

INFLUENCE OF LIME MATERIALS TO AMELIORATE ACIDITY ON IRRIGATED PADDY FIELDS: A REVIEW

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ABSTRACT

The importance of lime application to ameliorate acidity on paddy field has been reviewed. Emphasis is placed on acid sulfate commonly found in Southeast Asia and other related areas to which reference could be found. Most of the authors show that in acid sulfate soils, high content of Al caused adverse effect to rice growth. Application of lime precipitates Al and Fe in the soil and result in higher rice yield. The paper specifically covers the extent and types of acid sulfate soils, amelioration using lime and other combinations in rice cultivation and management.

Keywords: acid sulfate soil, acidity, irrigation, lime materials, paddy field

INTRODUCTION

Lowland rice is being cultivated on approximately 128 million hectares of irrigated and rain fed land (Maclean *et al.*, 2002). As many as 100 million hectares show some sort of nutritional constraint to rice growth caused by either nutrient deficiencies or toxicities (Brady, 1982). Among the toxicities, iron toxicity is well-recognized as the most widely distributed nutritional disorder in lowland-rice production (Dobermann and Fairhurst, 2000). On acid soils, iron toxicity is one of the most important constraints to rice production, and together with Zn deficiency, it is the most commonly observed micronutrient disorder in wetland rice (Neue *et al.*, 1998). Under the conditions prevailing in the acid sulphate soils, silicate minerals in them disintegrate and weather, releasing elements (including Al and Fe). In the soil under paddy field in Malaysia, Al concentration was very high. Aluminium, whose pKa value is 5.0, had hydrolysed in water to produce protons (Shazana, *et al.* 2011).

Rice grown in acidic soils $\text{pH} < 4.0$ commonly encounter relatively severe mineral stresses. The H^+ associated with soil acidity has indirect effects on mineral elements in low pH soils so that deficiencies of P, Ca, Mg, K, and Zn and toxicities of Al and Mn commonly appear (Clark *et al.*, 1999). Of the deficiencies/toxicities that plants may encounter when grown in acidic soil, Al toxicity is considered to be the major disorder (Foy, 1992). Aluminium is highly soluble at low pH and is toxic to plants at relatively low concentrations. It also interacts with other mineral nutrients essential to plant growth, especially P, Ca, and Mg, so that these essential nutrients often become more limiting. Not only is excess Al damaging to root growth and development (Foy, 1992), but Al as well as Fe oxides so prevalent in acidic soils (Manning and Goldberg, 1996) adsorb P and make it unavailable to plants. Poor fertility of acid soils is due to a combination of mineral toxicities (aluminum and manganese) and deficiencies (phosphorus, calcium, magnesium, and molybdenum).

However, Al toxicity is the single most important factor, being a major constraint for crop production on 67% of the total acid soil area (Eswaran *et al.*, 1997).

In the tropical Africa and Asia most of the available land for rice expansion is that of acid sulphate soils. (Masulili and Utomo, 2010) reports that, these soils have a high iron sulfate mineral content of predominantly pyrite, and when the soil is drained it will release sulfuric acid, which in turn release Fe, Al, and other heavy metals that are dangerous for plants and other living organisms. Moore (1990), found that when these soils are used for rice the most important constraints were: (i) acidity (which

includes the combined effects of pH, Al toxicity, and P deficiency), and (ii) Fe stress (which is due to the combined effects of Fe toxicity and deficiencies of other divalent cation such as Ca).

According to Scott, et al., (2010), when mismanaged acid sulfate soils can severely degrade the quality of coastal water via acidification, de-oxygenation, and metal toxicity. A commonly treatment to reduce the solubility of Al, Fe and other heavy metals in soil is to increase the soil pH. Acidity and Al toxicity in surface soil can be ameliorated through liming. A liming material is defined as a material whose Ca and Mg compounds are capable of neutralizing soil acidity (Barber and Adams, 1984). The bulk of agricultural lime comes from ground limestone, and can be calcite (CaCO_3), dolomite (CaCO_3 , MgCO_3), or a mixture of the two. Other materials are used to neutralize soil acidity, including marl, slag from iron and steel making, flue dust from cement plants, and refuse from sugar beet factories, paper mills, calcium carbide plants, rock wool plants, and water softening plants (Thomas and Hargrove, 1984). However, total use of these materials is relatively small, and they are generally applied only in areas close to their source. Therefore, this paper attempts to review the importance of lime application on irrigated paddy field for management of acid sulfate soil.

