Review Article

Soil Acidity formation and its Amelioration methods in Ethiopia: A Review

Abstract

Soil acidification is one of the problems of chemical soil degradation affecting soil productivity in the world. This paper attempts to explain the concept of soil acidification, the causes of soil acidification and the methods to remedy it. Farmers need simple and sustainable techniques to improve acidic soils and increase yields of their chosen crops. Recommendations for reclamation of acid soils need to be adapted to new developments, such as liming, use of acid-tolerant crop varieties, integrated soil fertility management, and application of organic fertilizers. This review addresses the causes and management mechanisms of soil acidification and the resulting effects on soil fertility and crop yield. It also provides important information on management options to address soil acidity and improve overall soil fertility, as well as other organic amendments that can be applied to bring soil acidity to the desired pH and improve soil quality and health. Integrated management of acidic soils increases yield stability and maximizes nutrient use efficiency.

Key Words: *soil, acidity, lime, amendment, fertilizer.*

1. INTRODUCTION

Soil acidification is a widespread limitation to crop production in many parts of the world [1]. Throughout Africa, where heavy rainfall is frequent, it is a major constraint to agricultural productivity because it leads to deficiencies in nitrogen (N) through leaching, phosphorus (P) through fixation, and soil organic matter (OM) [2]. Soil acidification has become a serious threat to crop production in most of the highlands of Ethiopia [3]. Currently, an estimated 43% of the total arable land in Ethiopia is affected by soil acidification. The severity of the soil acidification problem results in many crops having very low productivity and foregoing larger areas in Ethiopia. This problem needs to be given due attention in order to solve it through various coping mechanisms [4]. Crop productivity in acidic soils with Al toxicity and low soil P availability can be improved by applying lime, fertilizers with liming effect and/or organic matter [5]. Liming is a common and effective method to overcome these limitations and improve crop production on acid soils [6].

Improving acidic soils through surface application of lime and other materials is the main commercially available option. Surface application of lime to the soil generally does not have a rapid effect in reducing subsoil acidity. Several practices have been recommended to reduce soil acidity and improve the productivity of highly acidic soils. These include growing acid-tolerant crops, covering the surface with non-acidic soil, using organic fertilizers, and liming. Of these practices, liming and the use of organic fertilizers are considered the best measures because their effects are more sustainable [7]. However, since fertilizers and lime are not affordable and crop production is not sustainable, locally available low-cost organic sources in the form of manure, green manure and mineral fertilizers must be used in a harmonized combination for sustainable production and soil quality. Agriculture in the highlands of Ethiopia is characterized by low agricultural productivity compared to developed countries, as soil fertility has continued to decline over the years and fertilization has been inadequate. Therefore, the overall objective of this paper is to review the cause, effect and mechanism of soil improvement in acidic soils which has been achieved through research and development work.

2. LITERATURE REVIEW

2.1 Causes of Soil Acidity

Acidic soils have a pH of less than 7 on the pH scale [8]. Theoretically, soil acidity is largely related to the presence of hydrogen and aluminum ions in exchangeable forms [9, 10].The higherthe concentrations of these ions in the soil solution, the higher the acidity.Soil acidification results from a combination of natural and anthropogenic processes.

As the soil acidifies, the chemical and biological properties of the soil also change. Most acidic soils have low fertility and exhibit poor physical, chemical, and biological properties. One chemical change is the increased solubility of aluminum (Al) and manganese (Mn), both of which can be toxic to plants. Plants tolerate Al and Mn differently, resulting in crop-specific soil pH requirements. Adding lime raises soil pH (reduces acidity), adds calcium (Ca) and/or magnesium (Mg), and reduces the solubility of Al and Mn in the soil. Soil acidity is a major environmental and economic problem in many areas of Ethiopia, resulting in significant losses in crop production. Soil acidification is a complex of several factors that include plant nutrient deficiencies and toxicities, low activities of beneficial microorganisms, and reduced plant root growth, which limits the uptake of nutrients and water [11]. The following factors are some causes of soil acidification.

