Reaction of Liming Materials in Pond Bottom Soils

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Abstract

Three techniques for treating fish ponds with agricultural limestone were evaluated in ponds with clayey soils in Brazil and in ponds with sandy soils in South Africa. Amounts of agricultural limestone equal to the lime requirement of bottom soils were applied by the following methods to each of three ponds: (1) direct application over the pond surface; (2) spread uniformly over the bottom of the empty pond; (3) spread uniformly over the bottom of the empty pond followed by tilling of the bottom. The effectiveness of agricultural limestone applications did not differ among treatment methods. Agricultural limestone also reacted quickly to increase total alkalinity and total hardness of pond water to acceptable concentrations within two weeks after application. Data on soil pH and exchangeable acidity suggested that the reaction of liming material to increase soil pH was essentially complete after one to two months. In the clayey soil, agricultural limestone had no effect below a depth of 8 cm. Agricultural limestone reacted to a depth of at least 20 cm in the sandy soil. This research suggests that full ponds can be limed effectively. Aquaculture methods that allow ponds to be operated for several years without draining are highly desirable from standpoints of water conservation and environmental protection. Moreover, findings suggest that tilling of pond bottoms to incorporate liming materials is unnecessary, considering that tilling consumes time and is an expensive practice.

Introduction

Acidic bottom soil is a common problem in pond aquaculture, and fish farmers often apply agricultural limestone to ponds as a remedy. Aquaculture ponds are usually limed after they have been drained for harvest and before they are refilled for the next crop (Boyd and Tucker, 1998). However, sport fish ponds usually are not drained for liming, and agricultural limestone is spread over the water surface from a boat (Boyd, 1982).

The objective of liming is to neutralize acidity in the upper layer of bottom soil and to increase the concentrations of total alkalinity and total hardness in the water (Thomaston and Zeller, 1961). There have been several studies that showed positive responses in phytoplankton productivity and fish production following liming of acidic ponds, and methods for determining the lime requirements of bottom soils have been developed (Boyd, 1995). Nevertheless, liming often is applied to ponds indiscriminately without concern for bottom soil pH or total alkalinity and total hardness concentrations. It is doubtful that liming has a large influence where soil pH is above 7 or total alkalinity is above 50 mg l^{-1}.

Aquaculture ponds normally are drained for harvest, bottoms are allowed to dry, and liming materials are applied. The liming material frequently is blended with the bottom soil by tilling. In spite of the widespread use of liming materials, studies to compare the effectiveness of different methods of application have not been completed. In this study, conducted on fish farms in Brazil and South Africa, three methods of applying agricultural limestone to ponds were compared. These methods were as follows: (1) application over the pond water surface, (2) application to the bottom of the dry pond, and (3) application to the bottom of the dry pond followed by tilling.

Methods and Materials

Trial in Brazil

The experiment was conducted at the Santa Barbara Fish Farm

Table 1. Data on pond sizes and depths, treatments, dates of treatments, lime requirements, and doses of agricultural limestone (ag lime) for experiment conducted at Q-Koi Farm near Bonnievale, South Africa.

Pond	Average Area (m^2)	Average Depth (m)	Treatment	Date	Ag Lime Requirement (kg $CaCO_3$ ha^{-1})	Ag Lime Dose (kg)
G33	840	0.70	Ag lime and tilling	5 September 2002	2,464	207
G34	744	1.32	Ag lime and tilling	8 September 2002	1,904	142
G35	1,300	0.64	Ag lime and tilling	8 September 2002	1,400	182
G29	1,011	1.42	Ag lime on bottom	3 September 2002	1,624	164
G31	828	0.76	Ag lime on bottom	3 September 2002	1,400	116
R4	535	1.50	Ag lime on bottom	3 September 2002	1,680	90
G30	835	0.87	Ag lime on water surface	3 September 2002	1,792	150
G24	611	1.60	Ag lime on water surface	3 September 2002	1,176	72
G23	717	1.34	Ag lime on water surface	9 September 2002	1,120	80

