



# Lime Requirement Methods of Aquaculture Ponds – A Review

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## Abstract

Liming has long been a common practice in the management of aquaculture ponds. This practice aims at sanitising the pond bottom between crops and improving the pond's buffering capacity for water quality stabilisation. Liming can also improve bottom soil pH and enrich pond water with calcium and magnesium. Methods for estimating a pond's lime requirement (LR) are of crucial importance because they provide pond managers with appropriate lime rates to maintain or improve the buffering capacity of aquaculture ponds. Regardless of the recent, rapid development of the aquaculture sector, LR methods for ponds have not yet been well-developed. Qualitative methods (e.g. using a single or multiple parameters of water and soil properties) have still been used in rural areas where access to laboratories is difficult. Quantitative methods (e.g. buffer methods) have not yet been widely used due to their inherent restrictions. Each of the LR methods can be used under specific targets for liming or pond conditions. The titration-based K-bicarbonate method has yielded the highest pond LR and seems superior to the other methods regarding accuracy, simplicity, cost, and environmental safety. It is a promising method for use in aquaculture ponds globally and deserves further investigation.

**Keywords:** acidity, alkalinity, aquaculture, buffering, K-bicarbonate method

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## Introduction

Liming has been one of the most common pond management practices in aquaculture, aiming mainly at sanitising pond bottom between crops and/or improving pond's buffering capacity for water quality stabilisation during grow-out periods (Boyd, 1995; Boyd et al., 2002; Wurts and Masser, 2013; Anderson and Tave, 2018; Khalid et al., 2024). Besides, liming can improve the pH of bottom soils, remove CO<sub>2</sub>, and increase the concentrations of calcium and magnesium (and thus hardness) in pond water (Boyd, 1995; Wurts and Masser, 2013). Although the two main purposes of liming could be achieved from a single application, they are often discussed separately. The effects of liming to pond's buffering capacity has been more focused, probably because of the direct link between total alkalinity (TA) and aquaculture production (Moyle, 1946; Boyd, 2015; Boyd et al., 2016). For an increased aquaculture production,

pond liming should be followed by the application of fertilisers (Boyd and Pillai, 1985; Green, 2015). From a practical point of view, the target of pond liming is to improve the pond's response to inorganic fertilisers so that phytoplankton and aquaculture production increases (Thomaston and Zeller, 1961; Boyd, 1974; Wurts and Masser, 2013; Green, 2015). The types, rates, and time of application differ among cases depending on the purpose of liming and specific pond conditions. The four most commonly used liming materials in aquaculture ponds are agricultural limestone (CaCO<sub>3</sub>), dolomite (CaMg(CO<sub>3</sub>)<sub>2</sub>), quicklime (CaO), and hydrated lime (Ca(OH)<sub>2</sub>) (Hansell and Boyd, 1980; Boyd, 2017). The best liming material for general use is CaCO<sub>3</sub> (Boyd and Masuda, 1994; Wurts and Masser, 2013; Nobre et al., 2014; Lucas et al., 2019).

The lime requirement (LR) of aquaculture ponds is the amount of liming materials needed to ensure that the

total alkalinity (TA) and total hardness (TH) of pond water are maintained at or above a specified level (Schaeperclaus, 1933; Boyd, 1974; Boyd and Tucker, 1998). Because waters with moderate to high TA are well-buffered against wide daily swings in pH, typically waters with a TA of 50–200 mg.L<sup>-1</sup> are more productive than those of 0–50 mg.L<sup>-1</sup> (Moyle, 1946). The LR is not a fixed pre-defined value but depends on context, mostly on the TA requirement of specific aquaculture species. In fact, most aquaculture species can live in a broad range of TA and do not have a specific TA requirement (Boyd and Tucker, 1998; Wurts and Masser, 2013). Many authors have argued that pond liming should bring TA and TH of pond water to at least 20 mg.L<sup>-1</sup> because ponds respond effectively to fertilisation at or above that threshold (Thomaston and Zeller, 1961; Boyd, 1974; Wurts and Durborow, 1992). Boyd and Tucker (1998), however, stated that TA values higher than 50 mg.L<sup>-1</sup> are required for an increased aquaculture production because the desired TA for most aquaculture species is often equal to or greater than that value. More recently, higher TA requirements, such as from 60 mg.L<sup>-1</sup> for food fish or from 100 mg.L<sup>-1</sup> for marine species have been reported (MARD, 2014; Boyd et al., 2016; Rajts and Shelley, 2020).

To provide accurate liming recommendations, the pond's LR should be determined. This is challenging because there have been no easy ways to determine the lime rates needed to provide adequate TA for pond water (Boyd, 2017). Although liming has long been a common management practice in aquaculture ponds, pond LR methods have not yet been developed in parallel with the rapid development of the aquaculture sector. In many cases, LR are estimated based simply on instructions of the manufacturers or farmers' experience. Meanwhile, liming materials have been used indiscriminately in aquaculture ponds, particularly in coastal areas (Queiroz et al., 2004; Silapajarn et al., 2005; Boyd et al., 2016). In some types of aquaculture, such as in lined ponds (in intensive and super-intensive models), water-based LR should be tested regularly and lime applied promptly because (1) TA and TH decrease throughout the farming season due to the moulting and new shell formation process of invertebrate species (Wurts, 2002) and/or (2) increase in CO<sub>2</sub> concentration in the pond water from midnight to early morning due to respiration of pond organisms (Wurts and Durborow, 1992). The water-based LR in lined ponds (can be obtained using simple test kits) is not discussed in detail here, as this paper focusses on LR methods in earthen ponds where soils constantly interact with the overlying water.

A number of LR methods for ponds have been introduced (Clifford, 1985; Pillai and Boyd, 1985; Bowman and Lannan, 1992; Boyd et al., 2002; Han et al., 2014; Han, 2018). However, selection of an appropriate method for use in specific conditions is often confused because each of the methods have their own advantages and disadvantages. It is therefore necessary to identify LR methods that yield reliable results, easy to use, and can be applied on a wide range of pond soils. To achieve the target, this paper

reviews the existing LR methods for pond soils and discusses the potential of a titration-based method for wider use in aquaculture ponds.

