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Review article

Soil acidification and lime quality: sources of soil acidity, its effects on plant nutrients, efficiency of lime and liming requirements

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A B S T R A C T

Agriculture sectors support economy of most developing countries. In Sub-Sahara Africa, the agriculture is predominantly based on rain-fed agricultural production of small, semi-subsistence, and increasingly fragmented farms. Thus, the farming is intensive and fields are concentrated on valleys, steep hillsides and mountains. This results in soil acidity, low fertility, accelerated soil erosion and low crop yields. Soil acidity affects crops in many ways and its effects are mostly indirect, through its influence on chemical factors such as aluminium (Al) and manganese (Mn) toxicity, calcium (Ca), phosphorus (P) and magnesium (Mg) deficiencies and biological processes. The application of lime believed to enhance soil health status through improving soil pH, base saturation, Ca and Mg. It reduces Al and Mn toxicity and increases both P uptake in high P fixing soil and plant rooting system. However, the liming effects depend on its source, its characteristics, composition, purity and how finely it is ground. The estimation of lime requirement is constraining its use for smallholder farmers and young soil scientists. This study therefore aimed at highlighting the most causes of soil acidification, lime quality and lime requirement. This review article will serve as a guide for farmers and young soil scientists in addressing soil acidity and properly determining lime requirement.

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1. Introduction

Agriculture sector is the economy pillar of most developing countries. However, agricultural productivity remains critically low in most of these countries. The low productivity of the agricultural sector is largely attributed to low and decreasing soil fertility due to many factors such as soil acidity, soil erosion, continuous cropping and inadequate sustainable soil fertility management(Berga et al., 2001; Van Straaten, 2002; Kiiya et al., 2006; Crawford et al., 2008). For instance, the acidity affects the fertility of soils through nutrient deficiencies (P, Ca and Mg) and the presence of phytotoxic nutrients such as soluble Al and Mn. Application of lime reduces Al and Mn toxicity, improves pH, Ca, Mg and increases both P uptake in high P fixing soil and plant rooting system (Black, 1992). The use of lime is a potential option for soils sustainable management among the other options for restoring soil health and fertility. In agriculture, the limes play a great importance in improving soil acidity and hence favour plant nutrition.

The lime is known as a material originated from rocks which can have multiple purposes (construction, cement production, water purification, disinfectant, agricultural amendments...). Locally available carbonates are relatively common in many countries of sub-Saharan Africa and are well suited for small-scale mining and processing (Van Straaten, 2002). However, due to the bulkiness of lime, the capacity to produce and supply enough lime in affordability manner (cost effectiveness) is very low. In sub-Sahara Africa, lime production rely on traditional techniques without appropriate machines for finely grinding limestone, consequently, limes produced are less effective and therefore, are very expensive as they are needed in high quantity (Coventry et al., 1989) to meet the requirement in the soils.

The use of lime and its requirement depends on the level of acidity in the soils. Some of limiting factors to widespread use of lime in many areas of sub-Saharan Africa are; lack of awareness among farmers on its use, lack of appropriate recommended rates, and high cost and unknown quality of the available agricultural limes. Furthermore, knowledge on the effectiveness of various lime sources in correcting soil acidity is lacking due to limited studies done in the region. Information on causes of soil acidity, lime quality, effectiveness of lime in reducing soil acidity and in improving crop yields is vital in lime selection and formulation of recommendations rates that are necessary for spurring farmer uptake of the liming technology. The young soil scientists need therefore a concise guide for determining lime requirements. This review article is presenting the causes and forms of soil acidity and some formulas and guide for lime requirement.

2. Soil PH and acidification

Soil pH is a measure of the number of hydrogen ions in the soil solution; the higher the concentration of hydrogen ions, the more acidic the solution is. Understanding soil pH is essential for the proper soil management and optimum crop productivity. In aqueous (liquid) solutions, an acid is a substance that donates hydrogen ions ($H+$) to some other substance (Tisdale et al., 1993). Soil pH is an excellent chemical indicator of soil quality. Theoretically, soil acidity is quantified on the basis of hydrogen ($H+$) and aluminium ($Al3+$) concentrations of soils (Fageria and Baligar, 2008).

Soil acidity occurs when there is a build-up of acid forming elements in the soil. The production of acid in the soils is a natural process; caused by rainfall and leaching, acidic parent materials and organic matter decay (Havlin et al., 2005) hence many soils in high rainfall areas are inherently acidic (McCauley et al., 2009). Acidification is a slow process but it is accelerated by agriculture through; use of some fertilizers, soil structure disturbance and harvest of high yielding crops (Fageria and Baligar, 2008). As soils become more acidic, plants intolerant to acidic conditions are negatively affected leading to productivity decline. The aim of attempting to adjust soil acidity is to neutralize pH and Al toxicity but the most important is to replace lost cations nutrients, particularly calcium and magnesium (Fageria and Baligar, 2008). This can be achieved by adding limestone to the soil (Maheshwari, 2006) and farmers can improve the soil quality of acidic soils by liming to adjust pH to the levels needed by the crop to be grown.