EXTENT AND DISTRIBUTION OF ACIDITY

Throughout the world where the water table has been dramatically and suddenly lowered in sulphide-rich soils, the results have been production of extreme acidity from sulphides and transport of enormous quantities of acid and metals into the surrounding environment (Bloomfield and Coulter, 1974; Dost and Pons, 1970; Hart *et al.*, 1963; Moormann, 1961; Roos and Astrom, 2006; Team, 1973).

Table 1: Areal extent of acid soils for the regions of the World

Class	World	Africa	Australia / New Zealand	Europe	Near East	Far East	South east/ Pacific Asia	North / Central Asia	America		
									North	Central	South
Acid land (* 10^9 ha)	3.95	0.66	0.24	0.39	0.005	0.21	0.31	0.51	0.66	0.04	0.92
Total land(* 10^9 ha)	13.15	3.01	0.82	0.48	0.50	1.48	0.40	0.85	2.11	0.10	1.75
Acid/ Total (%)	30	22	30	37	1	12	63	57	30	35	52
Cultivated land (* 10^9 ha)	1.40	0.158	0.032	0.15			0.52		0.24		0.08
Cultivated (%)	10.60	5.20	3.90	32.10			18.90		11.30		4.40

Source: After (Uexküll and Mutert, 1995)

Worldwide, the total harvested area of irrigated rice is about 79 M ha, (Dobermann and Fairhurst, 2000), with 43% (34 M ha) in East Asia (China, Taiwan, Japan, Korea), 24 M ha in South Asia, and 15 M ha in Southeast Asia. The countries with the largest areas of irrigated rice are China (31 M ha), India (19 M ha), Indonesia (7 M ha), and Vietnam (3 M ha). For decades, soil acidity has been a major constraint to crop production throughout the world. Several authors have published evidence on the extent of acidity on natural forest, areas under cultivation and grassland vegetation. (Sumner *et al.*, 2003) estimates that the total area of top soils affected by acidity throughout the world vary from 3.777×10^9 to 3.950×10^9 ha, representing approximately 30% of the ice-free land area of the world.

The total area affected by subsoil acidity is estimated at 2.918×10^9 ha (Eswaran, et al., 1997), meaning that approximately 75% of the acid soils of the world suffer from subsoil limitations due to acidity. Acid soil distribution by region in relation to cultivated land area is presented in Table 1. On global level acid sulfate soils occupy an area of over 17 million ha, (Roos and Astrom, 2006)

including large extensions in Africa with approximately 4.5 million ha, (e.g Nigeria, Senegal, Gambia, Madagascar and Guinea Bissau), Asia approx. 6.5 million ha, (e.g Vietnam, Indonesia and Thailand), Australia approx. 3.0 million ha, (mainly Queensland) and Latin America with approx. 2.8 million ha, (e.g Brazil, Central America and Venezuela). In Europe the largest occurrences are found in Finland and Sweden, approx. 460 000 ha ((Oborn, 1989)Oborn 1986, (Palko, 1994).According to (JanjirawuttikuL *et al.*, 2010), Dawson, (2009),(Khan *et al.*, 1994), (Van Breemen, 1982) and Beek *et al.*, (1980) acid sulfate soils have a worldwide distribution, estimated at 120,000-140,000 km² and are mostly distributed in Southeast Asia, particularly Indonesia. However, (Dent and Pons, 1995), revealed that estimates of the extent and distribution of acid sulphate soils suffer more from scant field survey.

