

Figure 2. Changes with time in magnesium concentration of water in limed and unlimed ponds.

ponds was greatest. Magnesium carbonate is much more soluble than calcium carbonate; as a result of photosynthetic activity carbonate is precipitated, if at all, primarily as calcium carbonate, leaving magnesium in solution. When accompanied by evaporation of the water an increase in magnesium concentration results.

Diel changes in carbonate, bicarbonate, free carbon dioxide, and pH

Diel changes were shown in carbonate and bicarbonate in both surface and bottom waters, in pH in surface waters only, but not in free dissolved carbon dioxide (Table 1).

Carbonate was significantly higher in surface than in bottom waters, but at both depths it increased towards midafternoon and thereafter declined towards dawn. In deeper waters it may have continued to decrease after 0400 hr.

In contrast to carbonate, bicarbonate was significantly higher in bottom waters than in surface waters and at both depths it decreased towards late afternoon and rose during the night. Bicarbonate disappeared altogether from the surface of one of the basic slag and limestone ponds.

The two ponds treated with basic slag did not have free dissolved CO_2 at any time even in their bottom water. Free CO_2 was present only in the deepest parts of the limestone ponds and in the control ponds at certain times of the day.

Effects of lime treatment on carbonate, bicarbonate, free CO_2, and pH

Afternoon carbonate concentration in unlimed ponds was significantly lower than in basic slag ponds but not lower than in limestone ponds (Table 2); it was also significantly higher in basic slag ponds than in limestone ponds. Afternoon bicarbonate values were statistically similar in limed and unlimed ponds. In terms of both carbonate and bicarbonate, there were significant treatment-versus-time interactions, mainly arising from greater amplitude of fluctuations in limed than unlimed ponds.

In the afternoon, free carbon dioxide was absent in all but the deepest water layer of the control ponds (Table 2). Lime treatment had no effect on afternoon pH; this ranged from 8.5 to 10.1.

Morning carbonate concentration in unlimed ponds was significantly lower than in basic slag ponds but not lower than in limestone ponds (Table 3); it was also significantly higher in basic slag than in limestone ponds. Morning bicarbonate values were significantly higher in limestone ponds than basic slag and control ponds; there was no difference between the basic slag and the control ponds (Table 3).

In the mornings the limestone ponds had slightly higher concentrations of free carbon dioxide than the control ponds, while the basic slag ponds had slightly lower concentrations of free carbon dioxide, (Table 3); the difference between the basic slag ponds and the limestone ponds was significant at the five per cent level.

Morning pH values were significantly higher in basic slag ponds than in either limestone or control ponds; there was no difference between the latter ponds.

Total alkalinity and total hardness

A positive correlation existed between total alkalinity and total hardness (Fig. 3). Both increased until mid-summer and then gradually

Table 1. Diel Changes in Carbonate, Bicarbonate, Free Carbon Dioxide, and pH of Waters of Limed and Unlimed Ponds.*

Hour	Basic Slag		Limestone		Control	
	Surface	Bottom	Surface	Bottom	Surface	Bottom
Carbonate						
4 A. M.	24.4	21.8	15.4	9.0	7.5	6.0
10 A. M.	24.8	16.5	24.0	15.0	12.4	5.2
4 P. M.	30.8	24.1	24.0	16.1	12.8	4.5
10 P. M.	27.8	18.4	21.4	5.2	10.5	1.9
Bicarbonate						
4 A. M.	14.1	20.2	22.1	37.4	19.4	25.2
10 A. M.	7.6	17.2	6.9	27.8	11.0	28.2
4 P. M.	6.1	17.2	1.1	24.4	11.4	34.3
10 P. M.	8.4	27.8	11.8	49.6	16.4	37.4
Free carbon dioxide						
4 A. M.	0	0	0	0.4	0	2.5
10 A. M.	0	0	0	0.4	0	1.5
4 P. M.	0	0	0	0	0	3.3
10 P. M.	0	0	0	1.1	0	3.6
pH						
4 A. M.	9.9	9.8	9.8	9.4	9.3	8.8
10 A. M.	10.1	9.9	10.0	9.6	9.7	8.8
4 P. M.	10.0	9.8	10.1	9.9	9.8	8.5
10 P. M.	10.2	9.8	10.2	9.1	9.8	8.4

*Except for pH all the values are in mg/liter. Each is the mean value of four samples.