2.1. Soil acidification and Aluminium toxicity

Soils become acidic for several reasons. The most common source of hydrogen is the reaction of aluminium ions with water. Aluminium toxicity in combination with low pH (Budianta and Vanderdeelen, 1995) is one of the major reasons that render acidic soils unsuitable for the growth of many plants in the humid tropic countries. The forms of aluminium ions present vary with pH (Fageria and Baligar, 2008). The increased soil acidity causes solubilisation of Al, which is the primary source of toxicity to plants at pH below 5.5 (Kariuki et al., 2007). As observed by Carson and Dixon (1979), under very acidic conditions of pH less than 4.5, the major form of aluminium is Al3+, and pH between 4.5- 6.5, aluminium-hydroxyl dominates. As the pH increases, exchangeable Al3+ precipitates as insoluble Al hydroxyl forms at a rate of 1000 fold decrease for each unit increase in pH (equation 1).

$$\mathrm{Al3+} + \mathrm{H2O} \leftrightarrow \mathrm{Al\,(OH)2} + \mathrm{H+} \qquad \text{Equation [1]}$$

The equation (1) explains the reaction of aluminium-hydroxyl in very acid soils. However, at pH greater than 6.5, aluminium becomes increasingly soluble as negatively charged aluminates form (Haynes, 1984). The heavy rainfall can also contribute to the soil acidification by natural causing parent materials to be acidic due to leaching of cations (Fageria et al., 1990). There are other important causes of soils acidification, such as, ammonium fertilizers, release of organic acids in decomposition of crop residues or organic wastes (Sparks, 2003) and continuous cultivation of legumes(Bolan and Hedley, 2003). The acidification caused by the use of ammonium fertilizers are explained by the release of H+ (equation 2).

$$\mathrm{NH+4} + \ 2\mathrm{O2} \leftrightarrow \mathrm{NO3^{-}} + \mathrm{H2O} + \ 2\mathrm{H+}$$

Equation [2]

The acidification due to legumes is explained by higher absorption of basic cations of legumes and the release of H+ ions by the root of legume crops to maintain ionic balance, and during N2 fixation through a function of carbon assimilation (Bolan and Hedley, 2003).

3. Soil acidity and base saturation and buffering capacity

A relatively high base saturation of CEC (70 to 80%) should be maintained for most cropping systems, since the base saturation determines in large measure the availability of bases for plant uptake, and strongly influences soil pH as well. Low base saturation levels results in very acid soils and potentially toxic cations such as Al and Mn in the soil. A high base saturation (>50%) enhances Ca, Mg, and K availability and prevents soil pH decline. Low base saturation (<25%) is indicative of a strongly acidic soils that may maintain Al3+ activity high enough to cause phytotoxicity (Soil Survey Division Staff, 1993).

The resistance of soils to changes in pH of the soil solution is termed buffering. In practical terms, buffering capacity for pH increases with increase in the amount of clay and organic matter (Soil Survey Division Staff, 1993). Thus, soils with high clay and organic matter content (high buffer capacity) will require more lime to increase pH than sandy soils with low amounts of organic matter (low or weak buffering capacity).

4. Soil acidity and crop responses

Soil pH affects crops in many ways and its effects are mostly indirect, through its influence on chemical factors and biological processes. Chemical factors include aluminium (Al) toxicity, calcium (Ca) and phosphorus (P) and magnesium (Mg) deficiencies (Uchida and Hue, 2000). Optimum nutrient uptake by most crops occurs at a soil pH near 7.0. The nutrients availability such as nitrogen, phosphorus and potassium is generally reduced as soil pH decreases. Phosphorus is particularly sensitive to pH and can become a limiting nutrient in strongly acid soils. Thus, reduced fertilizer use efficiency and crop performance can be expected when soil acidity is not properly controlled (McFarland et al., 2001). Hardy et al. (1990) reported exchangeable Al to affect crops (Table 1) by shallow rooting, poor use of soil nutrients, and Al toxicity.

The application of lime showed to increase the overall production of various crops. The previous studies done oh different crops demonstrated that when only 1 ha-1 of lime applied in cassava, there was a yield increase of 12.6t ha-1. The lime rate of 4t ha-1 applied in the field of beans, Irish potato and maize, the yield increase were 1.27t ha-1, 10t ha-1 and 1.4t ha-1, respectively (Table 2).