in Itupeva District, Sao Paulo State, Brazil. The farm is situated at coordinates 23º 11.211′ South and 47º 02.013′ West and is near the town of Itupeva which is about 50 km North of Sao Paulo. Soils in the area usually are of sandy clay or clayey texture and members of the ultisol (red-yellow podzols) and oxisol (red-yellow latosols) groups. The pond bottoms were clayey consisting of 30 to 40% clay, 40 to 50% silt, and 10 to 20% sand. The water supply for the farm is a small, natural stream, and all ponds are located on the flood plain of this stream.

Ponds used in this study were rectangular, 1,000 m^2 in area with average depth of 1.0 m. The ponds were each stocked with 320,000 to 450,000 of *Oreochromis nilotica* fingerlings. Feeds and fertilizers were applied according to the judgment of the farm manager. The commercial fish feed contained 32% crude protein and each pond received 170 to 200 kg per month. The farmer did not keep records of fertilizer additions or provide data on fish production. However, based on an assumed feed input of 2% body weight per day, standing crops of fish were probably around 2,800 to 3,200 kg ha^{-1}.

Nine ponds were available for use, but it was not possible to initiate the entire experiment at one time. One replication of each of the three treatments was installed in groups of three ponds in December 2001, 7 March 2002, and 18 May 2002. Each group of ponds was in production for about four months before fish were harvested. The agricultural limestone dose was based on the lime requirement of the pond bottom soil and ranged from 4,000 and 5,000 kg ha^{-1}. The treatments were as follows: agricultural limestone applied over the water surface at the beginning of the crop; agricultural limestone spread uniformly over the bottom soil before filling ponds with water; agricultural limestone spread uniformly over the bottom soil and soil tilled to a depth of 10 cm with hand tools before filling ponds with water.

South Africa

The experiment was conducted at Q-Koi Farm (Pty) Ltd. on the Boesmansrivier Farm in the Breede River Valley in the Western Cape Province of South Africa. The farm is situated at coordinates 34º 02′ south and 19º 57′ west and is 20 km south of the town of Bonnievale and 180 km east of the city of Cape Town. Soils in the area of the farm are of the Glen Rosa series. These are highly weathered alfisols. The terrain is gently sloping and the pond bottoms were constructed of a soil that contained a large amount of fractured shale. The soil, excluding the shale fragments, was 26.8% clay, 57.2% coarse sand, and 16% silt. However, because of the coarse sand and shale fragments, the pond bottoms seep badly. The main water supply is the Boesmans River, but additional water for use in the ponds is extracted from wells.

The ponds used in this study were rectangular with areas of 611 to 1,409 m^2 (average = 825 m^2) and average depths of 0.7 to 2.13 m (Table 1). The ponds were stocked with Koi carp, which were fed a commercial pelleted ration containing 45% crude protein twice daily. The farmer did not supply data on stocking density, but feed input averaged 0.75 kg per pond daily. Assuming the feed input was about 2% of body weight, average fish biomass was around 37.5 kg per pond or around 450 kg ha^{-1}.

While ponds were empty between crops, the lime requirement was determined on bottom soil samples from each by the Production Technology Laboratory, Western Cape Department of Agriculture, Elsenburg, South Africa. The treatments, dates of treatment, lime requirements, and agricultural limestone doses are summarized in Table 1. The treatments were applied by the same techniques used in Brazil.

Water and Soil Analyses

The same procedures were used in both Brazil and South Africa. Water samples were collected from ponds at weekly intervals and analyzed for total alkalinity and total hardness by acidimetry and EDTA (ethylenediaminetetraacetic acid) titration, respectively (Clesceri et al., 1998).