## Principles

Unlike agricultural soils, where liming aims at achieving a desired soil pH, the target of pond water liming is TA (and associated TH) because this variable indicates the pond's current buffering capacity which ensures the stabilisation of water quality (Han et al., 2014; Boyd et al., 2016). In case liming materials beyond those required to neutralise the pond's current acidity are applied, an alkaline reserve (as solid CaCO<sub>3</sub>) is formed on the pond bottom, and this provides further buffering to the ponds in the long term (Huet and Timmermans, 1994; Sà et al., 2021). Pond LR are highly dependent on the exchange acidity of bottom soils (Boyd, 1995; Boyd et al., 2002; Boyd et al., 2016), and ponds with different bottom properties respond differently to liming (Boyd, 2017). That is because the amount of liming material needed to neutralise bottom soil acidity is much greater than that to bring the water's TA and TH to desirable levels (Boyd, 1995). This is due to a continual exchange of materials between pond water and pond soils in natural conditions (Boyd, 1995; Wurts and Masser, 2013). Based on these concepts and current knowledge, most of pond LR methods so far have been focused on the exchange acidity of pond soils (Boyd, 2017). There are no exact LR values, and all testing procedures determine only the approximate pond's LR (Mischke, 2012).

## Lime Requirement Methods

### Use of a single or multiple parameters

Lime requirement of aquaculture ponds can be estimated using soil pH, soil pH and water TA, or soil pH and soil texture combinations. The methods are derived from the relationships between LR and those parameters and often yield rough LR estimates. Soil pH was used to estimate LR in semi-intensive shrimp ponds in Texas, USA (Clifford, 1985), carp ponds in India (Trivedi, 2011), and catfish ponds in the Mekong delta of Vietnam (MARD, 2011). Boyd et al. (2002) suggest a combination of soil pH and TA to determine the LR of aquaculture ponds (Table 1) when a LR test is not possible. Those authors further stated that either TA

Table 1. Estimates of an aquaculture pond's lime requirement (LR) based on total alkalinity and soil pH (from Boyd et al., 2002).

Total alkalinity <sup>1</sup> (mg.L <sup>-1</sup> )	Soil pH	CaCO <sub>3</sub> (kg.ha <sup>-1</sup> )
<5	<5.0	3,000
5–10	5.0–5.4	2,500
10–20	5.5–5.9	2,000
20–30	6.0–6.4	1,500
30–50	6.5–6.7	1,000

<sup>1</sup>Either total alkalinity or soil pH may be used to estimate pond LR. If both values are available but differ, use the one that gives the higher LR.

or soil pH could be used solely for that purpose, and the higher lime rate is recommended if results derived from these two variables differ. Several authors have used a combination of soil pH and soil texture to estimate pond LR (Schaeperclaus, 1933; Hora and Pillay, 1962).

It should be noted that pond LR by these methods vary greatly between studies, probably because of the differences in the chemistry of pond soils of different regions. Moreover, other characteristics, such as soil base unsaturation (BUS), soil organic matter, or water salinity also affect the estimates of pond LR (Boyd, 1974; Boyd and Tucker, 1998; Sá and Boyd, 2017; Han and Boyd, 2018; Sá et al., 2019) and thus contributed to LR discrepancies among the studies. This method has been used mostly in rural areas where small-scale aquaculture predominates and access to laboratory facilities is difficult.

### Use of predetermined relationships between pond soil characteristics

In this method, predetermined relationships between soil characteristics are used to estimate pond LR. The pH-BS (base saturation) relationships of soil classes in several locations of the United States were established and used in combination with cation

exchange capacity (CEC) and initial soil pH to estimate pond LR (Bowman and Lannan, 1992). Pond LR is equivalent to the amount of exchange acidity to be neutralised to obtain a desired TA in pond water (Bowman and Lannan, 1992, 1995). Practically, pond LR are estimated as follows (Equation 1):

$$LR = CEC \times (\text{desired BS} - \text{initial BS}) \times CT \quad (1)$$

where CT is a correction term required to convert the dimensions of CEC (cmol<sub>e</sub>.kg<sup>-1</sup>) to the dimensions of lime applied to a mass of soil (kg CaCO<sub>3</sub>).

The soil classes in those studies were included mixed clays, montmorillonite clays, fine-loamy, coarse-loamy, kaolinitic clays, and sandy soils (mineral soils) and peats (organic soils). The provisional LR for ponds in the United States using this method are presented in Table 2. Those relationships were also used to estimate LR of fish ponds in Alabama, USA (Boyd, 1974; Boyd and Cuenco, 1980). The estimation of pond LR by this method works for soils with an exchange acidity (acidity adsorbed on the surface of soil complex) but not for soils with mineral acidity, such as acid-sulphate soils or acid mine spoils (Bowman and Lannan, 1992). This method can be accepted for use in aquaculture ponds in rural areas where access to laboratory is limited.

Table 2. Lime requirements (kg CaCO<sub>3</sub>.ha<sup>-1</sup>) for different soil classes in the United States at target pH of 6.5 (5.5 for organic soils) (from Bowman and Lannan, 1992).