Table 1
Crops tolerance to Al saturation

Main crops	Al Saturation (Al/ECEC)	Adjustment options
Beans	0	Lime and fertilizers
Maize	<0.4	Lime and fertilizers
Irish potato	<0.5	Lime and fertilizers
Cassava	0.2-0.5	Lime and fertilizers

Table 2
Effects of lime son yield of some main crops

Crops	Exchangeable Al (cmol kg-1)	Lime applied (t ha-1)	Yield (t ha-1)	Reference
Beans	2.9	0	1.03	(Beernaert, 1999)
Beans	2.9	4.4	2.3	(Beernaert, 1999)
Maize	2.13	0	2.2	(Mbakaya et al., 2011)
Maize	2.13	3.2	3.6	(Mbakaya et al., 2011)
Potato	2.8	0	14	(Nduwumuremyi et al., 2013)
Potato	2.8	4.2	24	(Nduwumuremyi et al., 2013)
Cassava	1	0	17.74	(Ramos and Mojica, 1982)
Cassava	1	1	30.34	(Ramos and Mojica, 1982)

Liming is an important practice to achieve optimum yields of all crops grown on acid soils. Application of lime at an appropriate rate brings several chemical and biological changes in the soils, which are beneficial or helpful in improving crop yields on acid soils (Figure 1 and 2). Plant growth improvement in acid soils is not due to addition of basic cations (Ca, Mg), but because of increasing pH reduces toxicity of phytotoxic levels of Al (Crawford et al., 2008; Awkes, 2009).

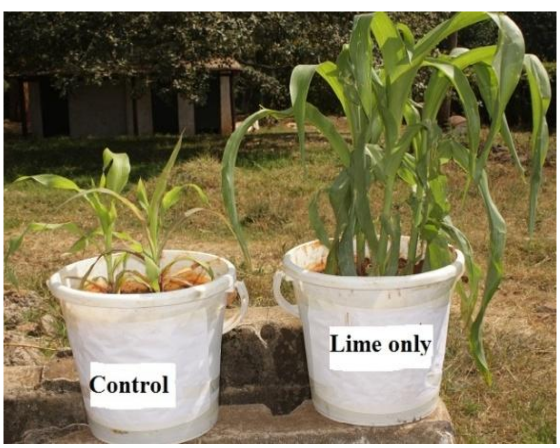

Fig. 1. Effects of lime on growth of Maize.

Fig. 2. Field of potato limed.

Potato needs heavy amounts of fertilizers and tuber yields are seriously affected in soils with shortages of P and K. Yamoah et al. (1992) found that Potato yield can be significantly increased by residual lime. Potato yields at lower lime differed from those at the higher rates by about 30%, again substantiating a much longer residual effect with the use of higher rates (Folscher et al., 1986). Hester (1936) reported 25 to 29% increase in potato yield due to small applications of lime on soil with a pH of 5.2. Plant nutrients are most available at soil pH levels near 6.5;

Potatoes grown in soils near pH 6.5 produce higher yields with less fertilizer (Rosemary, 1991). The ideal pH for Potato ranges from 5.2 to 6.5 (Adams, 1984). The beneficial effects of liming on crop growth are often related to neutralization of Al and not directly to the change in pH.

5. Liming and its advantages in acidic soils

Liming is an important practice to achieve optimum yields of all crops grown on acid soils. According to Kaitibie et al. (2002), liming is the most widely used long-term method of soil acidity amelioration, and its success is well documented (Scott et al., 2001). Application of lime at an appropriate rate brings several chemical and biological changes in the soils, which are beneficial or helpful in improving crop yields on acid soils (Fageria and Baligar, 2008).

Liming raises soil pH, base saturation, and Ca and Mg contents, and reduces aluminium concentration in acidic soils (Fageria and Stone, 2004). The acidic soils are naturally deficient in total and plant available phosphorus. This is because significant portions of applied P are immobilized due to precipitation of P as insoluble Al phosphate or chemisorptions to Al oxide and clay minerals (Nurlaeny et al., 1996). The liming of acidic soils result in the release of P for plant uptake; this effect is often referred to as ‘‘P spring effect’’ of lime (Bolan and Hedley, 2003). Increase in availability of P in the pH range of 5.0 to 6.5 is associated with release of P ions from Al and Fe oxides, which is responsible for P fixation (Fageria, 1989b). But at high pH (> 6.5) soluble P precipitate as Ca phosphate (Naidu et al., 1990).

Soil microbiological properties can serve as soil quality indicators. Soil acidity restricts the activities of beneficial microorganisms, except fungi, which grow well over a wide range of soil pH (Brady and Weil, 2002). Liming acidic soils enhance the activities of beneficial microbes in the rhizosphere and hence improve root growth by the fixation of atmospheric nitrogen because neutral pH allows more optimal conditions for free-living N fixation (Stephen et al., 2011). It can also suppress pathogens and producing phytohormones; enhancing root surface area to facilitate uptake of less mobile nutrients such as P and micronutrients and mobilizing and solubilising unavailable nutrients (Fageria et al., 1990).

According to McBride (1994), increasing soil pH through liming can significantly affect the adsorption of heavy metals in soils. Soil properties such as organic matter content, clay type, redox potential, and soil pH are considered the major factors that determine the bioavailability of heavy metals in soil (Treder and Cieslinski, 2005). Hence, liming certainly helps in reducing availability of heavy metals to crop plants.

Soil acidity is also responsible for low nutrient use efficiency by crop plants. Fageria and Baligar (2004) reported that liming acidic soils improved the use efficiency of P, and other micronutrients by upland rice genotypes. In this study, efficiency of these nutrients was higher under a pH of 6.4 than with pH 4.5. The liming improves efficiency of nutrients through soil acidity management for improving their availability, and enhanced root system (Fageria and Baligar, 2004).

