International Journal of Agricultural and Applied Sciences, June 2024, 5(1): 86-100
https://www.agetds.com/ijaas
ISSN: 2582-8053
https://doi.org/10.52804/ijaas2024.5113

Review Article

Soil Acidity Causes in Ethiopia, Consequences and Mitigation Strategies-A Review

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(Received: 28/02/2024; Revised: 19/05/2024; Accepted: 29/05/2024; Published: 20/06/2024)

ABSTRACT
Soil acidity is a serious land degradation problem and worldwide danger, impacting approximately 50% of the world's arable soils and limiting agricultural yield. Soil acidification is a complicated series of events that lead to the production of acidic soil. In its widest sense, it can be defined as the total of natural and human processes that reduce the pH of soil solutions. Soil acidity affects around 43% of agricultural land in Ethiopia's humid and sub humid highlands. Acid soils in western Ethiopia are mostly caused by topsoil erosion caused by heavy rains and high temperatures. This results in the loss of organic matter and the leaching of exchangeable basic cations (Ca^{2+}, Mg^{2+}, Na^{+}, and K^{+}). Because ammonium-based fertilizers are easily converted to nitrate and hydrogen ions in the soil, they play a significant role in acidification. One of the reasons of soil acidity is inefficient nitrogen usage, which is followed by alkalinity exports in crops. Soil acidity in Ethiopian highlands is mostly caused by the clearance of crop residues, continuous crop harvest without sufficient fertilization, cation removal, and usage of acid-forming inorganic fertilizers. Acid soil reduces nutrient availability and produces Al and Mn toxicity. In addition to these effects, soil acidity may rapidly degrade soil physicochemical qualities such as organic carbon (OC), cation exchange capacity (CEC), soil structure, porosity, and texture. Liming, the use of organic materials as ISFM, and the adoption of crop types that are resistant to Al toxicity are all alternatives for correcting acid soils. Liming can minimize toxicity by lowering concentrations, improving the availability of plant nutrients like P, Ca, Mg, and K in the soil, and reducing heavy metal solubility and leaching. Application of organic matter has a liming impact because of its abundance in alkaline cations (such Ca, Mg, and K) that were released from OM during mineralization. The pH of the soil is raised by soil organic matter, which helps with soil acidity supplements.
Keywords: Soil Acidity, Liming, nutrient availability.

INTRODUCTION

The main factor impeding the agricultural systems of many emerging nations is soil deterioration. South Africa's Ethiopia is a developing nation that faces significant challenges related to soil degradation. Acidification and salinization are the two primary processes that cause soil degradation. About 50% of the world's potentially arable soils are affected by soil acidity, which is one of the main issues causing land degradation and a worldwide danger. It is also one of the main factors limiting crop yield. In Ethiopia's humid and sub-humid highlands, it affects around 43% of the agricultural area (Sumner and Noble, 2003; Kochianet et al., 2004; Agegnehuet al., 2019).

Sustainable agricultural productivity has been hindered by the issues in almost all of Ethiopia's producing regions. Ethio SIS (2014) estimates that highly acid soils (pH 4.1 5.5) account for around 28.1% of Ethiopia's soils and that soil acidity affects about 43% of the country's arable land. Due to potential toxicities of aluminum and manganese as well as deficits in calcium, magnesium, phosphorus, and molybdenum (Mo) (Barber, 1984; ATA, 2014; Abebe, 2007; Agegnehuet al., 2019; 2021). Strongly acidic soils are often infertile. Moreover, one of the main factors impeding profitable and sustainable agricultural output in many African nations, as well as in many other parts of the world, is soil acidity. According to Osundwa et al. (2013), it has a detrimental effect on nutritional availability and results in Al and Mn toxicity. Moreover, acidity of the soil can quickly deteriorate the physico-chemical characteristics of the soil, including its structure, porosity, texture, cation exchange capacity (CEC), and soil organic carbon (OC). The complexation of metals with organic matter, the dispersal of colloids, and the ultimate bioavailability of trace elements are all impacted by acidification (Bolan et al., 2003). Reduced land productivity is the result of a fall in pH, which raises net charge (low in CEC) and causes a loss of soil fertility.

