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Organic based amendments for the management of tropical acid soils: Potentials and challenges

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Abstract:*Soil acidification is a major drawback to efficient crop production and actualization of global food security goal. Conventional liming materials such as limestone, quicklime and slaked lime have been widely used in its management. Organic carbon depletion, inability to substantially improve concentrations of soil macro nutrients especially phosphorus and nitrogen, loss of soil aggregate stability and high procurement cost by poor resource farmers are associated with use of conventional liming materials. These have opened research areas to soil and environmental scientists in developing other environmental friendly options in managing this soil menace. Use of organic materials such as green manure, animal manure, composted biomass, modified/fortified compost and many more in neutralizing soil acidity have been widely documented. Despite the abundance of these organic materials in the ecosystem and enormous researches into their use as soil amendments, there use especially in the management of soil acidity is still at bay. This review paper therefore aimed at bringing to lime light the potentials of these organic based materials in ameliorating acidity in the low activity clay of the tropical soils for enhanced crop production. The paper also carried out comparative assessment between the efficiency of these organic materials in alleviating toxic aluminum and hydrogen ions and the conventional liming and fertilizer materials. The work concluded by summarizing possible challenges to the use of organic based amendment in combating the problem of soil acidification.*

Keywords*: Plant residues, compost, phospho-compost, tropical acid soils, conventional liming materials*

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I. Introduction

Acid soils and their distribution in the world

A soil is acidic when the soil pH is less than 7. It becomes an issue of concern when the pH drops below 6.0. Soil acidification is one of the top five constraints to improved crop production in the world [1]. It is a limiting factor to sustainable cropping systems in the world [2,3]. It is of importance in highly weathered low activity clay soils of the humid and sub humid zones of the tropics [4,5].

Acid soils are widely distributed in the world. [6]reported about 40% of arable fields of the world as being naturally acidic. The rainforest and the savanna zones of the tropics are dominated by acid infertile oxisols, ultisols and alfisols with largest proportions in Latin America (81%), Africa (56%) and Asia (38%) [7]. Tropical soils are generally in acidic pH range as a result of high rainfall especially when rainfall exceeds the rate of evaporation and plant transpiration [6,8]. This encourages leaching of basic cations (Ca^{2+}, $Mg^{2+}$and K^{+}) from the top soil [4]. Soils of the wet forest zone where annual rainfall is more than 1750 mm per annum are more susceptible to natural acidification processes [4]. The soils are thoroughly leached and very acidic with pH ranging from 4.0 to 5.0 with characteristic low base saturation [4].

Causes of soil acidity

Natural causes

Soil acidification is caused by both natural and anthropogenic factors. Natural soil acidification is controlled by high rainfall intensities, leaching of basic cations when rainfall exceeds evapotranspiration [6,8], weathering of rock [5], oxidation of sulphur [5], acid rain [9] and hydrolysis of aluminum and iron [10,5]. Under optimum pH range (6.5-6.8) ideal for nutrient release for most plants, Al^{3+} are held tightly unto the exchangeable sites of soil colloids with stability state increasing with increasing soil pH. Occurrence of processes that encourage reduction in soil pH values contribute significantly to the solubilization of Al ion species into the soil which encourages its bioavailability to plant roots for uptake.

Anthropogenic causes

Acid soils occurrence through anthropogenic factors is on the increase in the tropics as result of poor management of intensively cultivated farmlands to cope with increasing demand for food caused by increasing human population. Continuous cropping of farmland without adequate replacement of nutrients taken up by plants has replaced the shifting cultivation and bush fallowing which were major farming practices that help in natural management of soil nutrient degradation. Basic cations such as Ca^{2+}, Mg^{2+} and K^+ which serve to counteract the effects of toxic Al and H ions are severely depleted in continuously cultivated fields [11]. The electrical vacuum left by the uptake of these basic cations results in the release of H^+ from the plant roots in order to maintain electrical balance. This effect is greater when plant absorbs nutrient more in the form of NH_4^+ [8].

The level of organic matter and essential nutrients particularly N and P are low in most tropical soils [12]. Most farmers depend on external sources of fertilizer majorly chemical fertilizers to replenish soil fertility. The use of chemical fertilizers became popular at the beginning of the 20th century [13]. The current reliance of farmers on chemical fertilizers surpasses that of organic amendments for soil fertility replenishment in the developing countries. Although these fertilizers are vital for high yields, but their indiscriminate use have associated effects. Reduction in the concentration of basic nutrient, soil pH decreases [14] and nutrient imbalance which contribute to increasing soil acidification have been reported for soils treated with chemical fertilizers such as single super phosphate, NPK 15:15:15, urea and ammonium nitrate [15,16,8,17,18].