Calcium released from applied lime in soil has been reported to enhance plant resistance to several plant pathogens (Fageria and Baligar, 2008), including Erwinia phytophthora, R. solani, Sclerotium rolfsii, and Fusarium oxysporum. Haynes (1984) reported that calcium forms rigid linkages with pectic chains and thus promotes the resistance of plant cell walls to enzymatic degradation by pathogens. Therefore, liming provides calcium, which can contribute to build up plant resistance to some pathogens.

Finally, liming has been promoted as mitigation option for lowering soil N2O emissions when soil moisture content is maintained at field capacity (Clough et al., 2004). Since soil pH has a potential effect on N2O production pathways, and the reduction of N2O to N2, it has been suggested that liming may provide an option for the mitigation of N2O emission from agricultural soils (Stevens et al., 1998).

6. Sources of liming materials in sub-sahara Africa

Almost all deposits of limestone in sub-Sahara Africa (SSA) are located in axis zones of N 35o E, this axis is the one of recent major fracture related to the genesis of African rift valley (SOFRECO, 2001). Thus, there are large mines of limestone (travertine and dolomite rocks) in SSA and exploitation of the main deposits is possible (Beernaert, 1999). Liming products (ground limestone and more or less burned limes) are at present almost exclusively produced in large quantity in some countries of SSA. Although, limestone (travertine and dolomite) mines are abundant in SSA, only 30 % are coherent rocks, required for the production of lime (Beernaert, 1999;

Van Straaten, 2002). The remaining 70 % occur as loose sandy travertine, which is not suitable for lime production for construction. From an agronomic and economical point of view, it would be logical to reserve the coherent rock fraction for lime production for construction and to exploit the sandy fraction for agricultural purposes, using a more simple and low cost treatment. Very often, there is more variation in the CaO and MgO content of local limes of the same deposit, as compared with travertine of different deposits. Therefore, there is need for local lime mines which are capable of homogenizing the mixture of local lime.

6.1. Limestone of travertine group

Travertine is limestone with high Ca content (CaO>40%) and low magnesium content (MgO<3%). Travertine is found in recent formations of Pleistocene age and is a less compact, soft rock, which is easily extractable without explosives. Beernaert (1999) reported that, travertine has a cationic (Ca/Mg) ratio of 13-15, which is much higher than the optimal ratio of 4-5. This can cause disequilibria in the cation balance and affect soil fertility (Beernaert, 1999). Kayonga and Goud (1989) observed that ground travertine rocks raised soil pH by 0.5 units, reduced exchangeable Al, increased base saturation, and introduced disequilibria between the exchangeable cations. These rocks have a suitable chemical composition to eliminate aluminium toxicity in acid soils but cause nutrient imbalance and hence create new problems.

6.2. Limestone of dolomite group

A dolomite rock is limestone with high content of magnesium (CaO 30%, MgO 20%). The dolomite rocks of SSA include dolomite limestone, dolomite marbles and dolomites (Giller and Brogniez, 1991). These are hard rocks used for building and construction and which need explosives and more sophisticated cutting, drilling and grinding equipment, for their extraction. Although records show the existence of very large reserves of dolomite deposits in SSA (Giller and Brogniez, 1991), very little is known about their agronomic efficiency. The report by Wouters and Gourdin (1989) showed that dolomite rocks can successfully eliminate soil acidity and Al toxicity but their chemical composition with a cation (Ca/Mg) ratio close to 1 is not suitable for agriculture.

7. Solubility and qualities of lime

Lime is lowly soluble in water, so particles must be finely ground to neutralize soil acidity for a reasonable period of time. Even very small changes in the sizes of the particles have a major effect on the time required to dissolve them. Effectiveness depends on the purity of the liming material and how finely it is ground. The purity of lime is rated by a laboratory's measurement of a Calcium Carbonate Equivalent (CCE). The lower the CCE value, the more lime you will need to neutralize the soil's acidity (Larry, 2000). When lime (e.g., CaCO3) is added to a moist soil, the following reactions will occur:

(1) Lime is dissolved (slowly) by moisture in the soil to produce Ca2+ and hydroxide (OH–): $\mathrm{CaCO_3 + H_2O\ (in\ soil) \rightarrow\ Ca^{2+}\ +\ 2OH^-\ +\ CO_2\ (gas)}$ Equation [3]

(2) Newly produced Ca2+ will exchange with Al3+ and H+ on the surface of acid soils:

$\mathrm{Ca^{2+} + [Soil\ particle\ +\ Al^{3+}\ and\ H^+] \rightarrow [Soil\ particle + Ca^{2+}] +\ Al^{3+} + H^+}$ Equation [4]

(3) Lime produced OH– will react with Al3+ to form solid Al (OH-)3, or it will react with H+ to form H2O as shown in equations 5 and 6.