a) Weathering and Leaching

When the parent material of the soil is acidic, an acidifying effect occurs, and when the parent material is basic, an alkalizing effect occurs. Both acidic and basic cations are released into the soil during weathering. However, the influx of these nutrient elements into the soil is cancelled by leaching, which removes most of the basic cations (Na^+, K^+, Ca^{2+} and Mg^{2+}) that would counteract the acidifying effects of the acidic cations (mainly H^+ and Al^{3+}) from the soil, so that the acidic cations predominate, making the soil acidic. This process is very effective in areas where temperatures are high and precipitation exceeds evaporation and plant transpiration to cause weathering and leaching.

b) Organic Matter Decomposition

During their lives, plants and animals absorb nutrients in various forms. When these plants and animals perish, the process of decomposition begins, breaking down these organic tissues into humus and releasing many different chemicals. As a result of this perpetual natural cycle, acids are either formed or consumed. In general, organic material contains reactive substances such as carboxyl and phenolic groups that behave like weak acids. Dissociation of these groups leads to the release of H^+ ions, which are responsible for acidity [12]. Decomposition of organic material also produces CO_2, which reacts with H_2O to form weak carbonic acids. Conversion of organic-N to mineral-N by nitrification can also increase soil acidity. The contribution of decaying organic matter to soil acidification is generally very small, and it is only the cumulative effects that could ever be measured [9].

c) Acid Rain

Precipitation is typically acidic and is caused by sulphur and nitrogen oxides released into the atmosphere by combustion engines, coal burning, and agricultural activities. The acidity of rain, which can have a pH between 4 and 4.5 [9], is transferred to the soil by precipitation [13]. The amount of H_2SO_4 and HNO_3 that reaches the earth as acid precipitation worldwide is enormous, but the amount that falls on a given hectare in a year and can cause a significant change in pH is rather small, especially in less industrialized countries such as Ethiopia. Over time, however, the cumulative effects of acid rainfall can affect both soils and the plants that grow on them [9].

d) Crop Production and Removal

The main goal of any agricultural production system is, of course, to produce saleable products. However, this is often fraught with some problems, such as soil acidification. The respiration of plants and microorganisms in the soil is necessary for their survival. However, this leads to the production of large amounts of carbonic acid with an acidifying effect. However, this effect is relatively small because most of the carbonic acid is decomposed and escapes into the atmosphere as CO_2 [14]. The uptake of nutrients by plants also leads to a distribution of acidity in the soil and alkalinity in the plant [15]. Plants take up basic cations such as Ca^{2+}, Mg^{2+} and K^+ as well as NH_4^+ from the soil solution for their nutrition. Consequently, H^+ is released by plants to establish electrical balance, especially when plants take up nutrients in the form of NH_4^+. The release of these H^+ ions has an acidifying effect on the soil [16]. When these plants are subsequently harvested from the field or burned and washed away via surface runoff, these basic cations responsible for counteracting the acidity created by other processes are lost and the net effect is increased acidity [17]. However, the amount of these nutrients removed by cultivation depends on the type of crop grown, the part of the crop harvested, and the stage of growth at harvest. The leaves and stem parts of the plant contain greater amounts of these basic nutrients than the grains.

Therefore, high-yielding forage crops such as Bermuda grass, hay, leguminous crop residue and alfalfa have a greater impact on soil acidity after harvest than grains.

e) Application of Acid Forming Fertilizers

In general, high temperatures and other natural phenomena such as rainfall and the continuous leaching of nutrients degrade the ability of soils to support crop production. The continuous use of agricultural land without appropriate management measures to ensure its regeneration has also led to many problems with infertility. Organic matter content and most essential plant nutrients, especially nitrogen and available phosphorus, are low in most Ethiopian soils [18]. Due to this inherent poverty of most soils, most farmers rely on external sources of fertilizer to deprive the soil of its fertility. Although chemical fertilizers are essential for high yields, their use is associated with many consequences such as soil acidification.

2.2 Management of Soil Acidity

Management of acidic soils should aim to improve production potential by adding additives to correct acidity and manipulate agricultural practices to achieve optimum crop yields. Soil acid-base balance (measured by pH) is very important to ensure optimal availability of nutrients in the soil and to minimize potential toxicities. For example, at a very low pH, Al may be more soluble and taken up by roots, making it toxic, P may be unavailable, and Ca levels may be low. At a high pH, Fe and other micronutrients (except Mo) become unavailable because they are bound in the form of insoluble hydroxides and carbonates [19].

a) Liming

Application of lime is recognized and used as the most important means of eliminating severe acidity, which limits the availability of nutrients needed in the soil in large quantities for maximum yields [11].