Nitrogenous fertilizers contain ammonium ions which when transformed into the nitrate form are accompanied by the release of hydrogen ions. For example, the overall reaction of urea a notable nitrogenous fertilizer in soil produces four moles of H^+ ions after an initial consumption of two moles of H^+ [5].Reactions of commonly used chemical fertilizers in Africa such as urea, NPK 15:15:15 and single superphosphate was studied by [18]. They reportedreductions of calcium and magnesium saturations by 16 and 31 % respectively and increase in acidity saturation by 25% after two consecutive cowpea croppings on an ultisol managed by applications of these chemical fertilizers (Tables 1 and 2).

Conventional management of acid soils

The management of acid soil has been achieved through planting acid tolerant species, application of inorganic phosphorus and conventional liming materials. The use of conventionalliming materials such as calcium chloride, dolomitic limestone, quick lime, slaked lime, marl, oyster shell and ashes from kilns are common in neutralizing acidity in soils.

Chemistry of conventional liming materials in acid soils

The chemistry of neutralization reaction of conventional liming materials in acid soils is centered on increases in soil pH over application time [19]. This is influenced by release of basic cations usually Ca^{2+} and Mg^{2+} from the liming materials on application into soils. [20] submitted that $SiO4^{4-}$ from the mineral lattice of theacidic clay minerals undergo hydrolysis in the presence of soil water and application of lime produce large concentrations of hydroxyl ions which results in a rise in soil pH

$$4Ca^{2+} + 4SiO_4^{4-} + 4H_2O \rightarrow 4Ca^{2+} + Si(OH)_4 + 4OH^{-} \text{-------} \quad \textbf{Eq. (1)}$$

As the soil pH continue to rise upon continuous release of more OH^- group and deprotonation of H^+ from the edges of the kaolinitic clay, the soluble Al in the soil become precipitated as inert Al-hydroxides. This is of importance as soil pH approaches 5.0 which is the solubility constant (pKa) of Al [21]. [22] opined that application of liming material such as $CaCO_3$ to an acidic soil dominated with acidic cations such as H^+ and Al^{3+} (denoted as Al-soil), the added liming material will react with the soil water containing CO_2 as illustrated below

$$CaCO_3 + H_2CO_3 \rightarrow Ca(HCO_3)_2 \quad \text{\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_} \quad \textbf{Eq. (2)}$$

Table 1: Effects of chemical fertilizers and lime on soil pH in Itagunmodi soil series at different weeks after sowing.

	First cropping						Second cropping					
Treatments	2*	4	6	8	10	12	2	4	6	8	10	12
CONTROL	4.5 b	4.4 ab	4.6 b	4.8 b	4.8 b	4.9 b	4.6 b	4.6 b	4.7 b	4.8 bc	4.7 b	4.8 b
Lime	4.9 a	4.7 a	5.0 a	5.5 a	5.1 a	5.4 a	4.9 a	5.3 a	5.1 a	5.2 a	5.1 a	5.4 a
NPK	4.0 c	4.0 c	4.2 d	4.5 b	4.5 c	4.4 c	4.3 b	4.3 c	4.2 c	4.4 c	4.2 c	4.4 b
Urea+SSP	4.2 ab	4.2 bc	4.3 cd	4.8 b	4.6 c	4.7 c	4.4 b	4.3 b	4.6 b	4.6 bc	4.4 bc	4.6 b
SSP+GL	4.5 b	4.4 ab	4.5 bc	4.7 b	4.6 bc	4.7 c	4.6 b	4.6 b	4.6 b	4.8 b	4.5 b	4.8 b

*Means followed by the same letter (s) in the same column are not significantly different by DMRT at $p<0.05$
AC= Absolute control, SSP= Single super phosphate, GL = *Gliricidia sepium* leaves, NPK=NPK 15:15:15.*weeks after sowing
Source:[18].

Table 2 Aluminum, hydrogen and acidity saturation percentages in chemical fertilizer and lime treated acidic soil at different weeks after sowing

	Aluminum saturation (%)			Hydrogen saturation (%)			Acidity saturation (%)		
Treatments	4*	12	24	4	12	24	4	12	24
CONTROL	8.5 a	8.4 a	7.8 a	45.9 a	44.3 b	49.0 a	54.4a	52.7 b	56.8 a
Lime	8.8 a	0.8 d	2.9 b	31.8 b	18.63 c	27.9 d	40.6 b	19.4 d	30.8 d
NPK	9.4 a	7.4 bc	9.1 a	50.6 a	58.5 a	38.6 b	60.0 a	65.9 a	47.7 b
Urea+SSP	10.5 a	10.6 a	4.6 b	21.0 c	13.0 d	34.0 c	31.5 c	23.6 c	38.6 c
SSP+GL	9.5 a	5.3 c	2.6 b	23.9 bc	16.3 cd	20.4 e	33.4 c	21.6 cd	23.0 c

Means followed by the same letter (s) in the same column are not significantly different by DMRT at $p<0.05$.AC= Absolute control, SSP= Single super phosphate, GL = *Gliricidia sepium* leaves, NPK=NPK 15:15:15.*weeks after sowing.
Source: [18].