This illustrates the extent to which agricultural productivity is being jeopardized by soil acidification, hence diminishing food security, especially in the highlands of Ethiopia, where the environment favors soil acidification processes (Agegnehuet al., 2019; Hossainet al., 2021). In the Ethiopian highlands, where most people depend on agriculture for a living, it is one of the primary environmental hazards (Fanuel and Kibebew, 2021).

Ethiopia's political, economic, and social growth is still largely dependent on agriculture, which also has the greatest influence in these areas. Furthermore, according to the NBE Annual Report 2017 2018, it is a major contributor to Ethiopia's economy, accounting for over 35% of the nation's GDP, 66% of jobs, and over 76% of total export revenue. Soil is vital to this industry. The agricultural GDP is mostly composed of crops (72%), with livestock (20%) and other sectors (8.6%) making up the remaining 20%. The majority of crops produced as primary staples are cereals, which include wheat, maize, tef, sorghum, and millet (CSA, 2019/20).

Furthermore, a vast range of crops are cultivated, including fruits, vegetables, oilseeds, legumes, and spices. Because of enhanced soil management, higher yields, and horizontal expansion, cereal output has grown by 6.21% over the prior season and more than quadrupled over the previous ten years (CSA, 2019 20). However, food security continues to be a major concern for a lot of households and the nation at large. For instance, the World Food Program (2017) reported that 5.6 million Ethiopians were classified as having a crisis requiring severe humanitarian assistance.

The poor level of agricultural productivity and production, which is impacted by low soil fertility and soil degradation, is one of the primary factors limiting food poverty. According to Kassaye Gurebiyaw and Abay Gelanew (2019), human activity is the primary cause of Ethiopia's declining soil fertility since it cultivates unkempt regions without using soil conservation techniques and has inadequate soil cover.

Chemical processes such as soil acidity and alkalinity affect plant nutrition availability. It is believed that the two main crop production restrictions that pose the greatest danger to the global food production system and, consequently, food security are soil acidity and soil calcareousness (Hossain et al., 2021). Despite the fact that Ethiopia is home to a sizable section of East Africa's greatest croplands, the country's natural features and the heavy fertilizer use on many of its farms have caused widespread soil acidity and desertion. According to Kassaye Gurebiyaw and Abay Gelanew (2019), human activity degrades Ethiopian soil when impoverished regions are cultivated without employing soil conservation measures and have insufficient soil cover.

This makes the environment difficult for the nation to improve staple crop yields and food supplies, especially when combined with the loss of topsoil (Gurmessa, 2020). Acidity in soils results from the replacement of basic elements by hydrogen ions in soil colloids, which include calcium, magnesium, sodium, and potassium. Natural processes like rainfall-induced leaching or human-caused activities like heavy fertilizer application and ongoing cultivation without organic inputs may both remove bases from an environment.

N-based fertilizers have varying effects depending on the situation, although they may cause acidity to rise if some N is lost through leaching (Tully et al., 2015; McCauley, 2017). In Ethiopia, urea (46N-0-0) and diammonium phosphate (DAP) (18N-46P2O5-0) applied repeatedly over many years were reported to be favoring factors for soil acidification in the country's Northwestern and Southwestern highlands, despite the fact that inorganic fertilizers were applied in small amounts (Laekemariam et al., 2016; Eyasu et al., 2019).

Ethiopia's total clearance of crop leftovers from crop fields, excessive grazing, and heavy rainfall all contribute to the country's increased soil acidity problems by robbing organic matter and basic cations through soil erosion and leaching (Abebe, 2007; Abate et al., 2017; Elias, 2021). Numerous research have indicated that heavy rainfall regions in Ethiopia's southwest, northwestern, southern, and western regions are particularly plagued by the issue of acidity in the soil (Kebede and Yamoah, 2009; Warner et al., 2016). On the other hand, the soils in the country's north and east are alkaline (ATA, 2014; Agegnehue et al., 2019).