TYPES OF SOIL ACIDITY

Acidity can be classified as active (in which only H⁺ is referred to in the soil solution) or exchangeable acidity which includes Al³⁺. Measurement of acidity in water and soil is commonly achieved from pH scale. The term pH stands for the potential (p) of the hydrogen ion (H⁺) in water. It is measured based a scale from 1 to 14 as shown in Figure 1. The value of pH varies with depth and from one spot in the field to another. Soils may have different pH value due to factors like climate, living organism, parent material, topography and time. (Sumner, *et al.*, 2003) have categorised acid soils into two classes, the naturally occurring acid soils and the anthropogenically derived acid soils. The anthropogenic acid soils exist from either acid deposition, intensively managed row crop agriculture or from pasture systems ((Sverdrup *et al.*, 1994), (Bouman *et al.*, 1995) and (Johnston *et al.*, 1986). (Benham, 1997), (Uexküll and Mutert, 1995) reports that, the naturally occurring acid soils are those formed due to intensive weathering, soil form from parent materials poor in basic cations and acid sulphate soils. However, (JanjirawuttikuL, *et al.*, 2010) recognized five different kind of acid sulfate soil. This is based on the definition of acid sulphate soil given by some authors like Pons (1973),(Fanning, 2002) and the (Staff, 2006). The distinct characteristics were divided into:

Potential Acid Sulphate Soil

Soil with pH value greater than 3.5 and that, after being air-dried slowly in the shade, shows a drop in pH of 0.5 or more units to pH value of 4.0 or less (1:1 water) within 8 weeks; no observation of jarosite and redoximorphic features.

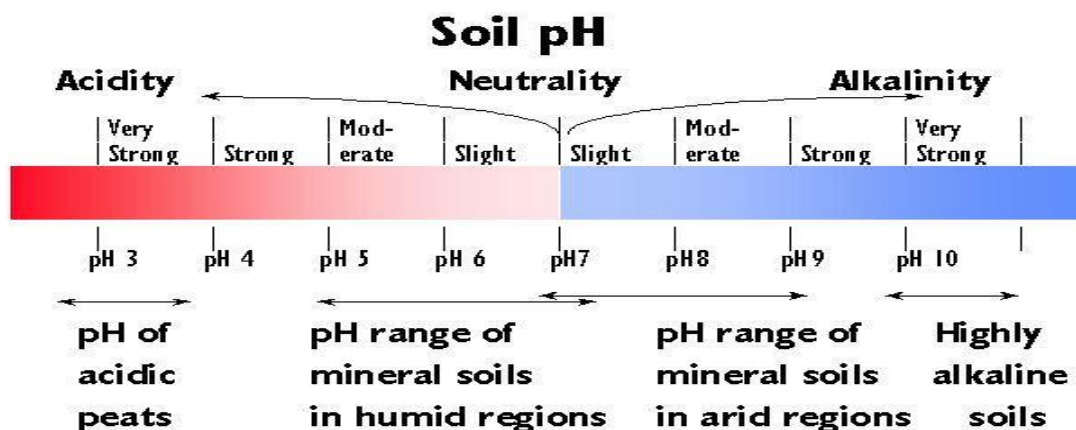


Figure 1. Range of acidity levels on Soil pH scale (Source: Mitchell, 2000)

Active Acid Sulphate Soil

Soil with a very low pH of 3.5 or less and commonly containing a concentration of jarosite and/or directly underlying the potential acid sulphate soil.

Post- Active Acid Sulphate Soil

Soil with a field pH greater than 3.5 but having a similar appearance as active acid sulphate soil in containing a concentration of jarosite and/or directly underlying the potential acid sulphate soil.

Transitional Soil

soil that has immediate properties between that of sulphide mud and non-acid sulphate soil; it has high field pH value and shows a dramatic drop to a very low pH, generally to 4.0-5.0, after drying.

Non-Acid Sulphate Soil

It is any soil not defined above.