Soil pH	SAN <sup>1</sup>	COCO	FIFI	KKCL	MXCL	MTCL	HIST
6.5	0	0	0	0	0	0	0
6.4	131	249	202	494	306	481	0
6.3	302	498	605	1,006	611	1,005	0
6.2	522	871	807	1,530	917	1,576	0
6.1	796	1,120	1,211	2,061	1,528	2,194	0
6.0	1,124	1,493	1,413	2,595	1,834	2,862	0
5.9	1,501	1,742	1,816	3,126	2,139	3,581	0
5.8	1,911	2,239	2,220	3,647	2,751	4,353	0
5.7	2,335	2,613	2,624	4,155	3,056	5,177	0
5.6	2,748	3,110	3,027	4,645	3,668	6,055	0
5.5	3,129	3,732	3,431	5,113	4,279	6,984	0
5.4	3,462	4,355	4,037	5,557	4,890	7,964	1,412
5.3	3,741	5,101	4,642	5,973	5,502	8,992	2,842
5.2	3,967	5,972	5,247	6,360	6,418	10,064	4,272
5.1	4,143	6,843	6,257	6,719	7,335	11,176	5,682
5.0	4,277	7,589	7,468	7,047	8,864	12,323	7,054
4.9	4,378	8,336	9,284	7,347	11,003	13,499	8,374
4.8	4,452	8,834	11,908	7,619	18,644	14,698	9,627
4.7	4,507	9,456	13,926	7,685	21,395	15,913	10,803
4.6	4,547	9,829	15,137	8,085	22,923	17,135	11,896
4.5	4,575		16,146	8,282	24,146	18,357	12,900
4.4	4,596		16,751	8,458	25,062	19,572	13,815
4.3	4,610			8,614	25,674	20,772	14,642
4.2	4,621			8,752		21,950	15,382
4.1	4,629			8,873		23,099	16,041
4.0	4,634			8,981		24,214	16,625

<sup>1</sup>SAN: Sandy, COCO: Coarse-loamy, FIFI: Fine-loamy, KKCL: Kaolinitic clay, MXCL: Mixed clay, MTCL: Montmorillonite clay, HIST: Organic.

## Use of empirical relationships between lime rates and total alkalinity

This is the direct and most accurate LR method for aquaculture ponds because LR is estimated from the actual relationship between the lime rates and TA of pond water at equilibrium. For example, Hickling (1962) estimated the LR of aquaculture ponds in Malacca, Malaysia by applying various  $\text{CaCO}_3$  rates and recording the corresponding TA in the water column (Table 3). He found that TA reached the expected equilibrium concentration at the highest lime rates, consistent with previous studies (Boyd, 1995; Boyd et al., 2002). Similarly, Bowman and Seim (1996) determined the LR of a pond with acid soil and low alkalinity water at Soap Creek Corvallis, Oregon, USA by adding  $\text{CaCO}_3$  to isolation columns in the field and monitoring the TA over the following 28 days. Although this method has the highest accuracy and has a high practical significance, its use has been limited because it is very labour-intensive, time-consuming, and costly. This method is suitable for validating other quick LR methods for aquaculture ponds.

Table 3. Empirical relationships between lime rates and total alkalinity of aquaculture ponds in Malacca, Malaysia (Hickling, 1962).

Lime rate added (kg $\text{CaCO}_3$ .ha <sup>-1</sup> )	Alkalinity (mg $\text{CaCO}_3$ .L <sup>-1</sup> )
0	12
500	20
1000	30
1500	35
2000	40
4000	55

## Buffer methods

Boyd (1974) modified the Adams-Evans buffer method (Adams and Evans, 1962) designed for LR estimates of Red-yellow podzolic soils (agricultural soils) in the southern United States for use in sportfish ponds in Alabama (called Alabama pond method or AP method). This method was based on the observation that pond muds with BUS of 0.2 or less had waters with a TA of  $\geq 20$  mg.L<sup>-1</sup>, implying that TA would increase to  $\geq 20$  mg.L<sup>-1</sup> when BUS of pond mud is reduced to 0.2 or less. The buffer solution of this method contains 20 g of p-nitrophenol, 15 g of boric acid, 74 g of potassium chloride, and 10.5 g of potassium hydroxide dissolved and diluted to 2 L with distilled water, with the pH being adjusted to 8.0 (Boyd, 1974). Pond LR is estimated using soil pH measured in water (1:1, w/w), in the buffer solution (1:2, w/w), and relationships among soil pH, BUS, and TA. A correction factor of 1.5 was used to compensate for the low effectiveness of liming materials in neutralising soil acidity in this method. The procedure of the AP method can be summarised as (1) dry and sieve soil sample (0.85-mm screen), (2) mix

20 g of soil and 20 mL of distilled water, and stir for 1 h, (3) measure pH, (4) add 20 mL of the buffer and stir for 20 min, (5) set pH meter at 8.0 with a 1:1 mixture of the buffer and distilled water, and read pH of the soil-buffer-distilled water mixture while stirring, and (6) obtain the liming rate from the relationship between soil pH in water and that in the buffer solution (Boyd, 1974). Lime rates by the AP method consistently decrease BUS of bottom soils to 0.25, increase soil pH to 6.0 and TA of pond water to 20–30 mg.L<sup>-1</sup> (Boyd, 1974; Han, 2018). This method, however, has not been used outside the southern United States due to regional differences in soil characteristics and the higher TA required for food fish and crustacean ponds compared to sportfish ponds. Only some of the trials were successful in the United States, Europe, and Asia (Han, 2018).

To extend the use of buffer methods, the AP method was modified into the PB method (Pillai and Boyd method) using pond muds in Lee and Russell Counties, Alabama, United States (Pillai and Boyd, 1985). The buffer solution of this method contains 10 g of p-nitrophenol, 7.5 g of boric acid, 37 g of potassium chloride, and 5.25 g of potassium hydroxide diluted to 1 L with distilled water, and the pH is adjusted to 8.0. The PB method was designed to neutralise a large amount of exchange acidity and lower BUS of pond soils as much as possible. Lime requirements in this method were estimated from the pH change in the buffer solution when mixing with pond soils. Unlike the AP method, no liming factor was used in the PB method. The procedure of the PB method (Boyd et al., 2002) can be summarised as follows: (1) dry, crush, and sieve soil (0.84-mm screen), (2) mix 20 g of soil and 40 mL of the buffer, stir the mixture for one h, (3) set the pH meter at pH 8.0 with the buffer, measure the pH of the soil-buffer mixture to the nearest 0.01 pH unit (repeat the procedure with 10 g of soil and 40 mL of buffer if the pH is below 6.8), and (3) calculate LR (kg  $\text{CaCO}_3$ .ha<sup>-1</sup>) for a 20-g sample (Equation 2). In case where a 10-g sample was used, the LR is twice the value obtained by Equation 2.

$$\text{LR} = (8.0 - \text{pH}) \times 5,600 \quad (2)$$

The PB method was more effective than the AP method in terms of raising soil pH to 7.0–7.5 and water's TA to 40–50 mg.L<sup>-1</sup> and can be used for ponds globally, except for ponds with acid-sulphate soils (Pillai and Boyd, 1985). Although it seems superior to the AP method, the PB method does not raise the TA in pond water as high as desirable in some types of aquaculture. This method has not been widely used, possibly because of the presence of a hazardous chemical (p-nitrophenol) in the buffer solution (Han et al., 2014).