The calcium bicarbonate formed is soluble in water, bringing about dissociation of Ca^{2+} which is adsorbed by the soil in exchange for initially adsorbed Al^{3+} by the soil as illustrated below

$$3CaCO_3 + Al_2\text{-soil} \leftrightarrow Ca_3\text{-soil} + 2Al(OH)_3 + 6CO_2 \qquad \textbf{Eq. (3)}$$

[5] opined that regardless of the form in which calcium is added to the soil, in the presence of atmospheric carbon dioxide, it will be converted to calcium carbonate

$$CaO + CO_2 \rightarrow CaCO_3 \qquad \textbf{Eq. (4)}$$

or

$$Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O \qquad \textbf{Eq.(5)}$$

The calcium carbonate under acidic soil condition dissociates to release OH^- which neutralizes the H^+ to form water

$$CaCO_3 + H_2O \rightarrow Ca^{2+} + HCO_3^- + OH^- \qquad \textbf{Eq. (6)}$$

The dissociated Ca^{2+} ions therefore replace H^+ ions on the soil surface

$$2H\text{-soil} + Ca^{2+} \rightarrow Ca\text{-soil} + 2H^+ \qquad \textbf{Eq. (7)}$$

The OH^- reacts with the displaced H^+ ions to form water as shown below

$$OH^- + H^+ \rightarrow H_2O \qquad \textbf{Eq. (8)}$$

The increase in soil pH brought about by the neutralization of the H^+ and a shift in the ratio of the basic cations held on soil particles and that in the solution result into improved soil reaction. This encourages aluminum ions held on the negatively charged exchange sites of the soil particles to be displaced and the ions in soil solutions transformed into the solid state sesquoxides.

$$Al^{3+} + 3OH^- \rightarrow Al(OH)_3 \qquad \textbf{Eq.(9)}$$

The ability of liming materials to increase the concentrations of basic cations in the soil solution also solves the problem of multiple macronutrient deficiency in acid soils. This eventually increased the base saturation and cation exchange capacity (CEC) of the soil.

Limitations associated with conventional liming materials

The nature of acidity in variable charged soils has been studied and has helped to predict the behavior of lime within the soil profile [23]. Movement of lime in soils especially under conventional tillage is slow and does not move readily down the profile particularly in tropical soils characterized by variable charge as a result of presence of kaolinite and sesquoxides [24]. After the dissociation of Lime applied on soil surfaces, there is need for the movement of alkaline radicals (HCO_3^- and OH^-) into the subsoil through mass flow for it to be effective. [25] reported that alkalinity mobility of these radicals to sub soil requires that the top soil pH be above 5.4 at which concentration of alkaline radicals increase logarithmically. In variable charged soils however, this increasing concentration is reduced because part of the alkaline phase achieved is used to build up the CEC. Positive charged sites frequently found in acid sub soils bring about rapid downward movement and eventual loss of dissociated Ca^{2+} when lime is applied (as a result of repulsion of like charges) without any change in pH [25].

The use of liming materials that will supply only Ca and or Mg may not therefore sustainably correct soil acidity and translate into higher crop yield in tropical soils generally characterized by macronutrient depletion and low cation exchange capacity. Improved responses have been reported when such materials are combined with P source [4] and organic materials [26]. The continued application of lime in order to maintain soil pH at higher values can accelerate decomposition of organic matter, resulting in increased CO_2 emission with need for external carbon input [27]. [28] discovered that liming with conventional liming materials had adverse effects on plant growth and soil properties. They pinpointed inducement of P, Zn, Mn, Mo, Cu, Zn, and B deficiencies by indiscriminate lime application. On the other hand, [5] reported that the problem of over liming tropical acid soil is more of physical than chemical, affecting soil permeability. High infiltration rate and rapid basic cationic nutrient leaching prevalent in many tropical soils is associated with their highly stable structure resulting from Fe and Al oxides binding soil particles together. Over liming such soils however, flocculates and destabilizes this structure obstructing water permeability and drainage.

The practice of liming is expensive and can greatly increase cost of crop production [29]. Acid tolerant crop species are sometimes recommended for use on acid soils where liming materials are scarce. This however may not be sustainable especially where the crop species are not well adapted to the environment they are introduced to. From the foregoing, the need for a more sustainable soil acidity management is imperative for enhanced crop production in low activity clay minerals of the tropics.

II. Need for organic materials in soil acidity management

Low-input agriculture that utilizes organic matter from the farm was the usual practice among farmers in Africa many decades ago. Continuous cropping practiced now has increased occurrence of erosion on these soils leading to reduced levels of SOM [13]. Need for organic amendments that will help buffer the changes in nutrient ion concentrations in the soil solution and form complexes with the toxic Fe and Al ions had been suggested [30].

