



Ameliorants for the Management of Soil Acidity - A Review

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Abstract

Soil acidity is one of the major yield limiting factors in rice crop production. The H^+ and Al^{3+} ions in the soil must be neutralized by the release of OH^- ions on application of liming materials for the management of soil acidity. Liming material is the substance, which can increase the soil pH by combining with H^+ ions in the soil solution. Lime is the most widely used ameliorant for management of soil acidity. There are alternative products, such as dolomite, rice husk ash, gypsum, phosphogypsum and calcium magnesium silicates having high reactivity than lime in increasing the pH, supply of nutrients like Ca, Mg, Si *etc.*, and have the potential to reduce iron and aluminium toxicity and reduce methane emission. Fineness and chemical purity of the liming material are the major factors affecting the ability of the material to neutralise soil pH. Method and timing of application of liming material depend on the place of origin, nutrients and other elements associated with it, and amount of neutralising power. Relative worth of the liming material also depends on the cost of the same.

Key words: Soil acidity, Limestone, Dolomite, Calcium silicate, RHA, Phosphogypsum.

Introduction

Soil pH is the measurement of acidity or alkalinity of the soil pH stands for *potential of hydrogen* and is expressed as number from 0 to 14 and H^+ concentration is expressed in g/l. The term was first proposed by Sorensen, a Danish chemist in 1909, which gives the measurement of the hydrogen (H^+) ion concentration in soil water and is expressed as the negative common logarithm of H^+ concentration in the soil. It is an index of the activity of H^+ as it interacts with soil components, nutrients in the soil solution and plants growing in the soil. It is an important factor in the soil influencing nutrient availability, microbial activity and numerous soil chemical reactions and processes.

Soil acidity

When the concentration of H^+ ions in the soil increases, the soil pH decreases and acidity increases.

When the soil pH is lower than a neutral pH, it is said to be acidic. Because of the logarithmic scale, a small decrease in soil pH value denotes a large increase in acidity. The soil with pH of 4 is 10 times more acidic than a soil with pH of 5, hundred times more acidic than a soil with pH of 6 and thousand times more acidic than a soil with pH of 7. The main causes of soil acidity are acidic parent material, high rainfall and leaching of basic cations, decomposition of organic matter, application of acidic fertilizers and removal of basic cations by crops. About 15 Mha of rice soils in India are acidic with toxicity of Fe, Al, Mn and deficiency of K, Ca, Mg, B, Si, and problem of P fixation (Srinivasarao *et al.*, 2017).

Soil acidity due to concentration of hydrogen (H^+) in the soil solution is called active acidity (Getaneh and Kidanemariam, 2021). Active acidity is determined by

measuring pH of soil water suspension or extract from soil during routine soil test. It is the concentration of H^+ ions in the soil solution when measured in 1:2.5 soil to water ratio mixture. However, all H^+ ions are not released immediately from the soil into solution. Soil acidity due to the portion of the H^+ ions that remains attached or adsorbed to negatively charged exchange sites on clay and organic matter particles is called exchangeable acidity or salt replaceable acidity (Agegnehu *et al.*, 2019). Exchangeable acidity may be defined as the acidity due to hydrogen (H^+) and aluminium (Al^{3+}) ions retained on the exchange complex of the soil, *i.e.*, adsorbed on the surface of soil colloids and organic matter, which will supplement the H^+ ions in soil solution when depleted by neutralization. This acidity is also called reserve acidity because H^+ can be released into solution, as soil solution conditions change due to moisture changes and concentrations of dissolved ions and salts (Cihacek *et al.*, 2021). Accurate estimation of lime requirement of a soil is done by the measurement of reserve acidity. Reserve acidity can be measured by the addition of a dilute calcium chloride solution (0.01 M $CaCl_2$) or a buffer to the water pH suspension. The active acidity is in equilibrium with the exchangeable acidity permitting the ready movement from one form to another form and the aluminum and hydrogen that are removed from the soil solution will be replenished by the adsorbed aluminum and hydrogen ions on the exchange sites. The reserve-to-active acidity ratio refers to the soil's buffer potential or the ability to soil to resist pH change as an acid or base is added to the soil. Soils having more cation exchange sites can hold more H^+ ions and thus resist a decrease in pH. Once these soils became acidic, these soils can also resist the pH increase on lime application by releasing the H^+ ions from the soil surfaces into the soil solution. Buffering capacity of sandy soil, or its reserve acidity, is much lower than that of a soil that contains more

clay, like silt loam. Soils with high CEC (20% 2:1 type clay and 6% OM) resist acidification better than soils with low CEC (sandy loam with 2% OM and 10% kaolinite) and therefore, lime requirement of clay loam will be higher than that of sandy loam with same pH value (Weil and Brady, 2022). Soils with high CEC will require more lime in order to increase the pH to the desired level.

The acidity associated with non exchangeable aluminum and hydrogen ions that are bound to soil colloids by organic matter and silicate clay, which remains in the soil after active and exchange acidity has been neutralized is called residual acidity. The potential acidity is the sum of exchangeable and non-exchangeable acidity. The potential acidity and the active acidity contribute to total acidity in the soil.