This problem of soil acidity poses a serious threat to the nation's future agricultural output because it raises the concentration of aluminum (Al3+) in the soil solution to a toxicity level (Alvarez et al., 2020), restricts crop performance (Fageria and Baligar, 2008), and limits the availability of vital plant nutrients (Wendimu, 2021). This would suggest that one of the main obstacles to achieving sustainable production and food security is soil acidity and the resulting limited nutrient availability. Soil fertility and health have continued to be key components in raising and maintaining crop yields in order to meet the world's growing need for food and raw commodities.

This means that in order to optimize agricultural output, knowledge of soil acidity and how to mitigate it must be applied appropriately. Therefore, obtaining sustainable levels of agricultural output requires a thorough investigation of appropriate management strategies. The country's highlands have seen the creation of several strategic strategies for the control of soil acid.

Numerous research projects have focused on soil management, which affects agricultural yield and the physiochemical properties of the soil in different ways. So, the main objective of this seminar is to highlight different literatures on the concepts of soil acidity and to give a wealth of knowledge on the sources of soil acidity, the effects it has on agricultural production, and management strategies for reducing soil acidity and raising crop yield. This is predicated on an extensive literature study and synthesis conducted within the Ethiopian setting.

Soil Acidity, Extent and its Distribution in Ethiopia

Global food production is severely hampered by acidic soil, which is defined as pH less than 5.5 (FAO and ITPS, 2015). It happens when high numbers of hydrogen (H^+) ions combine with clay particles, releasing aluminum that then generates more H+ ions. Natural processes include the interaction of CO2 with water, the uptake of excess cation by plant roots over anion nutrients, and the breakdown of organic matter which is particularly severe in podzols and histosols all contribute to the formation of H^+ ions. The clay minerals easily adsorbe aluminum and hydrogen, releasing Ca^{2+}, Mg^{2+}, and K^+ ions that can then be leached from the soil by percolating water, resulting in shortages in these elements (Blum, Shad, and Nortcliff, 2018).

Thus, in many developing nations where food production is vital, acid soils restrict agricultural yields. Because of nutritional inadequacies, diseases, and the toxicity of aluminum, manganese, and hydrogen activity, as well as the unavailability of vital elements including calcium, magnesium, molybdenum, and phosphorus, acid soils are phytotoxic (Hede et al., 2001; Taye, 2007). Plant development in acidic soils is strongly impacted by aluminum's dominance on the ion exchange complex, especially in agronomic crops. One specific management issue is aluminum toxicity, which mostly happens when water has a pH of less than 5.0. Abdenna et al. (2007) ascribe the rising trend of exchangeable Al^{3+} and soil acidity in arable and abandoned areas to intensive farming practices and ongoing use of inorganic fertilizers that generate acids. The loss of nutrients through leaching, the loss or decrease in the availability of specific plant nutrients (like P, Ca, Mg, and Mo), the increase in the solubility of toxic metals like Al and Mn, which may affect root growth and nutrient and water uptake, and alterations to microbial populations and activities are other changes in soils that may happen during soil acidification (Marschner, 2012; Abdenna et al., 2013). Although the degree of change may depend on a variety of features within a particular soil, such changes will frequently be followed by changes in the pH of the soil overall.