In recent years, animal manure from livestock farms and organic wastes from rural and municipal areas have seriously contaminated the environment. Recycling such materials into compost is a step in the right direction [31]. The recycling of crop residue has been demonstrated to be one of the ways to improve soil nutrient content, maintenance of soil reaction and productivity [32]. [33] estimated that about 5 Mt/ha of N, 3 M t/ha P_2O_5 and 6 M t/ha of K_2O can be returned into the soil from the 100 M t/ha organic waste. The use of crop waste such as legumes, rice husk, burnt rice husk, maize stover, oil palm bunch, wood ash, peanut residue as soil amendments on acid soils have been studied by many authors [34,35,36,37,38,39,40]. Improve yield, soil pH, total N, available P, basic cation concentrations, overall CEC, reduced exchangeable Al, acidity resulting in better root growth and improved soil physical conditions have been reported [41,42,43,44] on acid soils amended with organic materials as summarized in Table 3.

Liming potentials of organic materials

The work of [45] showed enhancement in maize performance after application of crop residue such as *Hyptis suaveolens, Cordiaspp, Vignaunguiculata and Cajanuscajan*in an acid soil. They gave the high ash alkalinity content of the organic residues as a major factor for their acidity neutralizing potentials. The potential alkalinity expressed as mmol OH kg^{-1} of plant organic residue is a measure of the ability of residues to ameliorate soil acidity [45]. They classified ash alkalinity into available alkalinity and non-available alkalinity.
Available alkalinity defined as the readily soluble or active fraction of the organic anions is responsible for immediate increase in soil pH when crop residues are applied to soil. Non - available alkalinity is said to be the organic anions that do not readily ionize in soil solution which becomes significant with time as the residues undergo decomposition conferring long term ameliorative effect on acidic soils [45]. The liming potential of crop residue was found by [46] to be positively related to the basic cation content of the organic matter and negatively related to the nitrogen content of the organic matter. Plant residues with high basic cation contents such as soybean and cotton are more effective in neutralizing soil acidity than those with lower concentration such as maize and wheat [46]. Crop residue with higher N content tends to have a negative effect due to the acidity formed when the N is oxidized during decomposition [45].

Table 3: Effects of application of organic materials on soil acidic parameters and crop performance

Organic materials	Application rates	Effects on soils	Effects on crops	References
**Tithonia diversifolia*, cattle dung	Each was applied at 20 t ha^{-1} and 60 kg P ha^{-1}	Both organic materials increased soil available phosphorus with values superior to conventional phosphorus fertilizer (Triple superphosphate) tested. The soil pH and exchangeable acidity however did not improve significantly	Not reported	[41]
**Organic fertilizers	0.25 t ha^{-1}	Exchangeable Al concentrations in the soil was reduced and available P increased with values superior to the conventional lime used for the comparison study	Grain yield of rice improved compared to unamended soil but was lower than the conventional lime	[44]

**Tithonia diversifolia* *Imperata cylindrical* *Gliricidia sepium*	Each was applied at 10 t ha^{-1}	The plant residues significantly reduced exchangeable acidity in the order of Imperata > Tithonia > Gliricidia. The enhanced soil pH was responsible for up to 33 and 53% reductions in exchangeable Al and H respectively. Tithonia was highest in enhancing soil available phosphorus.	The improved soil pH contributed up to 22% increases in dry root weight of maize.	[40]
Phospho-composts (SD+PM+BM and RB+PM+BM)	Each was applied at 2.5 and 5.0 t ha^{-1}.	The two phospho-compost significantly increased soil pH from initial 4.8 to a range of 4.9 – 5.7 over 4.7 – 5.5 and 4.1 – 4.7 from CaCO3 and mix of N:P:K 15:15:15 and urea respectively.	Not reported	[43]
*Rice straw Rice straw biochar	Each was applied at 1 and 5%	The two organic materials decreased exchangeable Al concentrations in the soil compared to unamended soil with pH kept constant.	The enhanced soil conditions significantly increased shoot and root weights of wheat. The Al concentrations at the root tip of wheat seedlings was also reduced drastically compared to the unamended soil	[47]
Poultry manure*** Lime NPK 15:15:15	Poultry manure at 5 and 10 t ha^{-1},lime at 250 kg ha^{-1} and NPK 15:15:15 at 100 kg ha^{-1}	The poultry manure and lime increased soil pH in similar way. Spiking lime and NPK 15:15:15 with poultry manure reduced manganese toxicity	Co-application of lime or NPK 15:15:15 with poultry manure led to significant increases in maize grain yield.	[48]

*, ** and *** are incubation, glass house and field trials respectively.