Soil cores of 20 cm length were collected from ten locations in each pond with a 5 cm diameter core tube before ponds were treated with agricultural limestone and at one month intervals for four months in Brazil and four times during a six month period in South Africa. The cores were cut into 2 cm long segments as described by Munsiri et al. (1995). Soil samples were oven dried at 60ºC in a mechanical convection oven and pulverized to pass a 40-mesh screen (0.425 mm openings). Soil pH was measured in 1:1 mixtures of dry soil and distilled water

Table 2. Initial and average concentrations of total alkalinity and total hardness (mg l-1 as equivalent $CaCO_3$) in ponds in Brazil that were treated with agricultural limestone by three different methods.

Treatment	Initial Concentration (mg l^{-1})		Average Concentration (mg l^{-1})	
	TA	*TH*	*TA*	*TH*
Applied to Water	14.6 ± 1.3	15.7 ± 1.5	27.4 ± 1.1	24.7 ± 1.6
Applied to Soil	20.5 ± 2.8	17.4 ± 2.1	31.5 ± 4.1	29.6 ± 4.6
Applied to Soil and Tilled	15.0 ± 1.9	13.9 ± 1.1	28.1 ± 4.1	25.9 ± 3.6

Table 3. Soil pH in pond bottoms in Brazil at different depths and times following application of agricultural limestone over pond water surfaces.

Soil Depth (cm)	pH				
	Initial	*Time after Treatment* (month)			
		1	2	3	4
0–2	5.70	6.57	7.07	6.73	6.58
2–4	5.87	6.57	6.89	6.48	6.56
4–6	5.69	6.45	6.24	6.15	6.26
6–8	5.80	5.79	6.17	6.23	6.04
8–10	5.64	5.67	5.81	5.93	5.69
10–12	5.49	5.61	5.76	5.82	5.50
12–14	5.51	5.54	5.71	5.58	5.47
14–16	5.20	5.48	5.46	5.51	5.31
16–18	5.37	5.47	5.47	5.75	5.37
18–20	5.22	5.17	5.40	5.33	4.89

Table 4. Soil pH in pond bottoms in Brazil at different depths and times following application of agricultural limestone over empty pond bottoms.

Soil Depth (cm)	pH				
	Initial	*Time after Treatment* (month)			
		1	2	3	4
0–2	5.97	6.89	6.60	6.77	6.36
2–4	5.90	6.52	6.67	6.56	6.34
4–6	5.87	6.34	6.33	6.00	6.17
6–8	5.50	6.07	6.22	5.80	6.03
8–10	5.52	5.96	5.91	5.83	5.74
10–12	5.39	5.52	5.66	5.57	5.44
12–14	5.30	5.72	5.49	5.28	5.22
14–16	5.25	5.19	5.54	5.32	5.12
16–18	5.16	5.16	5.26	5.17	5.08
18–20	5.05	5.20	5.46	5.25	4.88

(Thunjai et al., 2001). The exchangeable acidity was measured by the change in pH caused by adding 5 g soil to 10 ml of a p-nitrophenol buffer solution (Adams and Evans, 1962). Analyses in Brazil were made in the soil laboratory of Embrapa Meio Ambiente, Jaguariuna, Sao Paulo State, while those in South Africa were made at the Production Technology Laboratory, Western Cape Department of Agriculture, Elsenburg, Western Cape Province.

RESULTS

Brazil

Immediately after filling with water, total alkalinity concentrations averaged from 14.6 to 20.5 mg l^{-1} in ponds of the three treatments. Total alkalinity increased above 20 mg l^{-1} within two weeks in all ponds and remained relatively stable throughout the study. Because there was little variation among sampling dates in total alkalinity, only the averages for the entire four month period are reported in Table 2. Total hardness concentrations averaged between 13.9 and 17.4 mg l^{-1} when the ponds were filled. Concentrations increased above 20 mg l^{-1} within two weeks, and as with total alkalinity, remained fairly stable. Averages for total hardness during the four month period also are provided in Table 2. Treatment with agricultural limestone increased concentrations of total alkalinity and total hardness ($P < 0.05$), but the method of applying agricultural limestone did not have an influence on average concentrations of the two variables.