Table 2. Afternoon Values of Carbonate, Bicarbonate, Free Carbon Dioxide, and pH of Water of Limed and Unlimed Ponds.*

Date	Basic Slag		Limestone		Control	
	Surface	Bottom	Surface	Bottom	Surface	Bottom
Carbonate						
April 27	17.1	22.2	2.2	2.6	9.4	10.1
May 11	8.2	6.4	14.6	10.5	13.5	9.4
May 25	18.0	18.4	10.1	9.4	3.8	2.2
June 3	30.8	24.0	24.0	16.1	12.8	4.5
Bicarbonate						
April 27	24.0	13.7	43.5	42.0	16.4	14.5
May 11	47.2	51.8	27.4	35.8	11.4	19.8
May 25	32.0	33.2	36.2	37.7	29.7	32.4
June 3	6.1	17.2	1.1	24.4	11.4	34.3
Free Carbon Dioxide						
April 27	0	0	0	0	0	0
May 11	0	0	0	0	0	0
May 25	0	0	0	0	0	0.4
June 3	0	0	0	0	0	3.3
pH						
April 27	9.5	9.8	8.7	8.8	9.4	9.6
May 11	9.1	9.0	9.5	9.3	9.6	9.4
May 25	9.4	9.4	9.3	9.3	9.0	8.5
June 3	10.0	9.8	10.1	9.7	9.8	8.5

*Except for pH all the values are in mg/liter. Each is the mean value of four samples.

Table 3. Morning Values of Carbonate, Bicarbonate, Free Carbon Dioxide, and pH of Water of Limed and Unlimed Ponds.*

Date	Basic Slag		Limestone		Control	
	Surface	Bottom	Surface	Bottom	Surface	Bottom
Carbonate						
June 3	24.4	21.8	15.4	9.0	7.5	6.0
June 16	19.5	6.0	10.1	1.5	3.8	2.6
June 30	11.6	3.0	4.9	1.9	2.2	1.1
July 7	16.1	10.5	0.2	0.2	0.4	0.4
July 14	19.9	18.4	4.0	2.1	0.8	0.4
Aug 19	21.8	2.6	6.2	3.2	1.9	0.0
Sept 18	17.5	5.6	6.4	0.0	5.6	0.0
Oct 17	3.8	3.5	0.0	0.0	0.0	0.0
Bicarbonate						
June 3	14.1	20.2	22.1	37.4	19.4	25.2
June 16	22.5	65.2	32.0	61.7	26.3	29.7
June 30	41.2	67.5	45.0	62.9	32.2	39.1
July 7	34.7	48.8	58.0	60.3	36.6	37.0
July 14	27.2	28.9	52.4	59.3	40.3	40.2
Aug 19	21.4	65.7	44.5	50.5	37.7	42.7
Sept 18	30.6	48.3	37.9	48.0	27.6	39.6
Oct 17	51.1	52.3	50.7	51.8	35.1	36.6
Free carbon dioxide						
June 3	0	0	0	0.4	0	2.5
June 16	0	4.3	0	4.0	0	2.2
June 30	0	6.9	2.1	10.1	0.4	3.7
July 7	0	2.1	1.9	5.1	0.9	1.1
July 14	0	0	2.3	4.0	2.8	2.8
Aug 19	0	2.3	1.5	3.2	1.2	5.7
Sept 18	0	1.0	0.8	1.7	0	4.7
Oct 17	0	0	2.8	3.0	3.8	3.7
pH						
June 3	9.9	9.8	9.8	9.4	9.3	8.8
June 16	9.7	8.5	9.4	8.1	9.0	8.5
June 30	9.2	8.3	8.3	7.4	8.6	8.
July 7	9.5	8.9	8.0	7.6	8.4	8.2
July 14	9.7	9.7	8.3	7.8	7.9	7.8
Aug 19	9.7	8.4	8.6	8.0	8.3	7.2
Sept 18	9.3	8.7	8.7	7.9	9.1	7.3
Oct 17	9.2	9.2	7.8	7.7	7.2	7.1

*Except for pH all the values are mg/liter. Each is the mean value of four samples.