Several buffer methods, other than the Adams-Evans buffer for agricultural soils, could be modified for use in aquaculture ponds (Shoemaker et al., 1961; Godsey et al., 2007; Pagani and Mallarino, 2011). Modifications of these methods are technically feasible, but their use

is still questioned because of some inherent disadvantages, such as the use of toxic chemicals in the buffer solutions and the need to be calibrated on specific soil types (Aitken et al., 1995; McFarland et al., 2020).

### *Titration method for sulphide-containing soils*

Although it is widely known that sulphide-containing soils should not be used for pond aquaculture (Singh and Poernomo, 1984; Boyd, 1995; Boyd et al., 2002; Lucas and Southgate, 2012), aquaculture ponds have still been built on those soils due to the lack of land resources in many rural areas. From a theoretical framework, the LR of these ponds are the lime rates required to neutralise acidity from both the oxidation of sulphide material (constituting most of the acidity) and exchange acidity (Singh and Poernomo, 1984; Boyd, 1995). To determine the former, a titration method was recommended by Boyd (1995). Specifically, soil samples passing a 100-mesh sieve (0.15-mm openings) are oxidised by 30 % hydrogen peroxide at 40 °C until no reaction occurs. Distilled water is then added to the mixture, and the excess hydrogen peroxide is removed by heating at 90–95 °C for 30 min. The mixtures are then cooled and titrated using a standard NaOH solution with phenolphthalein as colour indicator. The end point of the titration is determined when the solution turns a faint pink colour for at least 30 sec.

Liming aquaculture ponds in sulphide-containing soils has been studied (Boyd, 1995; Mustafa et al., 2020; Fitrani et al., 2020, 2023). In general, LR of those ponds range from 25–150 ton.ha<sup>-1</sup>, and such large lime applications are often infeasible (Boyd, 1995). Further, many years are required to oxidise the most part of sulphide material in the ponds and release acids to the surroundings (Simpson and Pedini, 1985; Boyd, 1995). The time required to flush out most of acidity produced in these ponds is longer than the normal grow-out periods in pond aquaculture. The above-mentioned facts have suggested that the approach to mitigating the impacts of acid-sulphate soils on pond aquaculture by liming is impractical. In fact, that issue has been solved by using a combination of management methods, such as avoiding using deeper soil layers for dike construction, proper pond design, water management, and extensive liming (Singh and Poernomo, 1984; Simpson and Pedini, 1985; Rizal et al., 2020; Tarunamulia et al., 2024).

### *The K-bicarbonate titration method*

To improve the extraction of exchange acidity and avoid the use of toxic chemicals in pond LR tests, a titration-based method referred to as K-bicarbonate method was developed using a potassium chloride-potassium bicarbonate solution (1.0 N in potassium ion and 0.04 N in bicarbonate, equal to 2 mg.mL<sup>-1</sup> TA as CaCO<sub>3</sub> equivalent) as the extraction solution. The pH of the K-

bicarbonate solution is 8.3 and this value remains above 7.0 after exposure to soils (Han et al., 2014; Han, 2018). This method was tested using bottom soils in the E.W. Shell Fisheries Center at Auburn University and ponds representing major physiographic regions and soil groups in Alabama, the United States. These soils had a pH range from 3.89 to 6.45, organic carbon content from 0.11 % to 2.5 %, and texture from sandy loam to clay, representative of the soil properties range expected for ponds with acidic bottom soils and low alkalinity waters (Boyd, 1995). The H<sup>+</sup> derived from the hydrolysis of Al<sup>3+</sup> displaced from soil will neutralise HCO<sub>3</sub><sup>-</sup>, and the corresponding decrease in TA of the solution allows a direct estimate of the amount of liming material (as CaCO<sub>3</sub> equivalent) necessary to neutralise the exchange acidity of pond soils. This method is expected to extract more exchange acidity than the PB method because the K<sup>+</sup> concentration of its extraction solution is higher (1 N vs. 0.59 N). The procedure of this method can be summarised as (1) mixing dry, pulverised soil samples with the bicarbonate solution and shaking, (2) allowing soil particles to settle and filtering the supernatant, and (3) titrating the filtrate to the methyl orange endpoint with a standard solution of sulfuric acid (Han et al., 2014).

The K-bicarbonate method yields LR about 12.9 % higher than the other methods and works effectively for soils with LR of up to 5–5.5 ton CaCO<sub>3</sub>.ha<sup>-1</sup> or even higher (Han et al., 2014; Boyd, 2017). This method is simpler in terms of equipment and operating procedures, and cheaper than the other available methods (Han et al., 2014; Boyd, 2017; Han, 2018). Besides, it uses only common and non-toxic chemicals. The K-bicarbonate method can be used for most aquaculture ponds worldwide except those in acid-sulphate areas (Han et al., 2014).