$\mathrm{3OH^- +\ Al^{3+} \rightarrow Al\ (OH)3\ \ (solid)}$ Equation [5]

$\mathrm{OH^- +\ H^+ \longrightarrow H2O}$ Equation [6]

Thus, liming eliminates toxic Al3+ and H+ through the reactions with OH–. Excess OH– from lime will raise the soil pH, which is the most recognizable effect of liming. Another benefit of liming is the added supply of Ca2+, as well as Mg2+ if dolomite [Ca, Mg (CO3)2] is used. Calcium and Mg are essential nutrients for plant growth, yet they are often deficient in highly weathered acid soils (Uchida and Hue, 2000).

8. Efficiency of liming materials

Quality of liming material is very important in correcting soil acidity. The source of lime, its characteristics, composition and the purity of lime are very important parameters for effective use of lime (Kemperl and Maček, 2009). The efficacy of liming materials is a key factor in determining its utilisation as profitable crop yield must be realised. The efficiency of a liming material is determined by its acid neutralising potential, particle size distribution, availability and convenience of spreading (Foth and Ellis, 1996).

Many terms are used when describing the efficiency of liming materials, and commonly used terms are relative neutralizing value (RNV), effective neutralising value (ENV) and effective calcium carbonate equivalence (ECCE) (Synder and Leep, 2007). The most methods for determining the quality and efficiency of liming materials are based on the neutralising value (NV) and particle size distribution and various formulas have been developed (Synder and Leep, 2007). The NV is determined by the chemical composition and the mineralogy of the liming material and is a measure of the amount of acid neutralising compounds expressed as the percentage of calcium carbonate equivalence (CCE), with pure calcium carbonate rated 100% (McFarland et al., 2001). The efficiency of liming material is determined by its effective calcium carbonate equivalence (ECCE), an estimation of the effectiveness represented as percentage and is the product of CCE and the fineness factors of the various particle size fractions (Synder and Leep, 2007). The key factors in determining the efficiency of liming materials are its chemical composition and particle size distribution (Table 3).

Table 3
Particle size and efficiency factors of limes

Particle size(mesh sieving size)	Opening size(mm)	Efficiency factor
>8	>2.36	0
8-60	2.36-0.25	0.5
<60	<0.25	1.0

Source: Halvin et al.(2005)

In addition to the efficiency of a liming material, its efficacy (amount of material required to adjust soil pH to the desired level for profitable crop production) depends on the liming potential of the material, initial soil pH, clay content and buffer capacity of the soil (Synder and Leep, 2007).

Studies on the effect of particle size on soil pH and crop yield have shown that liming with finer liming materials results in increments in soil pH over shorter time periods, and generally higher soil pH and crop yields (Huang et al., 2007). The degree of fineness indicates the speed with which lime materials will neutralize soil acidity. Fineness is measured by the proportion of processed agricultural lime which passes through a sieve with an opening of a particular size. A 60-mesh sieve, which is the standard for comparisons of lime fineness and efficiency rating of 100%, is assigned (Caudle, 1991).

9. Lime application

Methods, frequency, depth, and timing of liming are important practices in improving liming efficiency and crop yields on acidic soils. To get maximum benefits from liming or for improving crop yields, liming materials should be applied in advance of crop sowing and thoroughly mixed into the soil to enhance its reaction with soil exchange acidity (Fageria and Baligar, 2008). The best method is broadcasting it as uniformly as possible and mixing thoroughly through the soil profile. Liming frequency is mainly determined by intensity of cropping, crop species planted, and levels of $Ca2+$, $Mg2+$, Al, and pH in a soil after each harvest. The effect of lime is long lasting but not permanent (Fageria and Baligar, 2008). When values of exchangeable $Ca2+$, $Mg2+$, and pH fall below optimum levels for a given crop species, liming should be repeated.

Effects of lime do last longer than those of most other amendments. However, it is rarely necessary to lime more frequently than every 3 years (Caudle, 1991). The residual effect of coarse lime material is greater than with finer lime material because large lime particles react slowly with soil acidity and tend to remain in the soil longer. A reasonable depth of 20cm is required. Timing of lime application is important in achieving desirable results. Lime should be applied as early as possible before planting of crop to allow it to react with soil colloids and to bring about significant changes in soil chemical properties. Soil moisture and temperature are determining factors for lime to react with soil colloids. In oxisols, significant chemical changes can take place 4–6 weeks after applying liming materials so long as soil has sufficient moisture (Fageria, 2001a). Hence, to obtain desirable results, it is not necessary to wait for a longer period of time after applying lime.

10. Lime requirement

According to Soil Science Society of America (1997), lime requirement is defined as the amount of liming material, as calcium carbonate equivalent, required to change a volume of soil to a specific state with respect to pH or soluble Al content. However, in economic terms, lime requirement can be defined as the quantity of liming material required to produce maximum economic yield of crops cultivated on acid soils. Practically, different approaches are available in order to predict the limestone rate required to attain an adequate level aiming to avoid Al toxicity towards plant growth. One of the methods for predicting the lime requirement is to monitor the evolution of exchangeable Al. The base enrichment especially of Ca2+ ions in soil will neutralize exchangeable Al thus enhancing root growth (Bell and Bessho, 1993). Hakim et al. (1989) reported that the optimal lime rate to improve some food crops planted in the Ultisol is 6 tons CaCO3 per ha, then, over liming will occur at doses exceeding 12 tons per ha. Many extracting solutions have been proposed to estimate the extractable Al and still KCl predominates (Oates and Kamprath, 1983b). The non-readily exchangeable Al is estimated to be associated with organic matter, interlayer Al, and hydroxy-Al polymers that contribute to the active acidity in the soil solution.