Liming based on the amount required to neutralize exchangeable Al, which is the main factor for poor plant growth in acidic soils, and to supply Ca and Mg [4, 20], was beneficial for yield in soils with a pH of < 5.5, but not in moderately acidic soils or when liming targeted a pH of 7.0 or more [20]. The most common and, in most cases, effective method of correcting soil acidity is the application of lime. Liming involves adding lime to acidic soils to increase soil pH and create a favorable soil environment for plant growth [21]. A more favorable root environment can result from the following effects: desirable soil pH, reduction of Al and Mn toxicity, increase in Ca and Mg supply, improvement in P and Mo availability, improvement in mineralization of organic compounds and thus improvement in N, S, and P uptake, improvement in soil biological activity such as nitrogen fixation. The amount of lime to be added depends on the type of soil, liming material, plant type, variety, and economic considerations [20]. Incorporation of lime or dolomite into the upper tillable soil layer is an effective method for improving acidic soils [4]. Lime can also be used to prevent soil infertility and to supply soils with calcium and magnesium deficiencies [10]. Liming raises the pH of acidic soils so that the action of nitrogen-fixing bacteria is no longer inhibited and nitrogen fixation increases. It has been reported that nitrogen mineralization from plant residues and organic matter increases when lime is applied to acidic soils. Although lime is primarily applied to raise soil pH and address the toxicities associated with acidic soils, lime has also been used to improve soil structure. The application of liming agents is a prerequisite for optimal nutrient utilization in acidic soils [22]. Aluminum and manganese toxicity is the most important growth limiting factor in many acidic soils. In addition, the reduced uptake of calcium and magnesium into the soil solution can also be mitigated by the application of lime [23]. The application of liming materials to such soils can inactivate iron and aluminum, thus increasing the content of plant available phosphorus and other macronutrients.

b) Organic Amendments

An organic amendment is any material of plant or animal origin that is more or less decomposed and can be added to the soil to improve its physical, chemical, and biological properties [24; 25; 26]. Typical examples are animal and plant fertilizers, green manures, plant residues, worm compost and compost, and industrial and municipal wastes [27; 28; 29]. These various forms of organic matter collectively provide a reservoir of nutrients that are critical for plant growth [30]. Manure is the most common source used in agriculture to improve soil fertility and crop yield [31]. Therefore, manure application to reduce Al toxicity is a cost-effective alternative to traditional liming for smallholder farmers [32]. The release of cations and anions after manure mineralization affects the nutrient balance of the soil solution and consequently its response. The cations can increase the potential cations and base saturation of the soil, which increases the soil pH and reduces Al toxicity [25; 31; 33].

Other benefits of adding organic matter to acidic soils include improving nutrient cycling and the availability of nutrients to plants through direct addition and by altering the physical and biological properties of the soil [10]. The complementary use of organic manure and chemical fertilizers has been shown to be the best strategy for managing soil fertility in the tropics [34]. Increased soil organic matter increases soil aggregation and water holding capacity, provides a source of nutrients, and reduces P fixation, Al and Mn toxicity, and nutrient leaching [11].

Application of compost to soil has also received much attention as an environmentally friendly strategy to utilize the increasing amount of organic wastes and improve soil organic matter (SOM) status on agricultural land [35]. Application of compost to increase the quantity and improve the quality of SOM is especially important in highly weathered tropical soils to overcome SOM degradation and improve soil carbon (C) sequestration [35; 10].

2. MATERIALS AND METHODS

This review was based on a literature review of published materials. In all articles reviewed, extremely acidic soils were selected from areas of high acidity and measured with a portable pH meter. The pH, exchangeable acidity, and other chemical properties were analyzed in all materials studied. Lime, gypsum, and organic material were used to amend the acidic soil. The amount of amended materials applied based on exchangeable Al^{+3} and H^{+} was determined as follows [36] based on the mass of soil per 20 cm hectare furrow cut and exchangeable Al^{+3} and H^{+} of the study area:

$$LR, CaCO_3\ (kg/ha) = \frac{cmolEA/kg\ of\ \ soil * 0.15\, m * 10^4\ m^2 * B.D.\,(Mg/m^3) * 1000}{2000}$$

Where LR = Lime requirement (kg ha-1); $CaCO_3$ = Calcium carbonate; EA = Exchangeable acidity; and B.D. = Bulk density of soil.