In the western region of Ethiopia in particular, and in much of the country's highlands overall, soil acidity has emerged as a major danger to agricultural production (Taye, 2007). Previous research by Mesfin (2007) found that soil acidity, or Al3+ toxicity, affects around 41% of Ethiopia's agricultural areas. The state of the acidity of the Nitisols found in western and central Ethiopia was assessed in 2006 by an inventory. The findings showed that all samples were acidic, but to varying degrees depending on the region (Abdenna et al., 2007). Ethiopian soil acidity is increasing in both extent and amplitude, which is substantially reducing crop productivity (Wassie and Shiferaw, 2011; Tamene et al., 2017). According to a recent study by Eyasu (2016), 80 percent of the Nitisols and Luvisol subgroup soils in Ethiopia's north-central and south-western highlands have a pH of 4.5 to 5.5, making them extremely strong to strongly acidic soils. As a result, one of the obstacles to maintaining agricultural productivity and output in western Ethiopia was the acidity and low fertility of the land. According to Eyasu and Elias (2016), mismanagement and ongoing degradation processes that have taken a toll on the soils for generations are to blame for the rising depletion and turning of Ethiopia's north-central and south-western highlands' soils into infertile ones. Additionally, he enumerated low amounts of organic matter, acidic soil responses, and deficits of key critical plant nutrients as the main fertility obstacles and concerns in this region. The primary soil classifications characterized by acidity are nitisols; over 80% of landmasses derived from nitisols may be acidic, in part due to basic cation leaching (IFPRI, 2010; Eyasu, 2016). Both the most fertile and most acidic regions of Ethiopia are found in the southwest of the nation. Gimbi, Nedjo, Hosanna, Sodo, Chencha, Hagere-Mariam, Endibir, and the Awi Zone of the Amara regional state are among the regions that are known to be negatively impacted by soil acidity (Tamene et al., 2017).

In spite of these broad numbers, there remains a lack of localized understanding and current severity assessments for the issue. Soil acidity in high rainfall areas (roughly 41 percent of cultivated land; Mesfin, 2007) is becoming a major production constraint, even though the extent, distribution, causes, and management of problematic soils in Ethiopia are not well documented. (Getachew and Tilahun, 2017).

Abdenna (2013) reported that soils from several areas in the West Wollega, East Wollega, and West Showa zones had pH values that were outside of the typical range needed for agricultural cultivation. The availability of vital nutrients is severely impacted by such a low pH. Aluminum's toxicity to plants has a significant impact on nutrient and water absorption, as well as root and shoot development. Additionally, there is an impact on the actions of microbes, which are essential to the cycling of nutrients in agroecosystems. In south-western Ethiopia, the soils in the districts of West Wollega, East Wollega, and West Showa are acidic to varying degrees. A small number of the soils are moderately to slightly acidic, while the majority are extremely highly acidic (Abdenna, 2013).

Tropical and subtropical areas have a serious issue with soil acidity (Bordeleau and Prevost, 1994). Strong soil acidity, which impacts 28% of Ethiopia's total land area and 43% of its agricultural land mostly in the highlands of Oromiya, Amhara, and the Southern Nation Nationalities and Peoples region poses a major danger to crop output in the country (Tegbaru) (2015). The capacity of the soil to carry out its tasks in a sustainable way is known as soil quality (Lal, 2015). The biophysical and chemical characteristics of soil undergo gradual changes over time, which are expedited by management strategies.

Crop productivity on acidic soils, primarily the Nitisols of the Ethiopian highlands, is severely limited by the acidity of the soil and the resulting reduced nutrient availability (Zeleke et al., 2010). According to Haile et al. (2017), soil acidity affects around 43% of Ethiopia's farmed land. According to an evaluation of Ethiopia's soil acidity, highly acid soils (pH 4.1 5.5) account for around 28.1% of all soils (ATA, 2014). The western Ethiopian highlands have places with high acidity, especially in the highland sections of SNNP (Amede et al., 2001) and the western and central highlands of Oromia and Amhara (Deressa et al., 2007; Tilahun et al., 2019).

According to Dessa et al. (2007), 43% of Ethiopia's arable land is thought to be acidic overall. According to more recent evaluations, Ethiopia's soil acidity is becoming more widespread and severe, which has a negative impact on agricultural productivity (Lulu et al., 2020). For instance, farmers have switched to planting oats that are more tolerant of acidic soil in several barley, wheat, and fababean-growing regions of the central and southern Ethiopian highlands (Haile, 2009; Agegnehu et al., 2019). To lessen the detrimental impacts of soil acidity and increase soil fertility, many farmers use a barley-fallow-oats rotation system (Regassa and Agegnehu, 2011). But according to Alemu et al. (2017), this rotation method is not sustainable, and using lime to neutralize soil acidity appears to be essential for long-term sustainability.