### *Stepwise lime requirement method*

When pond liming is necessary, e.g. when bottom soil pH < 7, TA < 20 mg.L<sup>-1</sup>, or TA < 20 mg.L<sup>-1</sup> combined with soil pH < 6.5 in new ponds (Boyd, 1995; Boyd et al., 2002) but determination of LR by any of the above-mentioned methods is impossible, it is recommended to apply about 2 ton of agricultural limestone per ha and measure water's TA after 1 or 2 months. A similar application of CaCO<sub>3</sub> should be subsequently made if the TA measured is still less than 20 mg.L<sup>-1</sup>, and this procedure should be repeated until TA is equal to or higher than that value (Rouse, 1979). In most cases, LR by this method range from 2–6 ton CaCO<sub>3</sub>.ha<sup>-1</sup>. Silapajarn et al. (2005) recommended a similar procedure for aquaculture ponds in Thailand where farmers estimate pond's LR by judgement. The author suggests that CaCO<sub>3</sub> is added to ponds in 1 ton.ha<sup>-1</sup> increments until a TA value of 50–60 mg.L<sup>-1</sup> is reached. In general, a minimum rate of 2 ton CaCO<sub>3</sub> or 0.5–1 ton Ca(OH)<sub>2</sub> per ha can also be applied in mixed shrimp-mangrove systems at the start of the growing season (Baliao and Tookwinas, 2002). In a guidelines document, FAO (2022) recommended this method for ponds with water's pH from 6.5–8.5 and TA of less than 75 mg.L<sup>-1</sup> by using

several doses of 150–200 kg CaCO<sub>3</sub>.ha<sup>-1</sup> at weekly intervals until TA is improved. Although this method is very time-consuming and laborious, it is reasonably suitable for ponds in rural areas.

## Comparisons of methods

To figure out the methods that can be used widely, all the above-mentioned methods and their main characteristics are compared (Table 4). It can be seen

from the table that (1) each method has advantages and disadvantages and might be suited in specific conditions, and (2) the K-bicarbonate method is superior to the other methods.

Pond's LR methods most widely used are (1) use of a single or multiple parameters, (2) buffer methods, and (3) stepwise method. Due to its advantages, the use of a single or multiple parameters of water and pond soils for LR estimates has still been adopted in many

Table 4. Comparisons of pond's lime requirement methods.

No.	Methods	Main characteristics
1	Use of a single or multiple parameters	<ul style="list-style-type: none"> <li>• Single or multiple characteristics of water and bottom soil are used to estimate LR</li> <li>• Low accuracy</li> <li>• Fast</li> <li>• Suitable in rural areas where laboratory access is limited</li> </ul>
2	Use of predetermined relationships between pond soil characteristics	<ul style="list-style-type: none"> <li>• Predetermined relationships between soil characteristics are used to estimate LR</li> <li>• Low accuracy</li> <li>• Fast</li> <li>• Suitable in areas where relevant soil properties are available</li> </ul>
3	Use of empirical relationships between lime rates and total alkalinity	<ul style="list-style-type: none"> <li>• Relationships between lime rates and TA at field scale are used to estimate LR</li> <li>• Highest accuracy</li> <li>• Time-consuming</li> <li>• Suitable to validate other quick LR methods</li> </ul>
4	Buffer methods	<ul style="list-style-type: none"> <li>• LR is estimated using a buffer solution</li> <li>• High accuracy</li> <li>• Relatively fast</li> <li>• Might cause health and environmental problems</li> </ul>
5	Titration method for sulphide-containing soils	<ul style="list-style-type: none"> <li>• LR is estimated by a titration</li> <li>• High accuracy</li> <li>• Time-consuming</li> <li>• Estimating lime rate to neutralise acidity from sulphide material</li> </ul>
6	The K-bicarbonate titration method	<ul style="list-style-type: none"> <li>• LR is estimated by a titration</li> <li>• High accuracy</li> <li>• Relatively fast</li> <li>• Simpler and cheaper than the other methods</li> </ul>
7	Stepwise lime requirement method	<ul style="list-style-type: none"> <li>• LR is estimated based on pond response to liming at field scale</li> <li>• Reasonable accuracy</li> <li>• Very time-consuming</li> <li>• Used when other LR methods cannot be implemented (FAO, 2022)</li> </ul>

countries, such as Vietnam or India. This method is also recommended by FAO (2022) for ponds globally. The buffer methods have been used mainly in the USA. The stepwise LR method has been adopted in rural areas where implementation of the other methods is impossible (FAO, 2022). Although the K-bicarbonate titration method has a number of advantages, it is quite new and has not yet been widely spread (Han et al., 2014).

## Potential Use of the K-bicarbonate Method

The principles of quantitative LR methods for aquaculture ponds are to extract and determine as much

as possible soil exchange acidity because this component has been known as the main determinant of the water's TA (Pillai and Boyd, 1985; Han et al., 2014). The K-bicarbonate method is the best to meet those principles because its extraction solution has the highest extracting capability (K<sup>+</sup> concentration = 1 N) among the currently used methods. This concentration of K<sup>+</sup> is similar to those in the general extraction solutions for soil's exchangeable cations or CEC (Tan, 2005; Carter and Gregorich, 2007) and is thus expected to extract most of soil exchange acidity. The higher lime rate derived from this method compared to the other methods (Han et al., 2014) is one of its remarkable advantages because this would lead to a more stable TA, thus providing a longer buffering capacity and reducing the number of liming

applications during a grow-out period. Besides, the K-bicarbonate method is simple enough that it could be used to estimate LR of individual aquaculture ponds worldwide (Han et al., 2014; Han, 2018).

Regardless of its advantages (Table 4), the K-bicarbonate method has not yet been widely tested and its effectiveness in raising soil pH and water's TA has not yet been evaluated in field or field-simulated conditions. These data would be of crucial importance to assess the reliability of the K-bicarbonate method (Han et al., 2014). To promote its use globally, the K-bicarbonate method should be tested in various pond soils or pond soils of different regions. It should also be tested in areas where pond LR have still been estimated by qualitative methods, e.g. in the Mekong delta of Vietnam (MARD, 2011; Ca Mau Portal, 2018) or India (Trivedi, 2011; Adhikari et al., 2017). Given that the K-bicarbonate method is simple, it is also worth to be tested for use in rural areas where laboratory access is limited. All these results would be sufficient in evaluating the effectiveness of the method and promoting its global use.