Effect of soil acidity on nutrient availability

According to Tandzi *et al.*, (2018), acid soils are characterized by the presence of toxic heavy metal elements like iron, copper, manganese, zinc, aluminum, lack of essential nutrients like phosphorus, potassium, calcium, magnesium, sodium and low soil pH which can generate excesses of aluminum, iron, and manganese. Primary nutrients *viz.*, nitrogen, phosphorus and potassium have low availability at strongly acidic pH values. Nitrogen uptake in the NO_3 form is best at acidic pH, while NH_4^+ is absorbed more efficiently at a neutral pH. Phosphorus becomes insoluble aluminium or iron compounds at low pH. Among the secondary nutrients, Ca and Mg are less available in acid soils, while the SO_4^- ion form of sulfur is retained better by acidic soils. Availability of all the micronutrients decreases as pH rises, except for molybdenum (Mo). Zn, Cu and Mn availability decreases 100-fold in concentration with every one unit increase in pH (Miller, 2016). At high pH, Fe and other micronutrients (except Mo) are rendered unavailable since they are locked up as insoluble hydroxides and



carbonates. Iron and aluminum availability increases as soil acidity increases and aluminum become toxic to plants at pH values less than 5. Al, Fe, and Mn become more soluble and can be taken up by roots and thus become toxic to plants at low pH. As pH increases, their solubility decreases and precipitation occur. Plants may suffer deficiencies as pH rises above neutrality (Sparks, 2003). High Al and Fe oxides and hydroxide in low soil pH are responsible for P fixation, making it unavailable to plants Rastija *et al.*, (2014) reported that liming with dolomite raised the soil pH, affected soil chemical properties and resulted in great increases of plant available phosphorus. They also observed that potassium availability in the soil was independent of liming. The nutrient availability at different soil pH is given in the **Figure 1**.

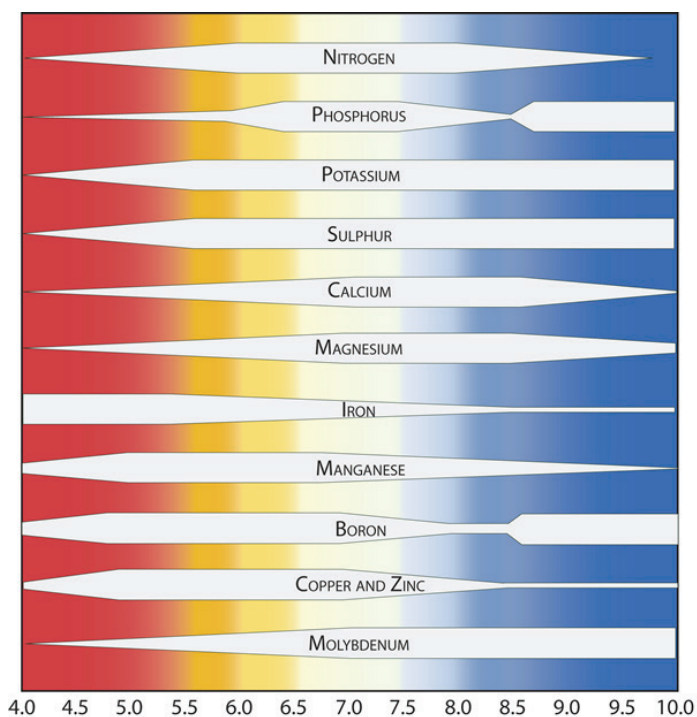


Figure 1: Nutrient availability for plant use at different soil pH
(Source: TNAU Agritech Portal)

Management of acidity

H^+ and Al^{3+} ions in the soil must be neutralized for the management of acidity by the release of OH^- ions on application of liming materials. A liming material is the substance which can increase the soil pH by

combining with H^+ ions in the soil solution. Acid sulphate soils will be suitable for crop production only by the addition of amendments to correct the acidity. The chemical and physical properties of acid sulfate soils can be improved by adding soil ameliorants for increasing the pH value, increasing nutrient availability, and improving water content and soil permeability (Maftuah *et al.*, 2023). Beena *et al.*, (2013) reported that for the amelioration of acid sulphate soils, special management practices such as liming and washing out of water, bunding, providing subsurface drainage *etc.*, must be undertaken. Application of liming materials at the rate of 6.0 to 12.5 tha^{-1} and leaching can reduce soil acidity to a great extent in acid sulphate soils of Kuttanad (Neenu *et al.*, 2020). The most economical method of ameliorating soil acidity is liming. Limestone is the widely used ameliorant. However, there are alternative products, such as dolomite, rice husk ash, gypsum, phosphogypsum and silicates. Ananthanarayana and Hanumantharaju, (1993) observed that CaO , $Ca(OH)_2$ and $CaCO_3$ reduced soil acidity at a rapid rate with maximum rate of reaction during the first week, while dolomite, and basic slag neutralize the soil acidity after about two months' time. Common liming materials used for management of acidity and their $CaCO_3$ equivalent are given in **Table 1**.