Ethiopian soil acidity frequently occurs in areas where high levels of precipitation and unfavorable temperatures combine to leach sizable amounts of exchangeable basic ions from soil surfaces, such as calcium (Ca), magnesium (Mg), sodium (Na), and potassium (K) (Mesfin 2007). The impact of parent materials, landform, vegetation, and climatic pattern all contribute to its very varying intensity (Achalu et al., 2012).

Major Acid Soils

Eutric In the central highlands of Ethiopia, where soil acidity is an issue, nitisol is the predominant soil type. The predominant soil type that covers Ethiopia's western region is nitisol (Abebe, 2007). These soils, which range in color from reddish brown to red clay, were created by intense weathering in humid environments. Their fertility is dependent on the base saturation, which is considered to be medium to high, and they have a significant inclination toward erosion despite having good drainage. Since nitisols have a solid structure and a large capacity for storing water, they offer excellent agricultural potential.

Even in the dry season or soon after precipitation, workability on these soils poses no issues. Land preparation is not difficult. According to Abebe (2007), these soils often contain very little accessible P and a rather low CEC for their clay concentration. Acidic parent material, which is found in heavy rainfall locations linked to nitisols and cambisols, is often the source of acrisols. Moderate to steep slopes are home to these soil types. They are only marginally suitable for agriculture; some of them are farmed, while some are left uncultivated for grazing. In general, the pH value is below neutrality and base saturation is low.

Abebe (1998) states that acrisols are the end product of intense weathering and leaching-induced base depletion. The steady loss of soil bases (such as Ca, Mg, and K) has resulted in the development of soil acidity under acidic soil conditions. The high amounts of aluminum (Al) and manganese (Mn) combined with the shortage of P, nitrogen (N), sulfur (S), and other nutrients cause soil acidity, which is most felt at soil pH <5.5, to hinder crop development (Abreha, 2013). The sub-soil units of nitisols are called eutric, dystric, and humic nitisols respective.

High base saturation in the soil profile, particularly in the A and B layers, and a comparatively high organic matter content in the top layer of dystric nitisol soil reflect the soil's high fertility status. Similar to Dystric Nitisol in terms of reproductive status, Eutric Nitisol has a crimson to dusky red lower lying horizon. On undulating plains, low plateaus, mild hills, and mountains on all areas' side slopes, nitisols are found where the slope ranges from 2 to 16 percent. These soil types have a tight relationship with the acidity issue because of their geographic location, intensive farming, and improper farm management techniques (Abebe, 2007). Generally speaking, acrisols form from acidic parent material that is found in heavy rainfall regions that are also home to nitesols and cambrisols.

Causes of Soil Acidity

Acidic soil is created by a complicated series of processes known as soil acidification. It may be broadly understood as the culmination of both man-made and natural processes that reduce the pH of soil solutions (Brady and Weil, 2016). The problem is made worse by anthropogenic causes such improper land use systems, monocropping, nutrient mining, and insufficient nutrient supplies (Wassie and Shiferaw, 2009; Tamene et al., 2017). The most frequent causes of soil acidity, low soil quality, and low soil fertility in Western Oromia, according to Achalu et al. (2012), were practices of extraordinary deforestation, overgrazing, and intense farming of soils with minimal inputs over many years. According to the same authors, the issue of soil acidity in Oromia, especially in the eastern and western regions, was extremely serious and required quick action to modify the soils in order to produce crops.

Additionally, because of soil acidity, which requires different amendments to improve soil fertility and acidity problems, smallholder farmers in various districts in the East and West Wollega zones have reported crop yield stagnation or even decline. They have also reported a lack of response to the application of urea and diammonium phosphate fertilizers (Abdenna, 2013). Soil physical qualities including bulk density and soil structure have been negatively impacted by the nation's ongoing use of chemical fertilizers that exclusively include N and/or P nutrients in the form of DAP and urea (Brady and Weil, 2008).