During decomposition of crop residue in the soil, lime is liberated in proportion to the basic cation contained in the residue. Shown below is the oxidation of calcium oxalate and gluconate in plant residue.

$$\mathbf{Ca(OOC)_2 + 1/2O_2 \rightarrow CaCO_3 + CO_2} \qquad \textbf{Eq. (10)}$$

$$\mathbf{Ca(C_6H_{11}O_7)_2.H_2O + 11O_2 \rightarrow CaCO_3 + 11CO_2 + 12H_2O} \qquad \textbf{Eq. (11)}$$

Lime is also formed when these crop residues are thermally decomposed which on exposure to the atmosphere would become carbonated[46] as shown below.

$$\mathbf{Ca(OOC)_2 + heat + 1/2O_2 \rightarrow CaO + 2CO_2} \qquad \textbf{Eq. (12)}$$

$$\mathbf{CaO + CO_2 \rightarrow CaCO_3} \qquad \textbf{Eq. (13)}$$

Reactions of organic based amendments in acid soils

A lot of reaction pathways have been reported for the neutralization of acidity in soils treated with organic based materials. Controversy however surrounds the mechanisms by which such Al detoxification occurs. Proposed mechanisms and reaction pathways include an increase in soil pH [2] from the readily available alkalinity in the organic material andadsorption of soluble Al on the surface of decomposing organic material [49]. [50], was of the opinion that the mechanism that best explain the neutralization reaction in organic matter treated soil is the microbial decarboxylation of organic matter complex containing calcium followed by hydrolysis of the calcium ions and reaction with the exchangeable hydrogen and aluminum ions to form water and insoluble aluminum hydroxide ($Al(OH)_3$). The dominant reactions involved in amelioration of toxic aluminum by organic materials are explained thus:

Increases in soil pH

Biomass of plant or animal origin are generally alkaline in nature as a result of high ash alkalinity values attained from continuous uptake of basic cations especially Ca^{2+} and Mg^{2+} from soils. On decomposition in soils, the organic materials mineralize the locked up ash in them into soils which is important in the modification of the soil pH from the acidic to neutral and alkaline ranges. The increase in soil pH to values above 5.5 is important in presenting the toxic monomeric Al and H in stable non-reactive forms. Solubility and reactivity of oxides and hydroxides of Al in soils are highest at pH below 5.5 [5]. Applications of crop residues have contributed to significant increases in soil pH both at short (Fig.1) and long term trials [40,51,52]. [53] submitted that return of residues of plant materials into fields is of importance in increasing the pH of soils initially reduced by uptake of basic cations by plants.

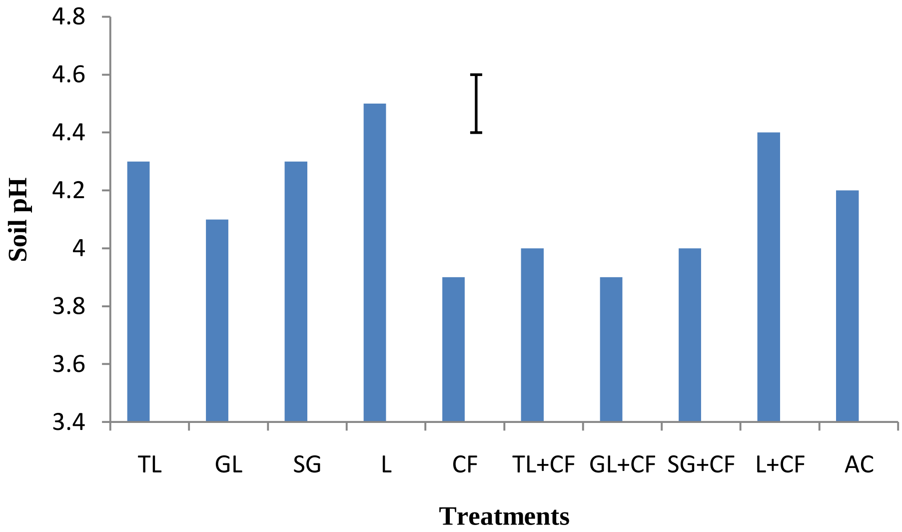

Fig.1: Effects of plant materials, lime and chemical fertilizer applications on soil pH after maize harvesting at 3 weeks after sowing.

TL=sole *Tithonia diversifolia* leaves, GL= sole *Gliricidia sepium* leaves, SG= sole spear grass (*Imperata cylindrica*), L=conventional lime ($CaCO_3$), CF= chemical fertilizer (NPK 15:15:15-Urea mix), AC= unamended soil (control). Bar= Standard error of means.
Source: [40].