Table 1: Common liming material and their $CaCO_3$ equivalent

Common name of liming material	Chemical formula	% of $CaCO_3$ equivalent
Calcitic limestone	$CaCO_3$	100
Dolomitic limestone	$CaMg(CO_3)_2$	95-108
Burnt lime	CaO	178
Hydrated lime	$Ca(OH)_2$	134
Basic slag	$CaSiO_3$	70-90
Marl	$CaCO_3$	40-70
Wood ashes	$CaO, MgO, K_2O, K(OH)$	40-80

Source: (Weil and Brady, 2022. *The Nature and Properties of Soils*)

Limestone

Soil acidity can be corrected easily by adding liming materials like calcitic limestone (CaCO_3) having neutralizing value of 100, and less frequently used other liming materials like burned lime (CaO), hydrated lime [$\text{Ca}(\text{OH})_2$] with neutralizing value of 179 and 136, respectively (Peters *et al.*, 1996). Lime which is made from calcium and carbonate in its most pure form, on application to acidic soils, increases availability of calcium (Mohammed *et al.*, 2021). According to Christenson *et al.*, (1993) lime applied to soil neutralizes acidity, supplies calcium to the soil and increases the availability of nitrogen, phosphorus, potassium, magnesium, sulfur, boron and molybdenum. According to Fageria and Baligar (2008), the most suitable method for lime application is broadcasting as uniformly as possible and mixing thoroughly through the soil profile. Lime, which is usually broadcasted on the soil surface and mixed with soil at the time of tillage, dissolves in water and hydrolyzes to form OH^- ions that can subsequently react with both H^+ ions formed from hydrolysis of Al^{3+} and exchangeable Al^{3+} (Thakuria *et al.*, 2016). When liming materials such as calcium carbonate is added to the soil, the calcium replaces the H^+ and Al^{3+} on the exchange sites and the carbonates neutralize these H^+ and Al^{3+} . The action of lime applied to soil to neutralize soil acidity and increase crop yields by the improvement of chemical attributes in the soil, is restricted to the topsoil (up to 0-20 cm) due to slow reaction in soil (Amaral *et al.*, 2004). Devi *et al.*, (2017) has reported that application of lime, dolomite or rice husk ash increased the soil pH or reduced acidity along with improvement in soil available P in very strongly acidic soils of Vaikom Kari in Kuttanad region of Kerala. Tang (2004) reported that liming cannot ameliorate subsoil acidity because of the slow movement of lime down soil profiles and deep placement of lime for amelioration of subsoil acidity is not economically feasible. The

lime requirement of a soil depends on the change in the pH required, the buffering capacity of the soil and the quality and degree of fineness of the liming material.

Dolomite

Dolomite is a natural sedimentary rock derived ameliorant and pure dolomite minerals contain 45.6% MgCO_3 or 21.9% MgO and 54.3% CaCO_3 or 30.4% CaO . (Farhati *et al.*, 2023). Dolomitic limestone made from rocks containing a mixture of Ca and Mg carbonates is comparatively cheaper liming material imported from the neighbouring states with neutralizing value of 109. Application of dolomite to soil can supply two essential nutrients calcium and magnesium to the plants. According to Devi *et al.*, (2017) dolomite and lime application in very strongly acidic soils of Vaikom Kari in Kuttanad region in two splits, as basal and 30 days after sowing, improved soil available Ca and Mg at both stages.

Dolomite application @ 2 t/ha along with steel slag @ 2.5 t/ha could increase the weight of 1000 grains in rice plants. (Farhati *et al.*, 2023). Hartatik *et al.*, 2023 reported that improvement of acid sulfate soils can be achieved by application of dolomite @ 4-6 tons ha^{-1} and micronutrients, to increase soil pH or decrease the soil acidity to the optimum level needed for plant growth. Shaaban *et al.*, (2014) observed that in a laboratory study with soil from rice paddy-rapeseed rotation and from rice paddy-fallow-flooded rotation, dolomite application not only counteracts soil acidification but also has the potential to mitigate N_2O emissions in acidic soils. According to Shaaban *et al.*, (2016), dolomite application to the acidic soils has the potential to enhance the CH_4 uptake at low moisture levels and to decrease the emissions of CH_4 at higher moisture levels and N fertilizer application. Dolomite application increased soil pH and increased rate of emission of CO_2 due to the priming microbial



decomposition of native organic matter resulting in greater availability of organic C and mineral N (Shaaban *et al.*, 2017).

Calcium silicate

Calcium or magnesium silicates (slags) are by-products of various industries like iron and steel. As silicate anions (SiO_3^{2-}) have the same valency as carbonate anions (CO_3^{2-}) from the limestone, slags have the same potential to correct soil acidity as limestone with a neutralizing value of 86% (Korndorfer *et al.*, 2003). Alcarde and Rodella (2003) reported that calcium silicate has higher potential for the correction of soil acidity in the subsurface than lime since it is 6.78 times more soluble than calcium carbonate. Silicates have greater reactivity, thus neutralizes soil pH faster than lime and products from silicate dissociation reach deeper layers of soil than lime and can correct a thicker soil layer further down in the soil improving the possibility of plant deepening the root system and absorbing more nutrients. Nolla *et al.*, (2013) reported that use of slag results in formation of monosilicic acid (H_4SiO_4), which dissociates less than H^+ adsorbed to the exchangeable cation capacity and therefore, soil pH increases.