Lime requirement is determined following different methods. However, in this study the method described by Kamprath (1970) is the one seems to be easy applicable in most of weathered soils of sub-Sahara Africa. It has ability to neutralize all extractable Al in soil. This method neutralizes exchangeable Al in the soil at the rate of 85-90% (Beernaert, 1999) and has been applied successfully in different countries (Sanchez, 1976).The calculation of lime rates (LR) needed for a given any type of lime is done through the following equation.

$$LR = \frac{\text{Amount of pure lime}}{\text{Calcium carbonate equivalent (any type lime)}} x100 \qquad \text{Equation [7]}$$

Table 4
Soil acidity and respective lime requirement

Soil pH	**Soil exchangeable Al (cmol kg-1)**	**LR (t ha-1) for first application***
>5.4	0-1	0-1.5
5.1-5.4	1-2	1.5- 3
5.1-4.7	2-3	3-4.5
≥4.7	≥3	≥4.5

LR: Lime requirement, LR (t CaCO3 ha-1) = Factor x Al cmol kg-1)

The factor depends on the amount of organic matter in the soil (Table 5). For soils with 4 to 5% organic matter content, lime application rates should be increased by 20 % (David et al., 2011). In this study, the organic matter was rough estimated at < 2.5%.

Table 5
Factors used to determine lime requirement

Factor	Organic matter (%)	extractable Al (cmol kg-1)
1-1.5	< 2.5	1
1.5-2	2.5-4	1
2	> 4	1

Source: adapted from Crawford et al.(2008)

11. Determination of agronomic and economic effects of lime

The agronomic and economic effects of limes are determined by calculating the ratio of total yield from limed and non-limed plots (Mercy and Ezekiel, 2007). The relative agronomic efficiency (RAE) and relative economic efficiency (REE) of limes is calculated to determine efficiency of lime. RAE and REE are calculated using the following equation.

$$REE\ (\%) = \frac{\text{Benefit - Cost (lime plots lime)}}{\text{Benefit (control plot)}} * 100 \qquad \text{Equation [8]}$$

$$RAE(\%) = \frac{\text{Yield (lime plots lime)}}{\text{Yield (control plot)}} * 100 \qquad \text{Equation [9]}$$

In the REE formula, the benefit and cost are those related solely to the liming cost.

12. Conclusion

Soil acidity associated to Al toxicities, soil erosion and soil nutrient depletion are the main soil related constraints to agricultural development in parts of developing countries relying on agricultural to feed their growing population. The smallholder farmers possess small sizes of land and are resource poor and have difficulties in managing acidic soils. The potentials of using lime for soils sustainable management are among the other options to explore in restoring soil health and fertility. In agriculture, the limes play a great importance in improving soil acidity and hence favour plant nutrition. However, both farmers and most of young soil scientists facing the challenges of estimating lime requirement for appropriately addressing soil acidity prevalence in most weathered tropical soils. The knowledge of soil acidification sources serve as the guide in determining the forms of acidity to address. In addition, lime requirement calculation is of help tool in avoiding under or overliming acidity soils which are detrimental and compromising soil health and plant growth in general. Therefore, there is a need of advocating the use of lime in proper manner and take precaution before liming any acidic soils.

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References

Adams, F., 1984. Soil acidity and liming, crop response on soil in tropics, Wisconsin, USA.

Awkes M.M. 2009. Comparison of calcium ameliorants and coal ash in alleviating the effects of subsoil acidity on maize root development near Middelburg, Mpumalanga. Faculty of Agrisciences, Stellenbosch University, Stellenbosch. South Africa.

Beernaert, F.R., 1999. Feasibility study of production of lime and or ground travertine for manegement of acidic soils in Rwanda. Pro-Inter Project Consultants, Brussels., p. 250.

Bell, L.C., Bessho, T., 1993. Assessment of aluminium detoxification by organic materials in ultisol using soil solution characterization and plant response. Soil organic matter dynamics and sustainability of tropical agriculture. Wiley-Sayce co-publication., p. 317-330.

Berga, L., Siriri, D., Ebanyat, P., 2001. Effect of soil amendments on bacterial wilt incidence and yield of potatoes in southernwestern Uganda. African Crop Sci. J., 267-278.

Black, A.B., 1992. Soil fertility evaluation and controlLewis Publisher, London.

Bolan, N.S., Hedley, M.J., 2003. Role of carbon, nitrogen and sulfur cycles in soil acidification. InHandbook of soil acidity. Rengel. Z, New York., p. 29-56.

Brady, N.C., Weil, R.R., 2002. The nature and properties of soilsPrentice Hall, New Jersey.