Specific adsorption of phytotoxic aluminum ions

The decomposition of organic based materials in soils confers variable charges (both positive and negative charges) in soils. Humic molecules and low molecular weight organic acids have been identified as dominant functional groups from the decomposition of organic materials in soils which are of importance in the amelioration of toxic Al^{3+} and H^{+} in acid soils. The negative charged ends of the organic colloid have characteristic affinity for sesquoxides. This results in the adsorption and stabilization of toxic acidic cations ($Al^{3+}$and H^{+}) into the mineral lattice of the soil. Cations stabilized by specific adsorption are not free to move in soil solution where they could be bioavailable for plant uptake [22]. The low molecular weight organic acids in soils include: formic, propionic, lactic, acetic, oxalic, succunic, tartaric, butyric, citric and fumaric acids. Large concentrations of these organic acids are added from plant leaves and soil microbial biomass [54]. The release of organic acids protects the root apex by chelating Al in the rhizosphere, thus rendering it non-phytotoxic. Soluble organic acids of concentrations 5-50 uM were observed by [55] to be effective in detoxifying Al and improving root growth of cotton seedlings. The organic acids that were most effective include: citric > oxalic > tartaric > malic >malonic> salicylic acids. For example, malic acid released from the tips of wheat plant conferred resistance to Al stress while citric acid achieved similar mechanism in maize [56].

Increased phosphorus availability through mineralization and positive non-specific adsorption processes.

The major limiting nutrient element in acid soils of the tropics is phosphorus. The main reason for the poor root development of plants growing on aluminum toxic soils is traced to phosphorus deficiency in acid soils. The positive charged end of the variable charged colloids of organic based amendment is responsible for positive non- specific adsorption of phosphate ions desorbed from the hold of toxic aluminum ions after been sorbed by the negative charged ends [22]. [57] observed redistribution of phosphorus with increases in labile P fractions and reduction in phosphate sorption characteristics of an alfisol after application of crop residues. The applied organic material hindered the loss of the desorbed phosphate to leaching by percolating water. The excess phosphate ions are thereby held by weak electrostatic forces unto the exchangeable sites of the organic colloids. Ions held this way are easily released into the soil solution pool when the state of equilibrium of concentrations of phosphate ions in soil solution pool is sifted as a result of depletion by plant and soil microorganism uptake. This positive non-specific adsorption initiated by positive charged ends of the organic colloids also helps to neutralize excess positive charges initially on the soil colloid of which Al^{3+} and H^{+} are dominant in acid soils. This favours efficient phosphorus management against leaching loses. Additional phosphate ions are released directly into the soil solution pool for plant uptake during the mineralization of the organic material for transformation of organic phosphate form into the inorganic form during decomposition (Fig.2.).

Amelioration of soil acidity using different organic materials

Many authors have studied the ameliorative potentials of organic materials in acid soils for improved crop production. Organic materials that have received attention from many authors are plant residues of different kinds applied raw or modified by heating in the absence of oxygen, animal manures and composted plant and animal wastes. Recently, research into use of fortified compost such as phospho-compost is gradually gaining attention. Results of the use of these organic materials from different authors are summarized.

Wang and coauthors tested biochar prepared from wheat, rice and peanut plant residues under slow pyrolysis on two strongly acid soils [58]. The biochar materials were incubated at 10 and 20g kg^{-1} soil. The biochar materials increased soil pH, exchangeable bases and reduced aluminum saturation in the two acid soils. The exchangeable acidity concentrations reduced with increasing biochar application rates. The soil pH recorded at low and higher biochar application rates were however reported to be similar. A negative linear correlation was observed

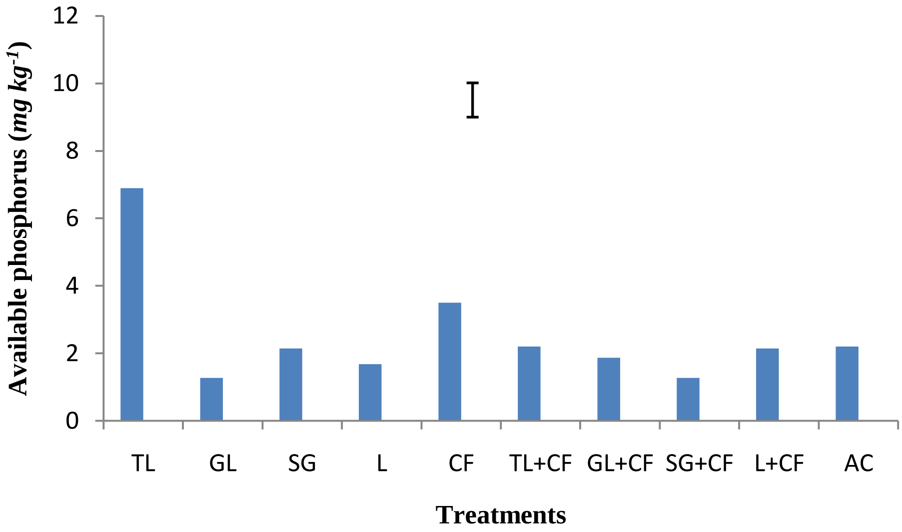

Fig.2. Effects of lime, plant materials and chemical fertilizer applications on available phosphorus after maize harvesting.