Silicate is an efficient source for acidity correction because it increases the number of exchangeable bases in the soil equivalent than lime. Calcium and magnesium silicates on application to the soil release calcium, magnesium and silicate ions in the soil solution and thus increase the availability of silicon, calcium, magnesium and phosphorus concentrations for plants and increase the yield. Silicate is more efficient than lime by its efficiency in increasing the phosphorus availability, reducing aluminum toxicity, improving mineral nutrition by supply of Ca and Mg reflecting in higher yield (Castro and Crusciol, 2013). According to Castro *et al.*, (2016), increased soil silicon levels increased the P concentrations in the crop than with the lime application due to the

competition of silicon with phosphorus for anion-binding sites on soil colloids, keeping more P in the soil solution for plant uptake. Thus, by the application of silicon, more phosphorus will be taken up by the plant, and less is left in the soil. Application of slags to the soil results in the formation of hydroxy aluminium silicates thus reducing the aluminium phyto toxicity in plants. Khalid and Silva (1980), observed that, due to the formation of insoluble alumino-silicates in the soil or due to precipitation of Si on hydrated aluminium oxides, application of calcium silicate increased the soil pH, exchangeable calcium content, decreases extractable aluminium in the surface soil. Elisa *et al.*, (2016) reported that application of calcium silicate in an acid sulfate soil, increased the soil pH and was effective in alleviating aluminium toxicity and supplied substantial amounts of calcium and silicon. For effectively reducing the aluminium concentration in acid sulphate, rice-cropped soil, calcium silicate should be mixed with the top 30-cm layer. Silicates also supply silicon to the soil solution, increasing silicon availability to the plant and thereby increase the plant resistance to biotic and abiotic stresses by higher tolerance to drought, increased lodging resistance and resistance to pest and diseases. (Nolla *et al.*, 2013 and Elisa *et al.*, 2016). Studies conducted at China on the effects of silicate application on CH_4 and N_2O emissions and global warming potentials in paddy soils revealed that silicate application can reduce the contribution of enhanced UV-B radiation to global warming potentials (Lou *et al.*, 2019).

However, use of silicates in agriculture depends on the concentration of the heavy metals present in them. The expensive purification process for removing the heavy metals in products with high levels of heavy metals limits the agricultural use of slags. However, slags derived from the steel industry with low heavy metal concentration can be used in agriculture. (Korndorfer *et al.*, 2003).

Rice husk ash

Rice husk, the yellowish brown outermost layer of paddy grain obtained as a milling by-product of paddy include 37.05% carbon, 35.03% oxygen, 11.06% nitrogen, 9.01% silicon and 8.80% hydrogen (Sarangi *et al.*, 2009; Babaso and Sharanagouda, 2017). Rice husk, which has 75% organic volatile content and 17-20% silica under uncontrolled burning, gets converted into rice husk ash which is 25% by weight of rice husk (**Table 2**). Every tonne of paddy produces about 0.2 t of husk and every tonne of husk produces about 0.18 to 0.2 t of ash depending on the variety, climatic conditions, and geographical location (Kothandaraman *et al.*, 2007; Singh, 2018). Rice husk ash (RHA), one of the major by-products of rice husk burning is obtained when husk is burnt in ambient temperature and pressure condition contains 87-97% silica with small amount of alkalies and other trace elements (Yadav, 2021).

Table 2: Chemical composition of the Rice Husk Ash

Compound / Element (constituent)	Weight (%)
Silica (SiO ₂)	91.59
Carbon (C)	4.8
Calcium oxide (CaO)	1.58
Magnesium oxide (MgO)	0.53
Potassium oxide (K ₂ O)	0.39
Haematite (Fe ₂ O ₃)	0.21
Sodium (Na)	Trace
Titanium oxide (TiO ₂)	0.20

Source: (Alaneme and Adewale, 2013)

RHA is a good and cheap source of liming material as it can improve the soil pH and fertility of acidic soils (Masulili *et al.*, 2010). Preetha *et al.*, (2022) reported that rice husk ash is an environmentally favourable agricultural resource, alkaline in nature, which can raise the pH of an acidic soil and also supply nutrients to crops as it contains CO₂-0.10%, SiO₂-89.90%, K₂O-4.50%, P₂O₅-2.45%, CaO-1.01%, MgO-0.79%, Fe₂O₃-0.47%, Al₂O₃-0.46%, MnO-0.14%.

Rice husk ash (RHA) which has an alkaline pH can be used as a potential liming material as it is cheap and environmentally friendly (Devi and Swadija, 2017). Okon *et al.*, (2005) observed that RHA which has low neutralizing value was found to stir up great soil reactions with evidence of increase in effective cation exchange capacity, exchange acidity, soil pH, and rapid growth and yields and can be recommended for adoption by the resource-poor farmers as a high potential and low-external-input material for ameliorating soil acidity. Rice husk ash reacts faster than limestone though it has low effective calcium carbonate equivalent of around 3% and low neutralizing value of around 1% (Islabao *et al.*, 2014). Kath *et al.*, (2018) reported that RHA reacts much faster than conventional limestone, as all bases contained in it are dissolved immediately after their incorporation into the soil. Okon *et al.*, (2005) reported that the ability of RHA to reduce soil acidity and raise the pH of the soil to the level needed for the cultivation of most vegetables and arable crops is due to its possession of reasonable quantities of the basic cations like Ca, Mg, K, Na, and other essential elements including P and very little N. Application of combination of humic materials from water hyacinth and silicon from rice husk biochar as soil ameliorants in acid sulphate soils increased the pH and decreased aluminium and sulphate concentration in oxidised conditions, decreased iron concentration under reduced conditions and thus decreased iron, manganese and aluminum toxicity (Maftuah *et al.*, 2023). Teutscherova *et al.*, (2023) reported that the application of RHA could be considered for soil application to recycle nutrients, ameliorate soil acidity, promote plant growth and, ultimately, to reduce losses of applied nitrogen. Preetha *et al.*, (2022) reported that application of rice husk ash @ 48.5 g kg⁻¹ registered comparable soil pH with the equivalent CaCO₃ level of 5.0 g kg⁻¹ confirming the possibility of using rice husk ash as an amendment for acid soil.