## Conclusion

Both qualitative and quantitative methods have been used for pond LR tests, depending mostly on the scales of aquaculture production, method availability, or laboratory access. Each of the LR methods currently used for ponds have their own advantages and disadvantages and can be used under specific target of liming or pond conditions. In general, the K-bicarbonate method is superior to the other methods regarding accuracy, simplicity, cost, and environmental safety. This method is therefore of great potential and should be investigated further for future use in aquaculture ponds worldwide. The following points to be addressed include (1) Standardising the method, (2) Testing the effectiveness of the method in raising pond soil pH and water's TA, and (3) Examining the suitability of the method in a wide range of pond conditions and management regimes.

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## References

Adams, F., Evans, C.E. 1962. A rapid method for measuring lime requirement of red-yellow podzolic soils. *Soil Science Society of*

- America Journal* 26:355-357. <https://doi.org/10.2136/sssaj1962.03615995002600040015x>
- Adhikari, S., Chakrabarti, P.P., Paul, B.N., Sundaray, J.K. 2017. Training manual on "Nutrient management in fish culture with emphasis on soil health and carbon budget management". ICAR - Central Institute of Freshwater Aquaculture, RRC, Rahara, Kolkata, West Bengal, India. 140 pp.
- Aitken, R.L., Moody, P.W., Dickson, T. 1995. Field calibration of lime requirement soil tests. In: *Plant soil interactions at low pH*, Date, R.A., Grundon, N.J., Rayment, G.E., Probert, M.E. (Eds.), Kluwer Academic Publishers, London, pp. 479-484. [https://doi.org/10.1007/978-94-011-0221-6\\_73](https://doi.org/10.1007/978-94-011-0221-6_73)
- Anderson, R.O., Tave, D. 2018. *Strategies and tactics for management of fertilized hatchery ponds*. CRC Press, Boca Raton, FL. 262 pp.
- Baliao, D.D., Tookwinas, S. 2002. Best management practices for mangrove-friendly shrimp farming. *Aquaculture Extension Manual 35*. SEAFDEC Aquaculture Department, Tigbauan, Iloilo, Philippines; Association of Southeast Asian Nations, Bangkok, Thailand. 50 pp.
- Bowman, J.R., Lannan, J.E. 1992. A simple approach to the estimation of lime requirements for aquaculture ponds on diverse soil types. In: *Classification and management of earthen aquaculture ponds, with emphasis on the role of the soil*, Bowman, J.R., Dissertation, Oregon State University, USA, pp. 125-172.
- Bowman, J.R., Lannan, J.E. 1995. Evaluation of soil pH-percent base saturation relationships for use in estimating the lime requirements of earthen aquaculture ponds. *Journal of the World Aquaculture Society* 26:172-182. <https://doi.org/10.1111/j.1749-7345.1995.tb00241.x>
- Bowman, J.R., Seim, W.K. 1996. Experimental evaluation of lime requirement estimators for global sites. Interim Work Plan, Africa Study 3. In: *Pond Dynamics/Aquaculture Collaborative Research Support Program, Fourteenth Annual Technical Report*, Burke, D., Goetze, B., Clair, D., Egna, H. (Eds.), Pond Dynamics/Aquaculture CRSP Management Office, Office of International Research and Development, Oregon State University, Oregon, USA, pp. 98-102. <http://crsps.net/wp-content/downloads/AquaFish/Inventoried%203.22/8-1996-8-112.pdf>
- Boyd, C.E. 1974. Lime requirements of Alabama fish ponds. *Bulletin 459*. Agricultural Experiment Station, Auburn University, Auburn, Alabama, USA. 20 pp.
- Boyd, C.E. 1995. *Bottom soils, sediment, and pond aquaculture*. Chapman and Hall, New York. 365 pp. <https://doi.org/10.1007/978-1-4615-1785-6>
- Boyd, C.E. 2015. *Water quality - An introduction*. 2<sup>nd</sup> edition. Springer, Switzerland. 374 pp.
- Boyd, C.E. 2017. Use of agricultural limestone and lime in aquaculture. *CABI Reviews* 12:1-10. <https://doi.org/10.1079/PAVSNNR201712015>
- Boyd, C.E., Cuenco, M.L. 1980. Refinements of the lime requirement procedure for fish ponds. *Aquaculture* 21:293-299. [https://doi.org/10.1016/0044-8486\(80\)90139-8](https://doi.org/10.1016/0044-8486(80)90139-8)
- Boyd, C.E., Masuda, K. 1994. Characteristics of liming materials used in aquaculture ponds. *World Aquaculture* 24:76-79.
- Boyd, C.E., Pillai, V.K. 1985. *Water quality management in aquaculture*. CMFRI Special Publication 22. Central Marine Fisheries Research Institute, Cochin, India. 106 pp.
- Boyd, C.E., Tucker, C.S. 1998. *Pond aquaculture and water quality management*. Kluwer Academic Publishers, Boston. 711 pp. <https://doi.org/10.1007/978-1-4615-5407-3>
- Boyd, C.E., Tucker, C.S., Somridhivej, B. 2016. Alkalinity and hardness: Critical but elusive concepts in aquaculture. *Journal of the World Aquaculture Society* 47:6-41. <https://doi.org/10.1111/jwas.12241>
- Boyd, C.E., Wood, C.W., Thunjai, T. 2002. *Aquaculture pond bottom soil quality management*. Pond Dynamics/Aquaculture Collaborative