Budianta, D., Vanderdeelen, J., 1995. Dynamics of exchaneable aluminium in ultisol. International conference on soil resources and sustainable agriculture. Kuala Lumpur. Malaysia.

Carson, C.D., Dixon, J.B., 1979. Acidity. The Encyclopedia of Soil Science. Hutchinson. Ross Inc. Penn., p. 1-3.

Caudle, N., 1991. Managing soil acidity. North Carol. State Univ. North Caroline.

Clough, T.J., Kelliher, F.M., Sherlockand, R.R., Ford, C.D., 2004. Lime and soil moisture effect on nitrous oxide emissions from urine patch. Soil sci. Soc. Am. J., 1600-1609.

Coventry, D.R., B.R, W., G.R, M., M.T, H., J.C, A., J.L, M., D.C, B., 1989. Yield response to lime of wheat and barley on acidic soils in north-eastern Victoria. Aust. J. Exp. Agric., 209-214.

Crawford, T.W., U., S., H., B., 2008. Solving agricultural problems related to soil acidity in central Africa's great lakes region. Int. center. soil fertil. agr. dev. Alabama.

David. W., Adrian, C.. Carl, W., 2011. Soil pH. Colorado State University, Colorado, USA.

Fageria, N.K., 1989. Effect of phosphorus on growth, yield and nutrient accumulation in the common bean. Trop. Agric., 249-255.

Fageria, N.K., 2001. Effect of liming on upland rice, common bean, corn and soybean production in cerrado soil. Pesq. Agropec. Bras., 1419-1424.

Fageria, N.K., Baligar, V.C., 2004. Ameliorating soil acidity of tropical oxisols by liming for sustainable crop productionElsevier Inc. Academic press.

Fageria, N.K., Baligar, V.C., 2008. Ameliorating soil acidity of tropical oxisols by liming for sustainable crop production. In: D. L. SPARKS, editor Advances in Agronomy. Acad. Press. Brazil., p. 345-389.

Fageria, N.K., Stone, L.F., 2004. Yield of common bean in no-tillage system with application of lime and zinc. Pesq. Agropec. Braas., 73-78.

Fageria, N.K., V.C, B., D.G, E., 1990. Soil plant nutrient relationship at low pH stress. Crops as enhancers of nutrient use. Academic press. California., p. 475-507.

Folscher, W.J., Barnard, R.O., Bornaman, J.J., Van Vuuren, J.A.J., 1986. Growth of wheat with heavy lime application. Trop. Agric, 133-136.

Foth, H.D., Ellis, B.G., 1996. Soil fertility. 2 ed. Lewis Publishers, Boca.

Giller, Y., Brogniez, D., 1991. Reference document on fertilizer and calcite amendment in scope of policy definition of agriculture inputs in Rwanda. Ministry of Agriculture, Kigali, Rwanda.

Hakim, N., Agustian, S., Soepardi, G., 1989. Effect of lime, fertilizers and crop residues on yield and nutrient uptake of upland rice, soybean and maize in intercropping system. Nutrient management for food crop production in tropical farming system. Wangenigen University, The Netherlands., p. 349-360.

Hardy, D.H., Raper, C.D., Miner, G.S., 1990. Chemical restrictions of root in ultisol subsoils lessened by longterm management. Soil Sci. Soc. Am. J., 1657-1660.

Havlin, J.L., J.D, B., S.L, T., W.L, N., 2005. Soil fertility and fertilizers: An introduction to nutrient managemntPearson prentice hall. New Jersey.

Haynes, R.J., 1984. Lime and phosphate in the soil–plant system. Adv. Agron., 249–315.

Hester, J.B., 1936. Results from lime experiment with potatoes for 1936. Am. Pot. J., 39-40.

Huang, J., Fisher, P.R., Argo, W.R., 2007. HortScience. Amer. Soc. for., 1268-1273.

Kaitibie, S., Epplin, F.M., Krenzer, E.G., Zhang, H., 2002. Economics of lime and phosphorus application for dual purpose winter wheat production in low pH soils. Agron. J., 1139-1145.

Kamprath, E.J., 1970. Exchangeable Al as criterion for liming leached minal soils. Soil Sci. Soc. Amer., 252-254.

Kariuki, S.K., Zhang, H., Schroder, J.L., Edwards, J.E., Payton, M., B.F, C., Raun, W.R., Krenzer, E.G., 2007. Hard red winter wheat cultivar responses to a pH and aluminium concentration gradient. Agron. J., 88-98.

Kayonga, J., Goud, B., 1989. Experiment for soil fertility improvement in crete Zaire-Nil. Soil fertility improvement trials in Crete Zaire-Nil. MINAGRI, Kigali, Rwanda., p. 131-144.

Kemperl, J., Maček, J., 2009. Precipitation of calcium carbonate from hydrated lime of variable reactivity,granulation and optical properties. Int. J. Miner. Process., 84-85.

Kiiya, W.W., Mwwoga, S.W., Obura, R.K., Musandu, A.O., 2006. Soil acidity ameriolation as a method of sheep sorrel (rumex acetosella) weed management in Potato (solanum tuberosum L.) in cool highlands of the north Rift, Kenya. KARI Biannual scientific conference. KARI. Nairobi.