Most papers research activities were based on different cereal/legume/oil crop rotations. In each season, the selected crops were planted in different rows in an adjacent block. The organic and inorganic acid soil amendments were applied one month before sowing depending on the treatment and as split plot method. The recommended phosphorus and nitrogen fertilizers were applied evenly depending on the location, using urea and NPS as N and P sources, respectively. For some research based on treatment and test crop, urea was applied in two parts, while phosphorus was applied in rows for seeding. The plots were maintained permanently for the duration of the experiments to observe the transfer effects of the meliorants. Partial budget and threshold analyzes were conducted to evaluate the economic feasibility of the different treatments [37]. Mathematically expressed as; $Total\ benefit - Total\ costs = Net\ benefit$

Where Total benefit = Increased revenue+ Decreased costs and Total cost = Decreased revenue + Increased costs.

3. RESULTS AND DISCUSION

4.1 Effect of lime on crop yield

The application of lime, gypsum and organic additives in the subsoil improved the physical properties of the soil. Lime and gypsum application at subsoil decreased bulk density and soil strength, and increased soybean yield by 18% compared to the control [38]. Rhizosphere modification by lime, manure and sawdust stimulated root development and increased sorghum yield from 4,322 to 5,987 kg ha-1 [39].

Due to its multiple positive effects on physical, chemical and biological soil properties, lime helps to increase crop productivity and quality. The improvement of plant growth in acidic soils is not due to the addition of basic cations (Ca, Mg), but to the increase of pH, which reduces the toxicity of phytotoxic Al levels [11].

4.2 Effect of Lime Application on Soil Chemical Properties

Post-harvest soil chemistry analysis showed that liming by both surface application and incorporation at 20 cm soil depth increased soil pH, soil nitrogen content, organic carbon, available P content, exchangeable K and Mg content, and Al content and Al saturation compared to no lime treatment [40]. Liming by surface application failed to improve the chemical properties of the subsoil because lime has low mobility. The results of previous researchers [41] showed that liming increased Ca concentration and decreased Al exchangeability and Al saturation at 20 cm and 40 cm soil depth after 9 months and two years of application, respectively.

In spite of the fact that it takes a long time, the development of lime into the more profound layers may happen through the method complexes arrangement of Ca or Mg with solventnatural matter so that it can move to more profound soil layers; the movement of life form, particularlylarge scale fauna; and lime with a small scalemeasure is generallysolvent [42; 43].

The pastanalysts [44] detailed that soil pH expanded from 5.03 to 6.72 and replaceablecorrosiveness (EA) was altogetherdecreased due to the application of 3.75 t lime ha-1 on Nitisol with an inalienable property of tall P obsession in southern Ethiopia.Furthermore;limingaltogetherexpanded CEC and accessible P, and diminishedaccessible micronutrients but Cu. The most noteworthy (33.34 cmol(+) kg^{-1}) and least (19.18 cmol(+) kg^{-1}) values of CEC were gotten from the most elevated lime rate and control treatment, separately.