RESULTS AND DISCUSSION

Amelioration Measures

Most acid sulphate soils belongs to fertile river alluvial soils fields and are suitable for rice culture, these lands can be improved for more rice cultivation to increase food production in the tropical deltas where they are most extensive. Several authors (Chang, 1961), (Attanandana and Vacharotayan, 1986), Charoenchamratcheep, et al., (1980), Shamshuddin, et al., (1986) Mitchell (2000) Chanchareonsook and Wada (2008), have mentioned amelioration measures, other products and by-products which may also be used to increase soil acidity. This includes:

- a. Pure CaCO_3
- b. Quick lime, burned lime, or oxide lime
- c. Calcitic agricultural lime, (CaCO_3 + Impurities)
- d. Dolomitic agricultural lime
- e. Ground oyster shells
- f. Marl or Selma chalk
- g. Burned lime, quick lime or oxide lime
- h. Hydrated lime or builders lime
- i. Basic slag
- j. Wood stove or fire place ashes
- k. Boiler wood ash
- l. Leaching and drainage
- m. Submergence
- n. Manganese dioxide addition
- o. By-products used as specified by manufacturer
- p. Addition of fertilizers (phosphorus, Nitrogen, Potassium and Copper)
- q. Use of resistant varieties
- r. Filter cake

Effects of lime materials on acid sulfate management

Ground lime or aglime, mostly in the form of CaCO_3 or $\text{CaCO}_3 + \text{MgCO}_3$, has been the traditional material for liming in acid sulfate soils. The fundamental reasons for using aglime are to increase soil pH (neutralize soil acidity), and add calcium and magnesium to the soil. However, it must be ground very finely since carbonates are not very soluble in water. The quantity of lime applied depends upon type of soil, quality of liming material, crop species/cultivar, and cost (Fageria and Baligar, 2001). Rice favours a pH between 4 to 8 with an optimum value of around 6 (FAO, 1979). Low pH is a characteristic feature in acid sulphate soils. Acid sulphate soil reclamation could be accomplished by many methods. Most important way to avoid building up of sulphuric acid levels is the prevention of oxygen penetration to iron sulphide layer. Cho, et al, (2002) mentioned that this could be accomplished practically by flooding, controlled irrigation, formation of sub-soil hard pan either with the use of heavy machinery or paddling and silting with the use of traditionally made cattle or buffalo driven implement or both.

Flooding has the beneficial side effect of transferring acidity from soil to surface water by oxidation of $\text{FeII}\text{SO}_4(\text{aq})$ at the soil-water interface, followed by precipitation of Fe III oxide on the soil surface and

release of H_2SO_4 into the surface water (van Breemen, 1975). This often depends on irrigation water availability and adequate scheduling. If water is a scarce resource and competitive, to keep water flooding during crop growth is difficult and acidification become eminent. Millar et al, (1987) reports that, in acid sulphate soils liming could be done at any time. Therefore, intermittent application of lime would be a measure to raise and maintain soil pH to favour the growth of crops in acid sulphate soils. Liming at suitable intervals would help the grower to optimize yield since pH changes could be monitored-in time to time. However, in the field, ground basalt takes longer time to disintegrate and dissolve (Shamshuddin and Fauziah, 2010). In the case of acid sulphate soils, the pH is less than 3.5, and as such, ground basalt is expected to dissolve faster and is therefore be more effective as an acid soil ameliorant (Shazana, et al. 2011).