Larry, O., 2000. Agricultural limestone neutralizing value, Plant and soil sciences. Mississippi State University, Mississippi. USA.

Maheshwari, D., 2006. Soil acidity. Department of Landscape architecture. CEPT University. Sandip patil.

Mbakaya, D.S., Okalebo, J.R., Muricho, M., Lumasayi, S., 2011. Effects of liming and inorganic fertilizers on maize yield in Kakamega north and ugunja districts, Western Kenya. KARI. Nairobi. Kenya.

McBride, M.B., 1994. Environmental chemistry of soilsOxford University Press, New York.

McCauley, A., C, J., J, J., 2009. Soil pH and organic matter, nutrinets managements module. Montana State University, Bozeman. USA.

McFarland, M.L., Harby, V.A., Redmon, L.A., Bade, D.H., 2001. Managing soil acidityTexas agricultural experiment station. Texas.

Mercy, O.A., Ezekiel, A.A., 2007. Lime effectiveness of some fertilizers in tropical acid alfisol. J. cental European agriculture., 8, 17-24.

Naidu, R., Syers, J.K., Tillman, R.W., Kirkman, J.H., 1990. Effect of liming and added phosphate on charge characteristics of acid soils. Soil Sci. J., 157-164.

Nduwumuremyi, A., Mugwe, J.N., Ruganzu, V., Rusanganwa, K.C., Nyirinkwaya, B., 2013. Effects of Travertine in Improving Selected Soil Properties and Yield of Irish Potato (Solumun tuberosum L.) in Acidic Soils. J. Agr. Sci. Technol., A 3,175-182.

Nurlaeny, N., Marschner, H., and George, E., 1996. Effects of liming and mycorrhizal colonization on soil phosphate depletion and phosphate uptake by maize(Zea Mays L.) and soybean (Glycine max L.) grown in two tropical acid soils. Plant Soil., 275-285.

Oates, K.M., Kamprath, E.J., 1983b. Soil acidity and liming: I Effect of the extracting solution cation and pH on the removal of aluminium from acid soils. Soil Sci. Soc. Am. J., 686-689.

Ramos, B., Mojica, P., 1982. Productivity of cassava, Manihot esculenta Crantz, in a clayey, kaolinitic, isohyperthermic, Paleudult (Antipolo clay). Phil. J. Crop Sci., 7, 123-127.

Rosemary L., 1991. Vegetable crops. Department of plant pathology, Cornell University. New York. USA.

Sanchez, P., 1976. Properties and management of soils in tropicsWiley-Interscience. New York. USA.

Scott, B.J., Fisher, J.A., Cullins, B.R., 2001. Alluminium torelance and lime increase wheat yield on the acidic soils of central and southern. Aust. J. Exp. Agric., 523-532.

SOFRECO., 2001. Evaluation and classification of travertines deposits. Ministry of Industries and tourism. Kigali. Rwanda.

Soil Science of America., 1997. Glossary of soil science terms. soil science society of America. Madison. USA.

Soil Survey Division Staff., 1993. Soil survey manual. US Dept. of agriculture handbook. US Govert. printing office. Washington. DC.

Sparks, D.L., 2003. Environmental soil chemistryAcademic press. California. USA.

Stephen, P.C., Caroline, H.O., Angel, J., Carlo, L., Julia, M.C., 2011. Diversity and activity of free-living nitrogen - fixing bacteria and total bacteria in organic and conventionally managed soils. Appl. Environ. Microbiol.

Stevens, R.J., Laughlin, R.L., Malone, J.P., 1998. Soil pH affects process reducing nitrate to nitrous oxide and Di-nitrogen. Soil Biol. Biochem., 1119-1126.

Synder, C.S., Leep, R.H., 2007. Fertilization forages. Sci. grassland agr., 355-379.

Tisdale, S.L., L, N.W., D, B.J., L., H.J., 1993. Soil acidity and basicity. 5 ed. Macmillan Publishing. New York.

Treder, W., Cieslinski, G., 2005. Effect of silicon application on cadminium uptake and distributiion in starwberry plants grown on contaminated soils. J. Plant nutr., 917-929.

Uchida, R., Hue, N.V., 2000. Soil acidity and liming. Plant nutrient management in Haweii soils, approaches for tropical and subtropical agriculture. College of tropical agriculture and human resources, University of Hawaii, Manoa, Hawaii.

Van Straaten P., 2002. Rocks for crops: Agrominerals of sub-saharan AfricaICRAF, Nairobi, Kenya.

Wouters, J., Gourdin., 1989. Summary report of soil fertility conservation and improvement in Burundi through local. Faculty of Agriculture, University of Burund. Bujumbura. Burundi.

Yamoah, C.F., Burleigh, J.R., L, R.J., Mukaruziga, C., 1992. Correction of acid infertility in Rwandan oxisols with lime from an indigenous source for sustainable cropping. Exploratory agr., 417-424.