Mini and Lekshmi (2020) reported that soil test based RDF + RHA @ lime (based on pH) + foliar spray of 0.5% solution of customized formulation @ 5 kg ha⁻¹ as foliar application of 0.5% solution in two splits at maximum tillering and panicle initiation stage increased the yield by 23 per cent in acid sulphate soils of Kuttanad compared to the recommended dose of lime and fertilizer application and the B : C ratio increased from 1.53 to 1.91. Gao *et al.*, (2019) reported that application of RHA to soil increases soil P availability, both by supplying P contained in the ash or indirectly by increasing soil P solubility upon soil pH increase. The application of RHA promoted higher plant biomass production than lime which had no effect on plant growth (Teutscherova *et al.*, 2023). According to Kath *et al.*, (2018), the residual effect of RHA in the pH and on the exchangeable Ca, Mg and K contents, increased with increasing the dose of RHA applied to the soil.

Gypsum

Gypsum is a mineral that is naturally found in the soil and can be mined out from the geological deposits. Gypsum is also obtained as a byproduct from many industries like flue gas desulfurization gypsum (FGD-gypsum) and Phospho gypsum. Gypsum is a good source of calcium and sulphur. Although both are sources of calcium, lime raises the pH of the soil, while gypsum does not. While calcium in gypsum can replace the H⁺ ions in the soil, sulphates cannot neutralize the hydrogen ions, these ions will remain in solution and will not adjust soil pH. Zoca and Penn (2017), reported that since gypsum is not an acid-neutralizing or acid-forming substance, depending on soil mineralogy, CEC and competing anions, the sulfate can potentially increase or decrease the pH. Gypsum can act as a soil conditioner that may be used to correct aluminum problems in the subsurface soil layers. Sneller (2011) reported that gypsum dissolution products cannot directly neutralize acidity but it is effective in reducing aluminium toxicity in soils with

pH lower than 4.5 as the sulfate may act as a counter ion on soil particles increasing aluminum absorption from the soil solution. Aluminum sulfate is less toxic to plants than the individual aluminum ion. Gypsum applied to the topsoil due to its high solubility, slowly moves down the profile and increases labile calcium levels and decreases aluminium and sodium levels in the subsoil, acts as a soil conditioner, which will improve soil structure to encourage roots to penetrate and proliferate in the subsoil resulting in higher nutrient uptake and yield. (Ritchey *et al.*, 1995). Even though the application of gypsum will not change the soil pH, it counteracts the toxic effect of soluble aluminum on root development and thus can promote better root development of crops, especially in acid soils (Dick, 2018). The problem of both deep acid subsoils and shallow acid subsoils in no-till systems where liming material cannot be incorporated can be remediated through, gypsum application due to its high solubility than lime, mobility of gypsum dissolution products, and potential to provide high rates of Ca and sulfate that can decrease Al³⁺ activity in solution (Zoca and Penn, 2017). Rate of application of gypsum depends on the purpose of gypsum application, type of soil, amount of rainfall in the region, cropping system and other potential factors (Kost *et al.*, 2014). Continuous application of gypsum can cause magnesium and sodium deficiencies in soil.

Phosphogypsum

Phosphogypsum is a byproduct of phosphate fertilizer industry formed during the production of phosphoric acid from rock phosphate. The phosphogypsum, generated from the phosphoric acid production plants is composed mostly of calcium sulphate (CaSO₄·H₂O). Phosphogypsum is more soluble than limestone, but its addition does not increase the soil pH as it cannot neutralize the replaced H⁺ ions. Caires *et al.*, (1999) reported that phosphogypsum applied to the soil surface moves along the profile under the influence of percolating water and thereby increase the supply

of calcium and reduce the aluminium toxicity in the subsoil. Phosphogypsum is therefore, an alternative for improving the root environment in the subsoil and can be used in acidic soils as a supplement for liming (Caires *et al.*, 2003). Gypsum and lime when applied together have synergistic effects. Ebimol *et al.*, (2017) observed an increase in soil pH and available calcium content by the application of phosphogypsum along with lime @ 300 kg/ha and was highly effective in lowering the toxic concentration of Fe and Al in the acid sulphate soils of Kuttanad. Costa and Crusciol (2016) observed that superficial liming with or without phosphogypsum increased the Ca^{2+} levels throughout soil profile and reduced the surface and subsurface soil acidity, five years after application in a no till system but had residual effect on the SO_4^- S levels, and high sulphate concentrations were observed in the subsoil after five years. The organic matter content increased with liming with or without phosphogypsum, indicating that in the long term, these practices can increase the carbon accumulation in the system. Application of phosphogypsum along with lime can correct both the surface and subsurface acidity. A major concern about the use of phosphogypsum is its radioactivity. However, the degree of radioactivity depends on the place from where the phosphate rock was mined (Guimond and Hardin, 1989).