The exchangeable acidity of the soil samples was quite low, and often no more than 1 or 2 meq 100 g^{-1}. Such low exchangeable acidity values for soils with a low pH reveals that the soil had a low cation exchange capacity (Boyd, 1995). The low exchangeable acidity concentrations also were difficult to measure, because an expanded-scale pH meter capable of 0.01 pH accuracy was not available. The variation was tremendous and thought to be related primarily to analytical variation. Thus, it was not possible to make meaningful inferences from the exchangeable acidity data, and it will not be reported here.

Soil pH exhibited great variation among the 10 locations in each pond, so the data were averaged for each pond by soil depth. These data were then averaged to provide a single mean for each soil depth by treatment. The means are provided in Tables 3, 4, and 5. Several features of the data are as follows: All ponds initially had soil pH below 6; treatment with agricultural limestone increased soil pH above 6 in the 0–6 cm layer for all samples of all treatments and in most samples from the 6–8 cm layer; treatment with agricultural limestone did not in-

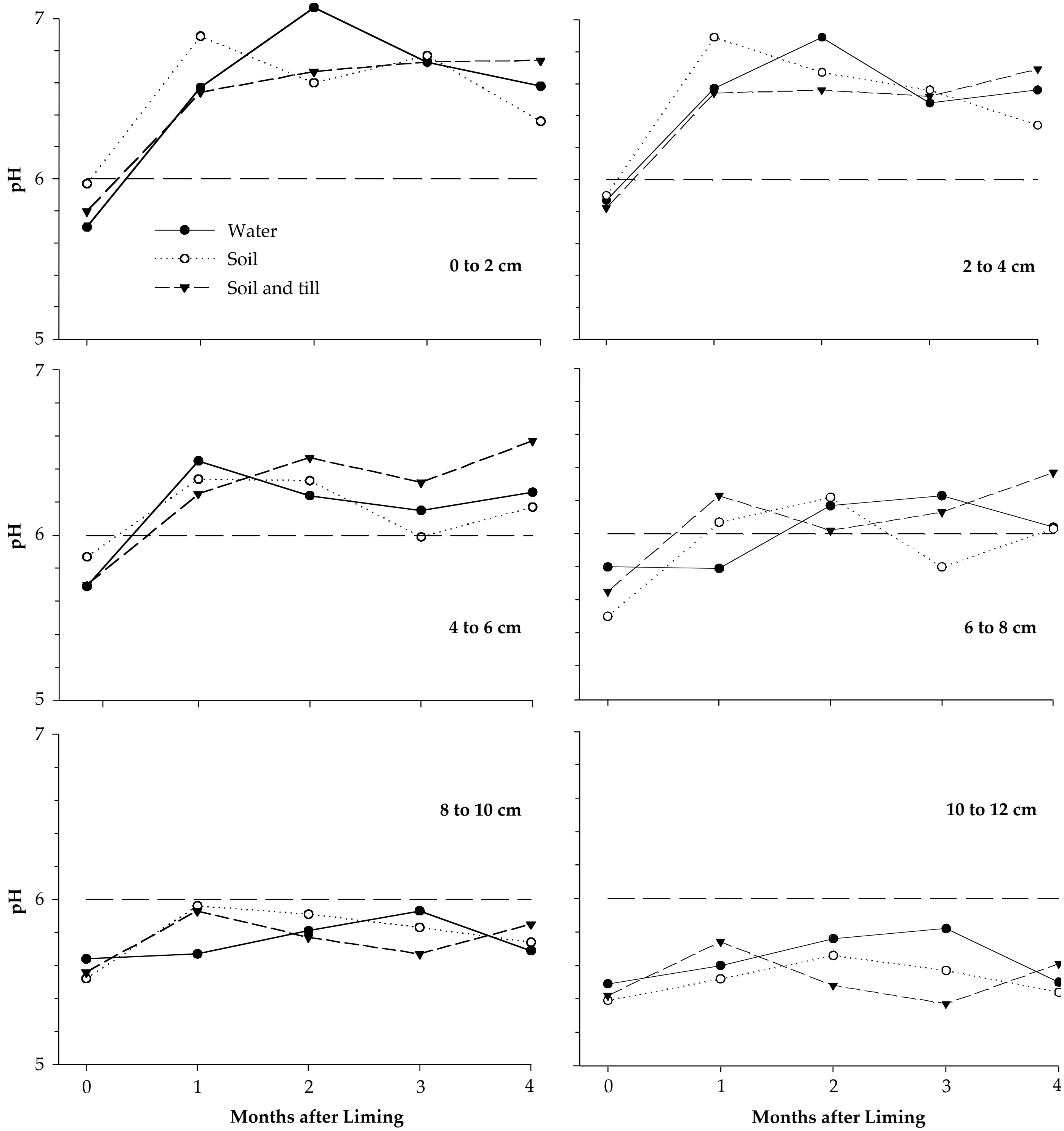

Figure 2a Average soil pH at different depth layers (0 to 12 cm) in the bottoms of fish ponds in Brazil before treatment and at monthly intervals after treatment with agricultural limestone. The agricultural limestone application methods were as follows: water - applied over water surface; soil - applied on the bottom of empty ponds; soil and till - applied over the bottom of empty ponds after which the bottom was tilled.

Figure 2b Average soil pH at different depth layers (12 to 80 cm) in the bottoms of fish ponds in Brazil before treatment and at monthly intervals after treatment with agricultural limestone. The agricultural limestone application methods were as follows: water - applied over water surface; soil - applied on the bottom of empty ponds; soil and till - applied over the bottom of empty ponds after which the bottom was tilled.

Table 5. Soil pH in pond bottoms in Brazil at different depths and times following application of agricultural limestone over empty pond bottoms and tilling.

Soil Depth (cm)	pH				
	Initial	*Time after Treatment* (month)			
		1	2	3	4
0–2	5.83	6.54	6.67	6.73	6.74
2–4	5.88	6.60	6.56	6.52	6.69