TL=sole *Tithonia diversifolia* leaves, GL= sole *Gliricidia sepium* leaves, SG= sole spear grass (*Imperata cylindrica*), L=conventional lime ($CaCO_3$), CF= chemical fertilizer (NPK 15:15:15-Urea mix), AC= unamended soil (control). Bars= Standard error of means.
Source: [40].

between exchangeable acidity and alkalinity balance in the plant biochar amended soils. The reactions of the plant biochar in the soil were also observed to reduce acidity production associated with nitrogen cycling in the soils. They reported decarboxylation and adsorption of H^+ unto the porous sites of the biochar materials as dominant mechanisms involved in the acidity neutralization in the two soils.

Smith and coworkers studied the effects of organic and inorganic calcium compounds in ameliorating sub soil acidity in a column experiment [59]. Calcium citrate from organic source improved active soil pH from initial 4.5 to 7.0, ameliorate toxicity of exchangeable Al ions by saturating the upper 10 cm soil depth of the column with Ca^{2+}. This improved CEC of the soil to 8.0 cmol kg^{-1} from initial 3.5 cmol kg^{-1} soil. The calcium chloride from inorganic source however, did not significantly increased soil pH. Their work concluded that Ca^{2+} alone could not successfully displace Al^{3+} from the exchangeable sites of the soil but the complexing ability of the organic acid (Citrate) didas against high calcium in leachates collected from the inorganic calcium sources.

Opala and his coworkers evaluated the ameliorative ability of *Tithonia diversifolia* and cattle dung applied solely and in combination with phosphorus sources such as triple superphosphate, Minjingu and Busumbu rock phosphates in an acid soil [41]. They observed higher liming efficiency in cattle dung and *Tithonia diversifolia* when applied solely. They submitted that there was no significant evidence of synergism when the organic materials were integrated with the phosphorus sources.

The liming and fertilizer potentials of plant materials such as *Tithonia diversifolia*, *Imperata cylindrical* and *Gliricidia sepium* were studied by [40]. The plant materials applied solely 10 g per 500 g soil had liming efficiencies ranging from 33 – 100 % relative to 100 % from the conventional liming material ($CaCO_3$). *Tithonia diversifolia* plant was efficient in enhancing soil available phosphorus by 97 % compared to soil that received conventional chemical fertilizer (NPK 15:15:15). The increased pH from soil amended with these plant materials at the end of the trial significantly reduced exchangeable Al and H by 33 and 53 % respectively. This resulted in enhanced dry root and shoot weights of maize seedlings.

Bessho and Bell studied the acidity ameliorative reactions of two plant materials; tree legume (*Calliandracalothyrsusmeissn*) and Barley (*Hordeumvulgare* L.) straw in production of mung bean (*Vignaradiata* (L.) Wilczek) [60]. The plant materials increased root length of mung beans similar to the conventional $CaCO_3$ as a result of reduced concentrations of Al^{3+} in the amended soil solution. They proposed precipitation of soluble Al along with formation of Al-organic matter complexes as dominant mechanisms utilized by the decomposed plant materials to neutralize acidity. The legume based plant was reported to be more efficient than barley straw in ameliorating acidity as a result of its higher Ca and Mg contents.

Residual effects of organic amendments were studied by [61]. They observed positive residual effects of the organic based amendments tested in the acid soil compared to inorganic based amendment applied solely.

The severe deficiency of phosphorus in acid soils has led to use of phosphorus modified compost (generally called Phospho-compost) in the amelioration of acid soils of the tropics. [62] assessed the liming efficiency of phospho-compost in acid soil. Very high liming efficiency values were observed from phospho-compost treated plots. Phospho-compost prepared from combination of sawdust, poultry manure and bone meal applied at 2.5 and 5.0 t ha^{-1} gave liming efficiency values above the 100% reference value from the conventional liming material ($CaCO_3$). This produced cowpea grain yield five times better than aglime treated plot and doubles the yield from synthetic fertilizer plots.

[43] also reported phospho-compost treatments to improve soil pH from initial 4.8 to 5.7, available phosphorus was increased to a range of 44.8 – 144.5 mg/kg from initial 3.6 mg/kg after two consecutive cropping. The calcium saturated percentage was increased to 68.6% in phospho-compost treated plot above 59.7% observed from plot that received conventional aglime.