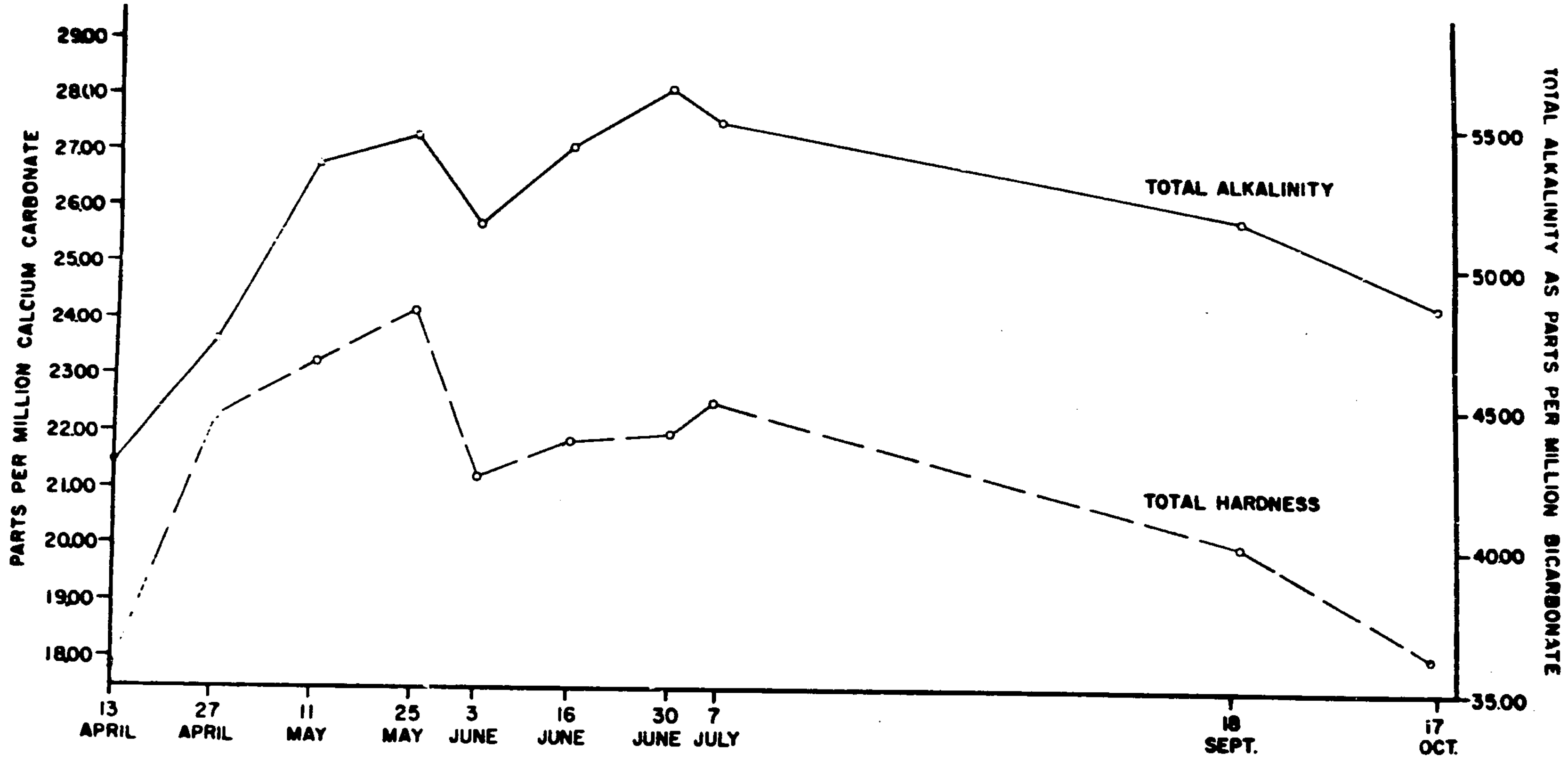

Figure 3. Relationship between total hardness and total alkalinity.

Table 4. Fish Production of Limed and Unlimed Ponds.*

Treatment	Pond	Original Stock		Original Stock Recovered			Weight of Young Produced (kg)			
		Number	Weight kg	Number	Weight kg	Average Wt. Gain g	2.5cm size	5cm size	7.5cm size	Total Fish** Recovered kg
Basic Slag	F-5	374	0.79	334	15.5	44	6.6	6.3	0.6	29.0
	F-8	375	1.19	303	10.6	31	2.2	2.2	0	15.0
Limestone	F-7	375	0.88	376	13.6	34	4.4	4.4	1.9	24.3
	F-10	375	1.22	309	12.4	36	9.4	3.3	4.7	29.8
Control	F-6	375	1.27	357	9.0	22	0.5	20.2	1.0	30.7
	F-12	373	0.96	328	9.4	26	7.3	2.5	0	19.2

*F-5 with 2 Golden Shiner; F-8 with 1 Goldfish, 1 channel catfish, 1 Israeli Carp, and 1 Golden catfish.**The six ponds also had 18, 19, 32, 28, 31, and 83 kg of tadpoles each, respectively.

decreased towards the end of the experimental period. Alkalinity was highly correlated with calcium (r = 0.94) but not with magnesium.