- Research Support Program, USA. 41 pp. [https://freshwater-aquaculture.extension.org/wp-content/uploads/2019/08/Aquaculture\\_Pond\\_Bottom\\_Soil\\_Quality\\_Management.pdf](https://freshwater-aquaculture.extension.org/wp-content/uploads/2019/08/Aquaculture_Pond_Bottom_Soil_Quality_Management.pdf)
- Ca Mau Portal. 2018. Bottom soil treatment in black tiger shrimp ponds. <https://english.camau.gov.vn/wps/portal/> (Accessed 25 June 2024).
- Carter, M.R., Gregorich, E.G. 2007. Soil sampling and methods of analysis. CRC Press, Boca Raton. 1224 pp. <https://doi.org/10.1201/9781420005271>
- Clifford, H.C. 1985. Semi-intensive shrimp farming. In: Texas shrimp farming manual, Chamberlain, G.A., Haby, M.H., Miget, R.J. (Eds.). Texas Agricultural Extension Service publication of invited papers presented at the Texas Shrimp Farming Workshop on 19–20 November 1985, Corpus Christi, Texas, USA, pp. IV15–IV42.
- FAO. 2022. Pond conditioning through liming. FAO Fisheries and Aquaculture. [https://www.fao.org/fishery/docs/CDrom/FAO\\_Training/FAO\\_Training/General/x6709e/x6709e05.htm](https://www.fao.org/fishery/docs/CDrom/FAO_Training/FAO_Training/General/x6709e/x6709e05.htm) (Accessed 25 June 2024).
- Fitriani, M., Wudtisin, I., Kaewnern, M. 2020. The impacts of the single-use of different lime materials on the pond bottom soil with acid sulfate content. *Aquaculture* 527:735471. <https://doi.org/10.1016/j.aquaculture.2020.735471>
- Fitriani, M., Wudtisin, I., Kaewnern, M. 2023. The combination of dolomite and hydrated lime with different compositions in sulfuric acid soil for fish culture ponds. *Jurnal Ilmiah Perikanan dan Kelautan* 15:170–178. <https://doi.org/10.20473/jipk.v15i1.37719>
- Godsey, C.B., Pierzynski, G.M., Mengel, D.B., Lamond, R.E. 2007. Evaluation of common lime requirement methods. *Soil Science Society of America Journal* 71:843–850. <https://doi.org/10.2136/sssaj2006.0121>
- Green, B.W. 2015. Fertilizers in aquaculture. In: Woodhead Publishing Series in Food science, technology and nutrition, feed and feeding practices in aquaculture, Davis, D.A. (Ed.), Woodhead Publishing, pp. 27–52. <https://doi.org/10.1016/B978-0-08-100506-4.00002-7>
- Han, Y. 2018. Experiments on the pond lime requirement test and the effect of organic matter on dissolution of agricultural limestone in aquaculture ponds. Dissertation, Auburn University. 107 pp.
- Han, Y., Boyd, C.E. 2018. Effect of organic matter concentration on agricultural limestone dissolution in laboratory soil–water systems. *Aquaculture Research* 49:3451–3455. <https://doi.org/10.1111/are.13810>
- Han, Y., Boyd, C.E., Viriyatum, R. 2014. A bicarbonate titration method for lime requirement to neutralize exchangeable acidity of pond bottom soils. *Aquaculture* 434:282–287. <https://doi.org/10.1016/j.aquaculture.2014.08.031>
- Hansell, D.A., Boyd, C.E. 1980. Uses of hydrated lime in fish ponds. *Proceedings of Southeastern Fish and Wildlife Conference* 34:49–58.
- Hickling, C.F. 1962. *Fish cultures*. Faber and Faber, London. 295 pp.
- Hora, S.L., Pillay, T.V.R. 1962. *Handbook on fish culture in the Indo-Pacific region*. Fisheries Division, Biology Branch, Food and Agriculture Organization of the United Nations, Rome. 204 pp.
- Huet, M., Timmermans, J. 1994. *Textbook of fish culture*. 2<sup>nd</sup> edition. Fishing News Books, Oxford. 418 pp.
- Khalid, S., Hafeez, M., Shah, S.M., Ullah, N., Aeman, H. 2024. Opportunities for brackish and saline aquaculture in Pakistan. Final Project Report, FR2024-015. ACIAR, Australia. 110 pp.
- Lucas, J.S., Southgate, P.C. 2012. *Aquaculture – Farming aquatic animals and plants*. 2<sup>nd</sup> edition. Wiley-Blackwell, New Jersey. 648 pp. <https://doi.org/10.1002/9781118687932>
- Lucas, J.S., Southgate, P.C., Tucker, C.S. 2019. *Aquaculture – Farming aquatic animals and plants*. 3<sup>rd</sup> edition. John Wiley & Sons Ltd., UK. 672 pp.
- MARD. 2011. Better management practices for striped catfish (tra) farming in the Mekong Delta, Viet Nam. Collaboration for Agriculture and Rural Development project “Development of better management practices for catfish aquaculture in the Mekong Delta, Vietnam (001/07VIE)”. Ministry of Agriculture and Rural Development, Hanoi. 92 pp. (in Vietnamese).
- MARD. 2014. National technical regulation on Striped catfish (*Pangasianodon hypophthalmus* Sauvage, 1878) culture farm in pond – Conditions for veterinary hygiene, environmental protection and food safety. QCVN 02 – 20: 2014/BNNPTNT. Ministry of Agriculture and Rural Development, Hanoi. <https://thuvienphapluat.vn/TCVN/Nong-nghiep/QCVN02-20-2014-BNNPTNT-nuoi-ca-tra-trong-ao-ve-sinh-thu-y-moi-truong-thuc-pham-910679.aspx> (in Vietnamese).
- McFarland, C., Shiwakoti, S., Carpenter-Boggs, L., Schroeder, K., Brown, T., Huggins, D.R. 2020. Evaluating buffer methods for determining lime requirement on acidified agricultural soils of the Palouse. *Soil Science Society of America Journal* 84:1769–1781. <https://doi.org/10.1002/saj2.20111>
- Mischke, C.C. 2012. *Aquaculture pond fertilization – Impacts of nutrition input on production*. Wiley-Blackwell, Oxford, UK. 297 pp. <https://doi.org/10.1002/9781118329443>
- Moyle, J.B. 1946. Some indices of lake productivity. *Transactions of the American Fisheries Society* 76:322–334. [https://doi.org/10.1577/1548-8659\(1946\)76\[322:SIOLP\]2.0.CO;2](https://doi.org/10.1577/1548-8659(1946)76[322:SIOLP]2.0.CO;2)
- Mustafa, A., Ratnawati, E., Undu, M.C. 2020. Characteristics and management of brackishwater pond soil in South Sulawesi Province, Indonesia. *IOP Conference Series: Earth and Environmental Science* 564:012021. <https://doi.org/10.1088/1755-1315/564/1/012021>
- Nobre, M.K.B., Lima, F.R.S., Magalhães, F.B., Sá, M.V.do C.e. 2014. Alternative liming blends for fish culture. *Acta Scientiarum. Animal Sciences* 36:11–16. <https://doi.org/10.4025/actascianimsci.v36i1.21282>
- Pagani, A., Mallarino, A.P. 2011. Comparison of methods to determine crop lime requirement under field conditions. *Soil Science Society of America Journal* 76:1855–1866. <https://doi.org/10.2136/sssaj2011.0327>
- Pillai, V.K., Boyd, C.E. 1985. A simple method for calculating liming rates for fish ponds. *Aquaculture* 46:157–162. [https://doi.org/10.1016/0044-8486\(85\)90199-1](https://doi.org/10.1016/0044-8486(85)90199-1)
- Queiroz, J.F., Nicolella, G., Wood, C.W., Boyd, C.E. 2004. Lime application methods, water and bottom soil acidity in fresh water fish ponds. *Scientia Agricola* 61:469–475. <https://doi.org/10.1590/S0103-90162004000500001>
- Rajts, F., Shelley, C.C. 2020. Guidelines for managing aeration and water quality in fish hatcheries and nurseries in Bangladesh. *Guidelines: 2020–35*. WorldFish, Penang, Malaysia. 24 pp.
- Rizal, S., Hutabarat, J., Anggoro, S., Prayitno, S.B. 2020. Brackish water pond management strategies based on salinity and pyrite distribution in the Mahakam Delta, East Kalimantan. *IOP Conference Series: Earth and Environmental Science* 584:012052. <https://doi.org/10.1088/1755-1315/584/1/012052>
- Rouse, R.D. 1979. *Water quality management in pond fish culture*. Research and Development Series No. 22, Auburn University, Alabama, USA. 32 pp.
- Sá, M.V.C., Boyd, C.E. 2017. Dissolution rate of calcium carbonate and calcium hydroxide in saline waters and its relevance for aquaculture. *Aquaculture* 469:102–105. <https://doi.org/10.1016/j.aquaculture.2016.11.033>
- Sá, M.V.C., Cavalcante, D.H., Lima, F.R.S. 2019. Dissolution rates of hydrated lime, Ca(OH)<sub>2</sub> in fresh, oligohaline, mesohaline and euhaline waters and its significance for liming of shrimp culture ponds. *Aquaculture Research* 50:1618–1625. <https://doi.org/10.1111/are.14039>
- Sá, M.V.C., Cavalcante, D.H., Lima, F.R.S. 2021. Total buffering capacity