Biochar

Biochar, a carbon-rich product is produced by a process known as carbonization, through thermochemical conversion of organic material or biomass materials such as crop residues, forestry waste, industrial by-product, municipal waste and animal manure under limited supply of oxygen and at relatively low temperature. Biochar can be used as a soil amendment to improve nutrient availability, soil productivity, carbon storage, and filtration of percolating soil water and act as stable form of carbon due to its resistance to decomposition and its influence on nutrient dynamics (Lehmann and Joseph, 2009). According to Gao

et al., (2019), biochar additions to soil increased available P by 45 per cent, but have negative effect on the accumulation of inorganic N. In highly acidic soils, application of biochar increased the soil pH, P availability, cation exchange capacity and soil organic carbon in a sustainable manner (Bedassa, 2020). Phares *et al.*, (2020) reported that combined biochar and triple superphosphate application increased soil pH, improved soil fertility, nodulation and nitrogen fixation in cowpea grown in a tropical sandy loam soil amended with biochar at 1.5 t ha^{-1} and 2.5 t ha^{-1} solely or together with inorganic phosphate fertilizer (TSP), applied at a rate of 60 kg P/ha. Biochar is a biomass-derived carbonaceous material often alkaline in nature and therefore, when used as a liming agent has the potential to alleviate soil acidity; however, more reliable datasets of its liming and consequent effects are still to be explored (Bolan *et al.*, 2023).

Conclusion

Adverse soil conditions like low pH, iron and aluminium toxicity, low nutrient availability and low fertilizer use efficiency are the factors limiting productivity of rice in extremely acidic soils. Application of lime shell is the most common practice adopted by the farmers for the management of acidity. But the high cost, low quality, reduced availability and evolution of CO_2 during the calcination process recommends the use of various other natural materials like RHA and industrial by-products like calcium silicate and phosphogypsum as an alternative option for the amelioration of acidic soils. These materials are having high reactivity in increasing the pH, supply of nutrients like Ca, Mg, Si *etc.*, and also has the potential to reduce iron and aluminium toxicity and reduce methane emission.

References

- Agegnehu G, Yirga C and Erkossa T. 2019. *Soil Acidity Management*, Ethiopian Institute of Agricultural Research (EIAR). Addis Ababa, Ethiopia. 55.



- Alaneme KK and Adewale TM. 2013. Influence of Rice Husk Ash - Silicon Carbide Weight Ratios on the Mechanical behaviour of Al-Mg-Si Alloy Matrix Hybrid Composites. *Tribology in Industry* 35(2): 163-172.
- Alcarde JA and Rodella AA. 2003. Quality and legislation of fertilizers and correctives. (Qualidade e legislação de fertilizantes e corretivos). In: Curi N, Marques, JJ, Guilherme LRG, Lima JM, Lopes AS, Alvares VVH (eds) Topics in soil science. (Tópicos em Ciência do Solo). *Viçosa: Sociedade brasileira de Ciência do solo*, pp. 291-334.
- Amaral AS, Anghinoni I and Deschamps FC. 2004. Cover plant residues and mobility of dissolution products of surface applied lime. *Brasilien Journal of Soil Science*, 28(1): 115-123.
- Ananthanarayana R and Hanumantharaju TH. 1993. Efficacy of different liming materials in neutralizing soil acidity. *Journal of Indian Society of Soil Science*, 41(3): 603-605.
- Babaso PN and Sharanagouda H. 2017. Rice husk and its applications: Review. *International Journal of Current Microbiology and Applied Sciences*, 6(10): 1144-1156.
- Bedassa M. 2020. Soil acid management using biochar: Review. *International Journal of Agricultural Science and Food Technology*, 6(2): 211-217.
- Beena VI and Thampatti MKC. 2013. Characterization of acidity in acid sulphate soils of Kerala. *Journal of Life Sciences*, 7(8): 907-912.
- Bolan N, Sarmah AK, Bordoloi S, Bolan S, Padhye LP, Zwieten L, Sooriyakumar P, Khan BA, Ahmad M, Solaiman Z, Rinklebe J, Wang H, Singh BP and Siddique KHM. 2023. Soil acidification and the liming potential of biochar. *Environmental Pollution*, 317.
- Caires EF, Fonseca AF, Mendes J, Chueiri WA and Madruga EF. 1999. Corn, wheat and soybean yields as a function of the changes in soil chemical characteristics due to surface application of lime and gypsum under a no-tillage system. *Brazilian Journal of Soil Science*, 23(2): 315-327.
- Caires EF, Blum J, Barth G, Garbuio FJ and Kusman MT. 2003. Changes in chemical soil characteristics and soybean response to lime and gypsum applications in a no-tillage system. *Brazilian Journal of Soil Science*, 27(2): 275-286.
- Castro GSA and Crusciol CAC. 2013. Effects of superficial liming and silicate application on soil fertility and crop yield under rotation. *Geoderma*, 195-196: 234-242.
- Castro GSA, Crusciol CAC, Costa CHM, Neto JF and Mancuso MAC. 2016. Surface application of limestone and calcium-magnesium silicate in a tropical no-tillage system. *Journal of Soil Science and Plant Nutrition*, 16(2): 362-379.
- Christenson DR, Warncke DD and Leep R. 1993. Lime for Michigan soils. *Extension Bulletin*.
- Cihacek L, Augustin, Buetow, Landblom, Alghamdi R and Senturklu S. 2021. *NDSU Extension Technical Report*. North Dakota State University Fargo, North Dakota. p.4.
- Costa CHM and Crusciol CAC. 2016. Long-term effects of lime and phosphogypsum application on tropical no-till soybean–oat–sorghum rotation and soil chemical properties. *European Journal Agronomy*, 74: 119 -132.
- Devi VS, Swadija OK, Geetha K and Mathew R. 2017. Acidity amelioration for rice yield enhancement in acid sulphate (*Vaikom kari*) soils of Kuttanad in Kerala. *Journal of Crop and Weed*, 13(3): 78-81.
- Devi VS and Swadija OK. 2017. Effect of acidity amelioration practices on micronutrient availability for rice in Vaikom kari soils of Kuttanad. *International Journal of Applied and Pure Science and Agriculture*, 86-90.
- Dick WA. 2018. Crop and Environmental Benefits of Gypsum as a Soil Amendment. Presentation abstract, American Society of Agronomy and the Crop Science Society of America. 244-5.