According to van Breemen, (1993), in liming the amount of base to neutralize the acidity produced by oxidation of one per cent of oxidizable sulphur is in the order of 30 tons of $CaCO_3$ per ha per 10 cm of soil of bulk density $10^3 kg m^{-3}$. Exchangeable cations provide a neutralizing capacity equivalent to between 3 and 30 tons of $CaCO_3$ on the same basis, depending on clay content and mineralogy (Dent 1986). Any oxidizable sulphur in excess of that can be removed only by leaching or liming. Considering that contents of oxidizable sulphur are commonly between 1 and 5 per cent, this illustrates the huge amount of lime that would be needed if reclamation of acid sulphate soils depended on it. In practice, liming is efficient only after most of the water-soluble acidity has been leached. At least in case of lowland rice, applications of 2 to 10 ton of $CaCO_3 ha^{-1}$ on leached acid sulphate soils often have a distinct beneficial effect, while larger doses are rarely economical, (van Breemen, 1993). Although ground limestone may have a calcium carbonate equivalency (CCE) of 100% (pure $CaCO_3$), it may be only 67% effective at neutralizing soil acidity because of some coarse particles (Clemson, 1999).

Some research reports using pot experiment have shown that liming is the simplest way of increasing the pH of the soil. Attanandana and Vacharotayan, (1986), reported the beneficial effect of leaching and liming on the rice yield on two flooded acid sulfate soils Table 2. Another advantage of using liming by Attanandana et al., (1981), shows availability of most plant nutrients, Table 3 in which, P, K, Ca, and Mg increased while Na, S, Al, Fe in the plant decreased due to liming.

Table 2: Effect of liming and leaching on the yield of rice on two acid sulfate soils

Treatment	Yield (g/pot)			
	Vietnam soil		Philippines soil	
	Grain	Straw	Grain	Straw
Control	21	24	0	0
Lime to pH 5.5	64	64	79	76
Leached + lime	88	78	83	82

Source: After Attanandana and Vacharotayan, (1986)

Table 3: Influence of liming on rice nutrients grown on two acid sulfate soils

Soils	P	K	Ca	Mg	Na	S	Si	Al	Fe	Dry weight
								(ppm)		(g/pot)
	(%)									
Rangsit very acid	0.18	1.25	0.43	0.33	1.00	0.76	2.1	255	215	73
Rangsit very acid + lime	0.22	1.85	0.70	0.42	0.53	0.49	2.2	133	152	91

Source: After Attanandana et al., (1981)

Table 4: grain yield of rice at the 3rd cropping season

Treatment	Without lime (kg/ha)	With lime (kg/ha)
DAP ₀	612.5	1506.6
DAP _{18.5}	431.5	1618.8
DAP _{37.5}	637.5	2443.8
DAP _{75.0}	956.3	2556.3
RP ₀	362.5	1412.5
RP _{18.0}	800.0	1618.8
RP _{37.5}	912.5	2600.0
RP _{75.0}	775.0	2418.8

Source Attanandana et al., (1990)

CONCLUSION

At pH5, Al in the soil solution starts to precipitate. This reaction could have occurred as soon as ground magnesium Limestone GML or ground basalt was applied onto the acid sulphate soil; they immediately disintegrated and subsequently dissolved to release hydroxyls. In their experiment Shazana, et al. (2011), the increase in solution pH resulting from GML application was due to the production of hydroxyl ions that were hydrolysed.

According to Brady (1973), there are a number of techniques for the reclamation of acid sulfate soils. Experiments in pots and in the field confirm that these treatments do improve yield, but little information is available on long-term reclamation. Controlling the water table and using lime are the most promising techniques; selecting rice varieties tolerance to ferrous iron toxicity could be worthwhile. In their conclusion, Charoenchamratcheep, et al., (1980) report that rock phosphate with ammonium sulfate showed a lower net profit than marl with ammonium phosphate. The result was strongly influenced by the fact that the price of rock phosphate is about 40 times as high as that of marl (1,600 Baht VS. 40 Baht per ton). It is recognized that lime and fertilizer are only two of the many factors needed for high production.

However, Shazana, et al. (2011) concludes that ground basalt has an additional advantage over GML because it contains other plant nutrients (K and P). The only problem with ground basalt is that it takes time to dissolve completely in soil. Some acid sulphate soils in Malaysia contain low amount of organic matter. It is therefore recommended that in order to ameliorate the infertility of acid sulphate soils for sustainable rice production, ground basalt should be applied in combination with organic fertilizer a few months ahead of the growing season.

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