4–6	5.78	6.25	6.47	6.32	6.57
6–8	5.65	6.23	6.02	6.13	6.37
8–10	5.58	5.93	5.77	5.67	5.85
10–12	5.44	5.74	5.48	5.37	5.61
12–14	5.40	5.71	5.50	5.29	5.48
14–16	5.22	5.43	5.40	5.16	5.44
16–18	5.26	5.09	5.20	5.07	5.26
18–20	5.14	5.22	4.91	5.05	5.01

crease pH above 6 in soil below 8 cm depth; soil pH in samples taken before agricultural limestone was applied tended to decrease with increasing soil depth. The same trend existed after agricultural limestone was applied.

The decrease in pH with increasing soil depth before, and four months after agricultural limestone treatment, is illustrated in Figure 1. Agricultural limestone caused an increase in soil pH within the upper 8 cm layer of soil, with the greatest increase being in the 0 to 4 cm layer ($P < 0.05$). Considering all data, there were no differences among treatments on any dates ($P > 0.05$) for pH values when comparisons were made among the same depth layers.

The reaction of agricultural limestone occurred quickly, and there was no difference in pH after the first month among treatments when a single soil layer was considered (Figure 2). Of course, the increase in pH over initial pH was greatest in the 0 to 2 cm layer and became progressively less with greater soil depth.

South Africa

Total alkalinity averaged between 2.5 mg l^{-1} and 17.5 mg l^{-1} in ponds of the three treatments (Table 6). Agricultural limestone treatment caused a rapid increase in total alkalinity, and all ponds had total alkalinity concentrations above 50 mg l^{-1} after two weeks. As also observed in Brazil, there was little variation in total alkalinity. Thus, only means were presented (Table 6) and these concentrations ranged from 52.5 to 107.1 mg l^{-1}. Average total hardness concentrations ranged from 9.2 to 27.3 mg l^{-1} before treatment (Table 6), and the average concentrations based on all sampling dates after liming were between 65.5 and 97.6 mg l^{-1}. The highest concentrations ($P < 0.05$) of total alkalinity and total hardness were for the ponds in which agricultural limestone was applied over the water surface. Agricultural limestone treatment also caused a large increase in total alkalinity and total hardness in the other two treatments, but tilling the liming material into the bottom was not superior to applying the liming material over the bottom and not tilling ($P > 0.05$).