- Ebimol NL, Suresh PR, Binitha NK and Santhi GR. 2017. Management of iron and aluminium toxicity in acid sulphate soils of Kuttanad. *International Journal of Current Microbiology and Applied Sciences*, 6(11): 1496-1503.
- Elisa AA, Ninomiya S, Shamshuddin J and Roslan I. 2016. Alleviating aluminum toxicity in an acid sulfate soil from Peninsular Malaysia by calcium silicate application, *Solid Earth*, 7(2): 367-374.
- Fageria N and Baligar V. 2008. Ameliorating soil acidity of tropical Oxisols by liming for sustainable crop production. *Advances in Agronomy*. 99:345-399.
- Farhati AA, Firnia D and Laila A. 2023. Effects of ameliorant application on the growth and yield of rice plants (*Oryza sativa* L.) *Agricultural Science*, 8(2): 107-112.
- Gao S, Deluca TH, Clevel and CC. 2019. Biochar additions alter phosphorous and nitrogen availability in agricultural ecosystems: A metaanalysis. *Science of the Total Environment*, 654: 463-472.
- Getaneh S and Kidanemariam W. 2021. Soil acidity and its managements: A Review. *International Journal of Advanced Research in Biological Sciences*, 8(3): 70-79.
- Guimond RJ and Hardin HM. 1989. Radioactivity released from phosphate-containing fertilizers and from gypsum. *Radiation Physics and Chemistry*, 34(2): 309-315.
- Hartatik W, Subiksa IGM, Setyorini D, Aksani D, Widowati LR, Ratmini NPS and Suastika IW. 2023. Nutrient dynamics in acid sulfate soil treated with dolomite and micronutrient fertilizers and their effects on the growth of lowland rice. *Transactions of the Chinese Society of Agricultural Machinery*, 54(11): 25-42.
- Islabao GO, Vahl LC, Timm LC, Paul DL and Kath A. 2014. Rice husk ash as corrective of soil acidity. *Brazilian Journal of Soil Science*, 38(3): 934-941.
- Kath AH, Islabao GO, Vahl LC and Teixeira JBDS. 2018. Reaction rate and residual effect of rice husk ash in soil acidity parameters. *Soil Science and Plant Nutrition*, 65(3): 278-285.
- Khalid RA and Silva JA. 1980. Residual effect of calcium silicate on pH, phosphorus, and aluminum in a tropical soil profile. *Soil Science and Plant Nutrition*, 26(1): 87-98.
- Korndorfer GH, Pereira HS and Camargo MS. 2003. Calcium and magnesium silicates in agriculture. *Technical Bulletin*, 1:23.
- Kost D, Chen L, Guo X, Tian Y, Ladwig K and Dick WA. 2014. Effects of flue gas desulfurization and mined gypsums on soil properties and on hay and corn growth in eastern Ohio, *Journal of Environmental Quality*, 43: 312-321.
- Kothandaraman S, Anitha R and Muthadhi A. 2007. Rice husk ash - properties and its uses: A review. *IE (1) Journal CV*, 88: 50-56.
- Lehmann J and Joseph S. 2009. Biochar for environmental management: An introduction. In: *Biochar for Environmental Management*, 1-13 pp.
- Lou Y, Ren L, Zhao S, Shi Y, Zhang Y and Zhu H. 2019. Effects of silicate application on CH₄ and N₂O emissions and global warming potentials in paddy soil under enhanced UV-B radiation. *Energy Science and Engineering*, 7(5): 1784-1794.
- Maftuah E, Nurzakiah S, Sulaeman Y and Lestari Y. 2023. Use of humic and silica materials as soil ameliorant to improve the chemical properties of acid sulphate soil. IOP Conf. Series: *Earth and Environmental Science*, 1162.
- Masulili A, Utomo WH and Syechfani MS. 2010. Rice husk biochar for rice based cropping system in acid soil. The characteristics of rice husk biochar and its influence on the properties of acid sulfate soils and rice growth in West Kalimantan, Indonesia. *Journal of Agricultural Science*, 2(1): 39-47.