Soil properties

The pond bottom soils were rich in phosphorus and no effect of liming was discerned on the concentrations of calcium phosphate, adsorbed phosphorus, or phosphorus held in iron and aluminum complexes. Both basic slag and limestone raised the soil pH but this remained acid (pH 5.4 to 6.7 versus 5.4 to 6.0 in the control ponds). The basic slag ponds had higher calcium content than either limestone ponds or controls. All ponds had similar magnesium content in soils.

Biomass of seston and benthos

No significant effect of liming on benthos biomass was found. One basic slag pond (F-8) had significantly higher seston biomass than all the others but this yielded the smallest amount of fish, evidently because of a fish kill and poor reporduction during a protracted heavy plankton bloom.

Fish production

The fish biomass (Table 4) was quite variable and did not differ significantly between treatments. One of the basic slag ponds (F-5) had the greatest total weight increase of the original stock and also the highest average weight gain, but F-8, its replicate, had very divergent results. On the other hand, the two replicates for the limestone treatment and the controls gave results that were fairly similar. The control ponds had the lowest total weight increase and average weight gain of the original stock, and the limestone ponds gave intermediate results. F-8, with basic slag, and F-12, a control pond, had the lowest total production and the lowest production of young bluegill. During 6.5 months, the experimental ponds produced 140 to 290 kg of bluegills per ha.

DISCUSSION

The added limestone raised total water hardness by an average of 10 mg/liter as $CaCO_3$, basic slag raised it by 16 mg/liter, the difference being due to the greater solubility of calcium compounds in basic slag. The resulting hardness (13 mg/liter for controls, 23 mg/liter for limestone ponds, and 28 mg/liter for basic slag ponds) still put the experimental ponds in the category of very soft waters of supposedly low productivity (Juday, Birge, and Meloche, 1938).

Addition of more limestone would not have increased hardness within the range of hard waters (50 to 100 mg/liter) within the period of this experiment because most of the limestone added had already failed to dissolve. Much of the calcium and magnesium in basic slag presumably also remained on the bottom. Evidently the upper limit to which carbonate and bicarbonate hardness of a body of water could be raised is determined by its rate of CO_2 production through community respiration and oxidation of organic matter.

Two objectives of liming are to increase the buffering capacity and the carbon dioxide reserve of the water but it is important to buffer the water within pH 7.0 to 9.5 for fish culture (Swingle, 1957). Limestone would have little effect while quicklime would raise the pH of the water above a suitable range and actually impair the carbon dioxide reserve if excessive amounts are added to ponds that produce insufficient carbon dioxide.

The concentrations of bicarbonate trended towards an increase in both limed and unlimed ponds, but the unlimed ponds did not reach the highest concentrations produced in the limed ponds. Even though there was no significant difference between basic slag ponds and controls the former showed much higher bicarbonate concentrations at times.

All experimental ponds had fairly high pH, 9 to occasionally more than 10 during the day, and there was no significant difference between treatments. During early morning hours before photosynthesis had influenced pH, however, the basic slag ponds had significantly higher pH than either limestone or control ponds.

In summary, the addition of basic slag or limestone would raise the concentrations of calcium, magnesium, carbonates, and bicarbonates, depress free CO_2, and elevate pH, but significant treatment effects in the photic zone could be masked by diel effects of community metabolism, both photosynthetic and respiratory. In deeper waters below the photic zone the addition of basic slag or limestone would more consistently show the elevation of carbonate, bicarbonate, and pH, and initially depress free CO_2. As more CO_2 is formed by respiration, more carbonate is converted to bicarbonate until some equilibrium is reached. The eventual concentration of carbonate, bicarbonate and free CO_2 will depend on the availability of CO_2, intensity of community metabolism, and the vertical mixing of bottom and surface waters.

Total alkalinity and primary productivity

The hypothesis that hard waters with higher alkalinity are more productive than soft waters of lower alkalinity (Welch, 1952) needs to be qualified. Too high bicarbonate alkalinity could be undesirable. Very alkaline waters are deficient in phosphorus (Hubault, 1943) and added phosphorus disappears rapidly in alkaline and hard waters (Barret, 1952; Hepher, 1958). At alkalinities ranging from 122 to 148 mg bicarbonate per liter, Deevey (1940) noted an inverse relationship between alkalinity and chlorophyll concentration which he suggested could be caused by removal of phosphate ions from solution by calcium. At a certain level alkalinity immobilizes phosphorus and begins to limit, instead of favor, biological productivity.

The apparent contradictions in existing information indicate that each body of water probably has an optimal alkalinity determined by rates of biochemical processes such as production of carbon dioxide, nutrient regeneration, and nutrient level. Existing alkalinities could be above or below the optimal, and we still do not know how to determine these optimal concentrations.