There was an unfortunate mistake in communications and core samples were not collected before ponds were limed. The initial samples were taken to a depth of about 20 cm, and the material was well mixed to provide a sample representing the 0 to 20 cm layer. The soil pH was 7.0 or above in the bottom soils of the ponds before liming (Tables 7, 8, and 9). This was surprising because ponds with total alkalinity concentrations below 20 or 30 mg l^{-1} usually have a soil pH of 6 or less (Boyd, 1995). A good explanation for this discrepancy could not be found. Also, the application of liming material did not cause significant changes ($P > 0.05$) in soil pH (Tables 7, 8, and 9). This observation also could not be explained.

Exchangeable acidity initially averaged between 1.95 and 2.75 meq 100 g^{-1} in ponds of the three treatments (Tables 10, 11, and 12). These are low concentrations of exchangeable acidity, but variation was not great and the data were useful in contrast with exchangeable acidity for the Brazilian samples. Application of agricultural limestone neutralized acidity and caused the exchangeable acidity to decrease, and concentrations were between 0.18 and 0.44 meq 100 g^{-1} two months after liming and between 0.13 and 0.28 meq 100 g^{-1} six months after liming (Tables 10, 11, and 12). A decline in exchangeable acidity occurred during the first two months ($P < 0.05$) to a depth of at least 20 cm and possibly to a greater depth. There was no difference in exchangeable acidity among samples from different treatments and different depths after two months ($P > 0.05$).

DISCUSSION

The study showed that agricultural limestone reacts quite quickly to increase the total alkalinity and total hardness of pond water. In Brazil, the total alkalinity and total hardness concentrations after liming averaged between 24.7 and

Table 6. Initial and average concentrations of total alkalinity and total hardness (in mg l-1 as CaCO3) for water of ponds in South Africa treated with agricultural limestone by three methods of application.

Treatment	Initial Concentration (mg l^{-1})		Average Concentration (mg l^{-1})	
	TA	*TH*	*TA*	*TH*
Applied to Water	17.5 ± 3.8	27.3 ± 5.2	107.1 ± 4.1	97.6 ± 3.9
Applied to Soil	2.5 ± 0.9	9.0 ± 1.3	68.2 ± 4.1	65.5 ± 4.1
Applied to Soil and Tilled	2.5 ± 0.1	9.0 ± 1.3	52.5 ± 1.9	72.4 ± 11.6

Table 7. Soil pH in pond bottoms in South Africa at different depths and times following application of agricultural limestone over pond water surfaces.

Soil Depth (cm)	pH				
	Initial[1]	*Time after Treatment* (month)			
		2	3	4	6
0–2	7.80	7.82	7.77	7.38	7.40
2–4	7.80	7.78	7.75	7.61	7.46
4–6	7.80	7.84	7.99	7.74	7.61
6–8	7.80	7.83	8.02	7.77	7.62
8–10	7.80	7.85	7.97	7.75	7.63
10–12	7.80	7.87	7.90	7.72	7.71
12–14	7.80	7.86	8.00	7.76	7.72
14–16	7.80	7.95	8.05	7.81	7.75
16–18	7.80	8.02	8.03	7.87	7.72
18–20	7.80	7.96	7.98	7.72	7.72

[1] Initial soil pH based on a composite sample representing the entire 0- to 20-cm depth layer.

Table 8. Soil pH in pond bottoms in South Africa at different depths and times following application of agricultural limestone over empty pond bottoms.