- Miller JO. 2016. Soil pH Affects Nutrient Availability. *Technical Report*, University of Maryland Extension.
- Mini V and Lekshmi S. 2020. Rice husk ash as a low-cost soil ameliorant for abating iron toxicity in lowland rice. *Agricultural Science Digest*, 41(1): 96-98.
- Mohammed W, Aman K and Zewide I. 2021. Review on Role of Lime on Soil Acidity and Soil Chemical Properties. *Journal of Catalyst & Catalysis*, 8(1): 33-41.
- Neenu S, Karthika KS, Anil Kumar KS and Nair KM. 2020. Kuttanad soils: the potential acid sulphate soils of Kerala *Harit dhara ICAR-IISS E-Magazine*, 3(2): 19-23.
- Nolla A, Korndorfer GH, Silva CATD, Silva TRBD, Zucarelli V and Silva MAGD. 2013. Correcting soil acidity with the use of slags-Review. *African Journal of Agricultural Research*, 8(41): 5174-5180.
- Okon PB, Ogehb JS and Amalua UC. 2005. Effect of rice husk ash and phosphorus on some properties of acid sands and yield of okra. *Communications in Soil Science and Plant Analysis*, 36:833- 845.
- Peters JB, Kelling KA and Schulte EE. 1996. Choosing between liming materials. A3671. University of Wisconsin.
- Phares CA, Atiah K, Frimpong KA, Danquah A, Asare AT and Woananu SA. 2020. Application of biochar and inorganic phosphorus fertilizer influenced rhizosphere soil characteristics, nodule formation and phytoconstituents of cowpea grown on tropical soil. *Heliyon*, 6(10).
- Preetha K, Malathi P, Selvi D, Parameswari E and Thamaraiselvi SP. 2022. Determination of calcium carbonate equivalent of rice husk ash. *International Journal of Plant and Soil Science*, 34(22): 470-475.
- Rastija D, Zebec V and Rastija M. 2014. Impacts of liming with dolomite on soil pH and phosphorus and potassium availabilities. *Proceedings of 13th Alps-Adria Scientific Workshop*, Villach, Ossiacher.
- Ritchey KD, Feldhake CM, Clark RB and Sousa DMG. 1995. Improved water and nutrient uptake from subsurface layers of gypsum-amended soils. *Agricultural Utilization of Urban and Industrial By-Products*, ASA Spec. Publ., Karlen DL. *et al.*, (eds.), 58: 157-181.
- Sarangi M, Bhattacharyya S and Behera RK. 2009. Rice effect of temperature on morphology and phase transformations of nanocrystalline silica obtained from rice husk. *Phase transitions*, 82(5): 377-386.
- Shaaban M, Peng Q, Lin S, Yupeng W, Zhao J and Ronggui H. 2014. Nitrous oxide emission from two acidic soils as affected by dolomite application. *Soil Research*, 52(8): 841-848.
- Shaaban M, Peng Q, Lin S, Yupeng W, Khalid MS, Lei Wu, Yongliang Mo and Ronggui H. 2016. Dolomite application enhances CH₄ uptake in an acidic soil. *Catena*, 140: 9-14.
- Shaaban M, Wu L, Peng Q, Zwieten LV, Chhajro MA, Wu Y, Lin S, Ahmed MM, Khalid MS, Abid M and Hu R. 2017. Influence of ameliorating soil acidity with dolomite on the priming of soil C content and CO₂ emission. *Environmental Science and Pollution Research*, 24: 9241-9250.
- Singh B. 2018. Rice husk ash. Waste and Supplementary Cementitious Materials in Concrete Characterization, Properties and Applications. Woodhead Publishing Series in Civil and Structural Engineering, 417: 46.
- Sneller E. 2011. Gypsum as a soil additive: use it or lose it?, *Michigan State University Extension*. <https://extension.msu.edu>.
- Sparks DL. 2003. The chemistry of soil acidity. *Environmental Soil Chemistry*, Academic Press. 267-283.

- Srinivasarao Ch, Srinivas K, Sharma KL and Kundu S. 2017. Soil Health Improving Strategies for Resilient Rice Based Cropping Systems of India. *Journal of Rice Research*, 10(1): 54-63.
- Tandzi, NL, Mutengwa, CS, Ngonkeu, ELM and Gracen V. 2018. Breeding maize for tolerance to acidic soils: A review. *Agronomy*, 8(6), p.84.
- Tang C. 2004. Causes and management of subsoil acidity. *Super Soil 2004: 3rd Australian New Zealand Soils Conference*, 5-9th December 2004, University of Sydney, Australia.
- Teutscherova N, Vazquez E, Drabek O, Hutla P, Kolarikova M and Banout J. 2023. Disentangling the effects of rice husk ash on increased plant growth and nitrogen recovery. *Geoderma*, 437(116577): 1-8.
- Thakuria D, Hazarika S and Rangappa K. 2016. Soil Acidity and Management Options. *Indian Journal of Fertilisers*, 12(12): 40-56.
- Weil RR and Brady NC. 2022. *The Nature and Properties of Soils*. Pearson India Education Services. 1104 p.
- Yadav V. 2021. Rice husk ash: a systematic review of its applications. *International Journal of Current Research*, 13(6): 17706-17713.
- Zoca SM and Penn C. 2017. An important tool with no instruction manual: a review of gypsum use in agriculture. *Advances in Agronomy*, 144:1-44.