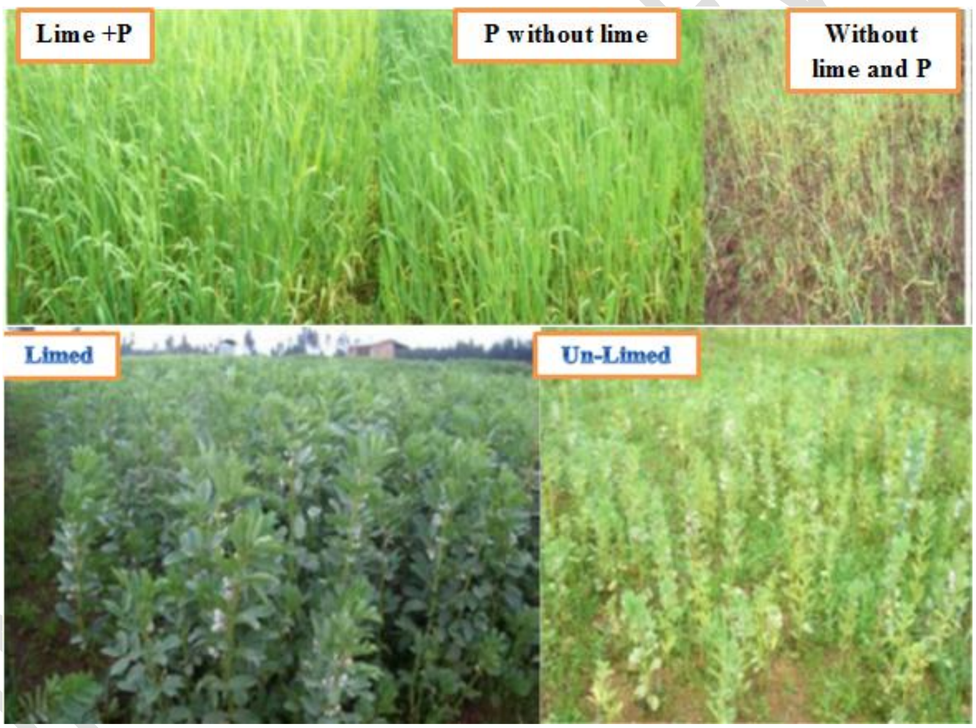

Figure 1: Growth of barley and faba bean plants with lime and P, with P alone and without lime in acidic soils of Welmerawereda respectively [45].

Acidic soil physico-chemical properties changed either by sole or combined utilize of lime and N fertilizer. Soils with 0.5 t ha^{-1} lime and 300 kg ha^{-1} nitrogen fertilizer were recorded in a greatest net advantage result. Consequently, liming ought to be given more accentuation in acidic soil improvement. Additionally, the government may encourage the supply calcite ($CaCO_3$) and urea fertilizer to the agriculturists [46].

Lime improves soil pH and reduced exchangeable acidity with sorghum grain yield improvements. The most noteworthy grain yield of sorghum was obtained from 5.65 t lime $ha^{-1}$with application of 23, 46 and 69 kg P_2O_5 ha^{-1} and 7.54 t lime $ha^{-1}$with application of 0, 23 and 46 kg P_2O_5 ha^{-1} treatments. The partial budget investigationindicated that 1.88 t lime ha^{-1}at the side 23 kg P_2O_5 ha-1 gives higher net benefits. From this result, Assosaarea agricultural land need to apply 23 kg P and 1.88 t lime ha^{-1} to improve the grain yield and yield component of sorghum at Nitosols under rain fed condition [47].

4. CONCLUSION

Soil managementpractices and the conservation of soil quality are central concerns to agriculturalsuitability. Soil acidityissues are expandingwithin thehighland of the countryzones. Soil acidity and relatedlow nutrientaccessibility are among the major limitations to crop production and productivity. Soil reaction is one of the physiological characteristics of the soil arrangementstated in terms of pH which shows whether the soil is acidic, neutral, or alkaline. This activityshows notable on numerous soil properties includingbiological activity, nutrient availability, and soil physical properties.The practice of acid soil liming used to mitigate soil acidity and reduce phytotoxic levels of Al and Mn has been recognized as fundamental for idealcrop production in acid soils. Despite that, application of lime ought to be considered as an approach to improve soil pH to optimize nutrient availability for optimum plant development and yield;otherwise, it isn't an end goal by itself to attain potential production.

Moreover, there's need for determiningareas where lime application brings criticalalter and benefit in crop yield. Generally, liming should be considered as soilamelioration to raise soil pH to the level that's reasonable for maximum nutrient availability, plant growth, and crop yield.

The review paper conclude that, the integrated use of all the available resource including acid tolerant crops and crop species, which move forward and maintain soil and agriculturalproductivity, is of extraordinarycommonsenseimportance. Overall, acid soil managementneedsto emphasize strategic research, integrated soil and water management with improved cropvarieties to generateprototype and environmentallyfriendly technologies for sustained food production within a framework of appropriate socio-economic and policy considerations. Lime and inorganic phosphate fertilizers are utilized to cure these issues. However, due to enhancing costs and inaccessibility when required, their utilization among our farmers in Ethiopiaisn't far reaching. In this way the government shouldgiveconsiderationand attention to the supply of lime where it is sensiblyrequired.

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