The work of [63] showed the higher potentials of phospho-compost to improve soil available phosphorus (the major limiting nutrient element in acid soils) concentrations and uptake by plants. The phospho-composts were prepared through fortifying compost earlier prepared from sawdust and poultry manure and rice bran and poultry manure with bone meal at 40 kg P_2O_5 ha^{-1}. Phospho-compost was responsible for mean 4.6.kg phosphorus uptake by cowpea per hectare compared to single superphosphate fertilizer (mean of 2.7 kg ha^{-1}) in the two acid soils studied. They reported a lower phosphorus use efficiency (PUE) by cowpea in phospho-compost treated soil (mean of 11.0%) compared to mean of 82.2% from single superphosphate treated soil. Possible increase in microorganism population in phospho-compost treated soil that might have competed with the cowpea plant for uptake of mineralized phosphorus nutrient was given as reason to the lower PUE.

The ameliorative capacity of phospho-compost and poultry manure compared to conventional synthetic phosphorus fertilizer (single superphosphate) in aluminum toxic soil was evaluated by [64]**.** Their results showed phospho-compost to significantly improve root length, germination index, dry shoot and root weights of cowpea seedlings compared to single superphosphate treated soil. The phospho-compost modified the rhizosphere for improved net negative charge to aid higher uptake of basic cations mineralized from the phospho-compost by the plant roots. The variable charges also displace toxic Al^{3+} from the soil colloids to liberate phosphate fixed into soil solution. The single superphosphate treated soil was however superior in enhancing available phosphorus in the aluminum toxic soil.

[65] studied the effects of compost prepared from sugar cane filter cake and conventional lime in acidity amelioration and nitrogen availability in acid sulfate soil. The compost application increased soil pH and reduced exchangeable aluminum. They observed the inability of $CaCO_3$ applied solely at 2 t/ha to improve soil pH significantly above unamended soil after 82 days of incubation. Co-application of $CaCO_3$ and compost however raised soil pH from 3.3 to 6.1 and reduced exchangeable and soluble aluminum in the soil. Application of compost alone also enhanced the concentrations of NH_4^+ N, NO_3^- N and biological processes in the soil. Chemical reactions between the anionic functional group of the organic molecules and soil solution Al^{3+} which led to reduced solubility of the Al^{3+} and toxicity was given as the dominant mechanism involved in acidity amelioration.

[48] tested influence of poultry manure, aglime and NPK 15:15:15 on soil chemical properties and maize yield in an acidic soil in Nigeria. Their work showed ability of poultry manure to improve soil pH to be similar to aglime. Sole poultry manure further reduced manganese concentrations in the soil compared to other sole treatments. Integration of the three amendments tested however gave higher effective cation exchange capacity than sole NPK 15:15:15, sole aglime or combination of the two. Combination of aglime and poultry manure gave highest maize yield.

[66] compared ability of phospho-compost to influence phosphorus availability and uptake by maize in an acid soil compared to rock phosphate and single superphosphate. Phospho-compost gave highest available phosphorus and phosphorus uptake compared to rock phosphate and single superphosphate. Increases in chelating effects of net negative charges conferred on the soil colloids by the phospho-compost was proposed as the dominant reaction path way.

[67] observed increases in soil pH by up to 2 units in all the acid soils amended with legume residues of varying chemical composition at 35 and 100 days of incubation. The concentrations of excess cations in the added legume residues correlated positively with the alkalinity produced in each soil. Legume resides high in excess cation, organic anions and well stabilized are thereafter recommended for use in the management of acid soils.

Qian and coworkers studied the aluminum ameliorative potentials of biosilicon released from biochar of rice straw [47]. The rice straw was applied fresh and as biochar (pyrolysed at 400 and 700˚C) into acid soil under slurry condition. Wheat seedlings were thereafter exposed to the amended soil for 15 days. They observed the silicon rich biochar play dual roles in Al phytotoxicity alleviation in the acid soil slurry. Firstly, the silicon significantly reduced soil exchangeable Al and hindered migration of Al into the plant as monitored by the plant tissue staining experiment using hematoxylin. This was achieved by the silicon released from the biochar forming Al-Si compound in the epidermis of the wheat roots. They submitted that the silicon which was released gradually from the rice straw biochar was a sustainable source of silicon replenishment for aluminosilicates.

III. Challenges and future work

Emanating from the literatures reviewed, there is no doubt that large range of organic materials are of importance in sustainable management of acid soils of the tropics. Despite these great potentials, adoption and use of these organic materials for neutralization of acidity on farmers' fields still remained very low in the tropics. This of course has led to increasing hectares of farm being lost annually to acidity and organic matter depletion. Future work should include ways of integrating these organic materials into the farmers' current method of soil fertility management usually achieved through the use of chemical fertilizers. Doing this will reduce high dosage use of chemical fertilizers over time by these farmers. More modification of these organic materials should be experimented to reduce their bulky nature and improve potentials to ameliorate acidity. Awareness on environment friendly nature of use of organic materials as soil acidity ameliorants should be intensified to enhance acceptance by farmers. Future work should also be channeled into developing near range calcium carbonate equivalent values for these organic materials which will help manage the wide variability in ash alkalinity contents of these organic materials.

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