Additionally, according to Faragia et al. (2014), the technique may exacerbate soil acidification and reduce the amount of macro- and micro-plant nutrients in the soil to levels below those that are required for the best possible crop development and yield. Because ammonium-based fertilizers are easily converted to nitrate and hydrogen ions in the soil, they have a significant role in the acidity of the soil. One of the main contributors to soil acidification is the inefficient use of nitrogen, which is followed by product that exports alkalinity (Guo et al., 2010).

Agricultural products (crop wastes) removal

In most of Ethiopia's highland regions, ongoing crop harvesting (without enough fertilization), cation removal, and continuous use of acid-forming inorganic fertilizers all play a significant role in the development of soil acidity. Therefore, issues with soil fertility caused by acidity are significant production barriers in Ethiopia, lowering the yield of the main crops farmed there (IFPRI, 2010). It is known that there are a number of reasons why soils might become acidic. The main sources of acidity in soil are as follows:

Climate

Because there is less water filtration through the soil in arid places, a substantial supply of bases is often available. As precipitation increases, soluble salt concentrations decrease to a minimum and any gypsum and calcium carbonate that may have been present are eliminated. There comes a point at which the rate of base removal outpaces the rate of base release from non-exchangeable forms with additional increases in rainfall. Soils that are more acidic are more likely to occur in wet climates (Tadesse, 2001). The basic components of the soil (Ca, Mg, Na, and K) that keep the soil from becoming acidic are gradually eroded by prolonged heavy rains. Elevated precipitation depletes soluble elements like calcium and magnesium, which are precisely substituted by aluminum from the exchange sites (Brady and Weil, 2016).

Parent Material Acidic Parent Material Furnishing Aluminum and Silicon Ions

Acid rocks, such as granite and rhyolite, are defined as rocks having a higher concentration of quartz or silica relative to their basic material or element content. Even though there is no loss of base throughout the soil formation process, rocks that are lacking in bases become acidic as they crumble or break down during the process of accumulating soil particles. Compared to soils formed from shale or limestone, those formed from worn granite are probably more acidic. Large tracts of sandy, siliceous soil that were formed from acid-parent rocks have always needed lime. But the majority of acid soils are the consequence of agricultural base removal and leaching losses (Brady and Weil, 2016).

Depending on the origin and makeup of the parent materials, Ethiopian soils with varying degrees of intrinsic fertility have formed under a variety of parent materials and climates. For example, the intrinsic soil fertility grown over simple parent materials is quite high, while soils produced from sandstones are poor sandy soils. When alluvium comes from relatively youthful materials in alluvium plains, it becomes rich and productive; when it comes from heavily worn surfaces, it becomes less fertile. The bulk of soils have pH values between 4.5 and 6.5. According to Regassa and Agegnehu (2011), the majority of the time, the soils found in the nation's high-altitude regions have low base saturation, few exchangeable cations, and an acidic response.

Application of Ammonium Fertilizers

Acidity of the soil ultimately rises with continuous use of inorganic fertilizer without soil testing and amendments.

In the end, adding more inorganic fertilizer without doing soil tests or amendments makes the soil more acidic. Acidification is a result of the use of ammonia-based N fertilizers (Fageria and Nascente, 2014; Guo et al., 2010). Acidity is created in the soil when ammonium fertilizers are applied, although the form of N that crops extract is identical to that of fertilizer. Fertilizers based on ammonia (NH4), urea (CO (NH2)2), and proteins (amino acids) in organic fertilizers may all contribute hydrogen. Soil acidity is produced when such sources of N fertilizers are converted into nitrate (NO3), which releases hydrogen ions (H+). The truth is that N fertilizer raises soil acidity by raising crop yields, which raises the quantity of essential components that are extracted during crop harvest without being incorporated. As a result, adding a lot of organic matter to a soil or applying fertilizers containing NH4 might eventually make the soil more acidic and reduce its pH (Guo et al., 2010).