Soil Depth (cm)	pH				
	Initial[1]	*Time after Treatment* (month)			
		2	3	4	6
0–2	7.17	7.25	7.19	7.23	6.93
2–4	7.17	7.38	7.37	7.31	6.83
4–6	7.17	7.60	7.64	7.27	6.85
6–8	7.17	7.56	7.76	7.36	7.01
8–10	7.17	7.64	7.82	7.25	7.43
10–12	7.17	7.65	7.78	7.42	7.42
12–14	7.17	7.73	7.73	7.28	7.15
14–16	7.17	7.69	7.81	7.09	7.57
16–18	7.17	7.49	7.87	7.24	7.82
18–20	7.17	7.43	7.72	7.57	7.67

[1] Initial soil pH based on a composite sample representing the entire 0- to 20-cm depth layer.

Table 9. Soil PH in pond bottoms in South Africa at different depths and times following application of agricultural limestone over pond bottoms and tilling.

Soil Depth (cm)	pH				
	Initial[1]	*Time after Treatment* (month)			
		2	3	4	6
0–2	7.0	6.62	6.94	6.28	6.84
2–4	7.0	6.79	6.96	6.63	7.10
4–6	7.0	7.22	6.98	5.82	7.05
6–8	7.0	7.44	7.35	6.59	7.45
8–10	7.0	7.51	7.43	7.00	7.60
10–12	7.0	7.59	7.87	-	-
12–14	7.0	7.67	7.93	7.32	7.75
14–16	7.0	7.68	7.66	7.29	7.70
16–18	7.0	7.66	7.95	7.35	7.83
18–20	7.0	7.62	7.87	7.46	7.90

[1] Initial soil pH based on a composite sample representing the entire 0- to 20-cm depth layer.

Table 10. Exchangeable acidity in soil of pond bottoms in South Africa at different depths and times following application of agricultural limestone over pond water surfaces.

Soil Depth (cm)	pH				
	Initial[1]	*Time after Treatment* (month)			
		2	3	4	6
0–2	1.95	0.19	0.26	0.21	0.19
2–4	1.95	0.18	0.29	0.22	0.20
4–6	1.95	0.18	0.29	0.21	0.20
6–8	1.95	0.19	0.29	0.24	0.21
8–10	1.95	0.19	0.31	0.25	0.21
10–12	1.95	0.19	0.33	0.25	0.21
12–14	1.95	0.21	0.32	0.24	0.23
14–16	1.95	0.18	0.32	0.23	0.22
16–18	1.95	0.22	0.30	0.25	0.23
18–20	1.95	0.24	0.32	0.29	0.24

[1] Initial soil pH based on a composite sample representing the entire 0- to 20-cm depth layer.

31.5 mg l^{-1}, while in South Africa, the averages were greater, ranging from 52.5 to 107.1 mg l^{-1}. The reason for the greater increase in South Africa is not clear, for at both locations, agricultural limestone was applied according to the measured lime requirement. Agricultural limestone is sparingly soluble, and the equilibrium concentration between solid calcium carbonate, water, and the normal atmospheric carbon dioxide level is about 57 mg l^{-1} (Stumm and Morgan, 1996). The solubility of agricultural limestone increases in waters where the dissolved carbon dioxide concentration is higher than that expected from equilibrium with normal atmospheric carbon dioxide (Hutchinson, 1957). In ponds, decomposition of soil organic matter by microorganisms and respiration of other aquatic organisms increases carbon dioxide concentration, and the total alkalinity and total hardness may become quite high. It is likely that the ponds in South Africa had a greater availability of carbon dioxide than did the ponds in Brazil.

The depth of reaction of liming material into bottom soil was greater in sandy soils in South Africa than in clayey soils

Table 11. Exchangeable acidity in soil of pond bottoms in South Africa at different depths and times following application of agricultural limestone over bottoms of empty ponds.