- of CaCO<sub>3</sub>-undersaturated and saturated waters buffered with agricultural limestone or hydrated lime and its importance to the liming of shrimp culture ponds *Aquaculture* 536:736455. <https://doi.org/10.1016/j.aquaculture.2021.736455>
- Schaepferclaus, W. 1933. Textbook of pond culture. In: Lime requirement of Alabama fish ponds, Bulletin 459, Boyd, C.E. (Ed.). Agricultural Experiment Station/Auburn University, Auburn, Alabama. 20 pp.
- Shoemaker, H.E., McLean, E.O., Pratt, P.F. 1961. Buffer methods for determining lime requirements of soils with appreciable amounts of extractable aluminum. *Soil Science Society of America Journal* 25:274-277. <https://doi.org/10.2136/sssaj1961.03615995002500040014x>
- Silapajarn, K., Silapajarn, O., Boyd, C.E. 2005. Evaluation of lime requirement procedures and liming materials for aquaculture ponds in Thailand. *Journal of Applied Aquaculture* 17:77-88. [https://doi.org/10.1300/J028v17n03\\_06](https://doi.org/10.1300/J028v17n03_06)
- Simpson, H.J., Pedini, M. 1985. Brackishwater aquaculture in the tropics: the problem of acid sulfate soils. FAO Fisheries Circular No. 791. 32 pp. <https://www.fao.org/4/R5676E/R5676E00.htm>
- Singh, V.P., Poernomo, A.T. 1984. Acid sulfate soils and their management for brackishwater fishponds. In: *Advances in milkfish biology and culture*, Juario, J.V., Ferraris, R.P., Benitez, L.V. (Eds.). Island Publishing House, Manila, pp. 121-132.
- Tan, K.H. 2005. Soil sampling, preparation, and analysis. CRC Press, Boca Raton. 672 pp. <https://doi.org/10.1201/9781482274769>
- Tarunamulia, T., Mustafa, A., Paena, M. et al. 2024. Soil remediation and nano-biosilica: a potential combination to improve the environmental quality of brackishwater aquaculture ponds affected by acid sulfate soils. *Environmental Science and Pollution Research* 31:54574-54588. <https://doi.org/10.1007/s11356-024-34757-x>
- Thomaston, W.W., Zeller, H.D. 1961. Results of a six-year investigation of chemical soil and water analysis and lime treatment in Georgia fish ponds. In: *Proceedings of the annual conference of the Southeastern Association of Game and Fish Commissioners* 15, pp. 236-245.
- Trivedi, T.P. 2011. Handbook of fisheries and aquaculture. 2<sup>nd</sup> edition. Indian Council of Agricultural Research, New Delhi, India. 1116 pp.
- Wurts, W.A. 2002. Alkalinity and hardness in production ponds. *World Aquaculture* 33:16-17.
- Wurts, W.A., Durborow, R.M. 1992. Interactions of pH, carbon dioxide, alkalinity and hardness in fish ponds. SRAC publication No. 464. Southern Regional Aquaculture Center. 4 pp.
- Wurts, W.A., Masser, M.P. 2013. Liming ponds for aquaculture. SRAC publication No. 4100. Southern Regional Aquaculture Center. 7 pp.