Liming and fish production

The present results show that liming at the rates used did not further increase production when enough essential nutrients were supplied to the ponds. The addition of basic slag or agricultural limestone did not alter the chemical conditions of the water in a way which would favor greater fish production than the control ponds. Under a different set of experimental conditions, e.g. without inorganic fertilization, low pH, and even lower hardness and alkalinity, liming could conceivably increase fish production, as found by Zeller and Montgomery (1957) and Snow and Jones (1959).

Literature Cited

American Public Health Association, Inc. 1955. Standard methods for the examination of water, sewage, and industrial wastes. 10th ed. Waverly Press, Baltimore. 522 p.

Barrett, P. H. 1952. Effects of alkalinity on adsorption and regeneration of phosphorus on natural lakes. Ph.D. Thesis, Mich. State Coll., East Lansing, Michigan.

Deevey, E. S. Jr. 1940. Limnological studies in Connecticut. V. A contribution to regional limnology. Amer. J. Sci. 238:717-741.

Demoll, R. 1925. Teichdungung. (Pond manuring.) Handb. d. Binnenfischerei Mitteleuropas. 4:53-160.

Hepher, B. 1958. On the dynamics of phosphorus added to fishponds in Israel. Limnol. Oceanogr. 3:84-100.

Hess, W. N. 1930. Control of external fluke parasites on fish. Parasit. 16:131-136.

Hubault, E. 1943. Les grands lacs subalpins de Savoie sont-ils alcalitrophes? (Are the great lakes of Savoy alkalitrophic?) Arch. Hydrobiol. 40:240-249.

Huet, M. 1952. Traite de pisciculture. (Treatise on fish culture). Bruxelle, Editions la Vie Rustique. 369 p.

Hutchinson, G. E. 1957. A treatise on limnology. I. Geography, Physics, and Chemistry. Wiley, New York. 1015 p.

Juday, D., E. A. Birge, and V. W. Meloche. 1938. Mineral content of the lake waters of northeastern Wisconsin. Trans. Wisc. Acad. Sci., Arts, Lett. 31:223-276.

Macan, T. T., C. H. Mortimer, and B. B. Worthington. 1942. The production of freshwater fish for food. Freshwater Biol. Assoc., Sci. Publ. No. 6. 36 p.

Maciolek, J. A. 1954. Artificial fertilization of lakes and ponds. U.S. Fish Wildlife Service, Special Scientific Report, Fisheries No. 113, 41 p.

Neess, J. C. 1949. Development and status of pond fertilization in Central Europe. Trans. Amer. Fish. Soc. 76:335-358.

Nerescheimer, E. 1911. Teichwirtschaftliche Streitfragen. (Pond farming controversies.) Ost. FischZtg. 8:75.

Pamatmat, M. M. 1960. The effects of basic slag and agricultural limestone on the chemistry and productivity of fertilized ponds. M.S. Thesis, Auburn Univ., Auburn, Ala. 113 p.

Schaeperclaus, W. 1933. Textbook of pond culture. Trans. from the German by F. Hund. U.S. Fish Wildlife Service, Fishery Leaflet 311:260 p.

Snow, J. R., and R. O. Jones. 1959. Some effects of lime applications to warm-water hatchery ponds. Proc. 13th Ann. Meet., Southeast. Asso. Game and Fish Comm.

Swingle, H. S. 1957. Relationships of pH of pond waters to their suitability for fish culture. Ninth Pacific Science Congress, Bangkok, Thailand.

Swingle, H. S. 1969. Methods of analysis for waters organic matter, and pond bottom soils used in fisheries research. Dept. Fisheries and Allied Aquacultures, Auburn Univ., Auburn, Alabama. 119 p.

Swingle, H. S., and M. C. Johnson. 1953. Water sampler and water analysis kit. Prog. Fish.-Cult. 15:27-30.

Wunder, W. 1947. Die Bedeutung des Kalkes fur die Teichwirtschaft. (The importance of chalk in pond culture). Allgem. Fischerei Zeit. 72:93-98.

Wunder, W. 1949. Fortschrittliche Karpfenteichwirtschaft. (Progressive pond-culture of carp.) Schweitzerbart'sche Verlagsbuchhandlung, Erwin Nagele, Stuttgart, 1949. 386 p.

Zeller, H. D., and A. B. Montgomery. 1957. Preliminary investigations of chemical soil and water relationships and lime treatment of soft water in Georgia farm ponds. Proc. Annu. Conf. Southeast. Assoc. Game and Fish Comm., Mobile, Alabama. 11:71-76.