Soil Depth (cm)	pH				
	Initial[1]	*Time after Treatment* (month)			
		2	3	4	6
0–2	2.24	0.44	0.21	0.24	0.25
2–4	2.24	0.34	0.22	0.25	0.28
4–6	2.24	0.34	0.22	0.26	0.28
6–8	2.24	0.33	0.23	0.28	0.27
8–10	2.24	0.32	0.22	0.28	0.24
10–12	2.24	0.34	0.22	0.28	0.23
12–14	2.24	0.34	0.22	0.28	0.23
14–16	2.24	0.34	0.23	0.28	0.21
16–18	2.24	0.33	0.24	0.28	0.19
18–20	2.24	0.33	0.25	0.27	0.20

[1] Initial soil pH based on a composite sample representing the entire 0- to 20-cm depth layer.

Table 12. Exchangeable acidity in soil of pond bottoms in South Africa at different depths and times following application of agricultural limestone over bottoms of empty ponds and tilling.

Soil Depth (cm)	pH				
	Initial[1]	*Time after Treatment* (month)			
		2	3	4	6
0–2	2.75	0.30	0.33	0.30	0.21
2–4	2.75	0.30	0.35	0.33	0.20
4–6	2.75	0.24	0.33	0.31	0.19
6–8	2.75	0.23	0.27	0.28	0.18
8–10	2.75	0.23	0.25	0.26	0.17
10–12	2.75	0.21	0.25	0.25	0.17
12–14	2.75	0.21	0.25	0.25	0.17
14–16	2.75	0.24	0.24	0.24	0.16
16–18	2.75	0.24	0.24	0.28	0.15
18–20	2.75	0.24	0.24	0.25	0.13

[1] Initial soil pH based on a composite sample representing the entire 0- to 20-cm depth layer.

in Brazil. Nevertheless, the upper 5 cm of pond soil has the greatest influence on pond water quality and shrimp and fish production (Boyd, 1995). All three methods of application resulted in an increase in pH (Brazil) or exchangeable acidity (South Africa) in this layer. These results and the increases in total alkalinity and total hardness concentrations confirm that the three methods of application were effective. In this study, the rate and the depth of reaction were not related to the method of application, the maximum benefit of agricultural limestone was achieved in one to two months.

The findings suggest that ponds can be effectively limed by spreading agricultural limestone over water surfaces. Of course, if ponds are drained after each crop, it is easier to spread agricultural limestone over the bottoms of empty ponds than to spread it over the water surface. Tilling of the pond bottom after applying agricultural limestone was not necessary in this study to promote the reaction of the liming material with soil. Although tilling is beneficial for improving dry out and decomposition of organic residues (Boyd, 1995), ponds with sandy or loamy soils usually dry out easily and tilling to lessen soil organic matter concentration is only necessary after several crops.

CONCLUSIONS

Agricultural limestone was equally effective when applied on water surfaces, spread over the bottom of empty ponds, or mixed into the bottom of empty ponds by tilling.

Agricultural limestone caused concentrations of total alkalinity and total hardness to increase to acceptable levels within two weeks.

Data on soil pH (Brazil) and exchangeable acidity (South Africa) suggested that the reaction of liming material in the soil was essentially complete in one to two months.

Agricultural limestone reacted to a greater depth in sandy soil in South Africa than in clayey soil in Brazil.

ANTICIPATED BENEFITS

Liming is a common practice in pond aquaculture, and greater efficiency in the use of liming materials will benefit many fish and shrimp producers. This research shows that ponds can be effectively limed by applying liming materials over the water surface. It is not necessary to drain ponds and lime the bottoms. Pond effluents can pollute receiving waters, so aquaculture methods that allow ponds to be operated for several years without draining are highly desirable. The results of this study provide evidence that undrained ponds can be prevented from becoming acidic through applying agricultural limestone over the water surface.

The results also show that agricultural limestone reacts quickly and can increase concentrations of total alkalinity and total hardness within two weeks and soil pH within one or two months. Thus, liming does not have to be done several months before benefits are accrued.

Finally, agricultural limestone does not have to be tilled into the soil. This can lead to a savings in labor costs.

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