Decomposition of Organic Matter

Acidity results from the production of H^+ ions during the breakdown of organic materials. The short-term impact of soil acidity resulting from organic matter breakdown is negligible. The causes of soil acidity include large amounts of carbonic acid created by higher plants and microbes, as well as by other physicochemical and biological processes. However, the influence of this acid's dissociation is minimal because the majority of it is lost to the atmosphere as CO_2 (Kochian et al., 2004; Paul, 2014).

Reactive carboxylic, enolic, and phenolic groups found in soil organic matter, or humus, operate as weak acids. They release H^+ ions when they separate. Additionally, during the breakdown process, bases on exchange complex are replaced with H^+ ions due to the creation of CO_2 and organic acids (Somani et al., 1996).

Removal of Mineral Elements through the Harvest of High-Yielding Crops

Soil acidity is caused by elemental removal, particularly from soils with tiny reservoirs of bases as a result of high-yielding crop harvest. Crops that are cultivated on mechanically worked soils upset the balance and make the soils more acidic. This is the outcome of base cations being eliminated along with crops and the concurrent rise in leaching that occurs from working and disturbing soils (Brady and Weil, 2016; Fageria, 2009).

High-yield crop harvest is the main cause of the rising acidity of the soil. Basic elements including calcium, magnesium, and potassium are absorbed by crops throughout growth in order to meet their nutritional needs. More of these fertilizers that resemble lime are being removed from the field as crop yields rise. Grain has much smaller concentrations of these essential elements than the plant's leaf and stem sections. Soil acidity is impacted more by the harvesting of high-yielding forages like alfalfa and Bermuda grass than by the harvesting of grains (Fageria and Baligar, 2008; Rengel, 2011).

Land Use Change or Land Cover Changes

Research has demonstrated that changes in land cover or use have a detrimental impact on the characteristics of soil. For instance, the impact of land use systems on various physical and chemical soil qualities was studied by Gebrekidan and Negassa (2006), who found that the sand, silt, and clay fractions were considerably impacted by land use systems. The depth of the soil increased clay but decreased silt and sand. There were notable differences across the land use systems in terms of soil pH, total N, organic carbon, accessible P, exchangeable cations, exchangeable Al, effective cation exchange capacity, and Al saturation. Al saturation rose with soil depth, and while the subsoils showed Al toxicity, the top layers had issues with acidity. Similarly, Chimdi et al. (2012) found that a decrease in the overall porosity of cultivated and grazing land soils relative to forest land soils was caused by a decrease in the distribution of pore sizes and the amount of soil organic matter (SOM) lost, both of which are dependent on the level of soil management methods. In addition, Bore and Bedadi (2015) found that, in comparison to forest soil, the amount of SOM in cultivated and grazed lands has decreased by 42.6 and 76.5%, respectively. Native forest and range area being converted to agricultural land degrades the qualities of the soil. The fertility status of a particular soil type is lowered by such activities, which also result in an increase in bulk density and a decrease in CEC and the amount of soil organic matter (SOM). Additionally, substantial differences in soil parameters and a decrease in productivity might result from changes in land use related to deforestation, continuous farming, overgrazing, and mineral fertilizer (Lemenih et al., 2005; Bore and Bedadi, 2015).

Low Buffer Capacity from Little Clay and Organic Matter

Contact exchange between exchangeable hydrogen on root surfaces and bases in exchangeable form on soils is another source of acidity in soil. Microbial synthesis of sulfuric and nitric acids also takes place in areas where leaching is restricted. The amount of lime needed for acid soil depends on the pH of the soil as well as the buffer, or CEC. The amount of organic matter and clay present affects the buffering, or CEC; the more of these elements there are, the larger the buffer capacity. If acidic, soils having a larger buffer capacity (clayey, peats) require more lime. Coarse-textured soils with minimal or no organic matter will require less lime even if they are acidic since they will have a poor buffer capacity.

Over liming damage could result from the careless use of lime on soil with a coarse texture. Because a substantially higher base saturation was needed to elevate the pH to 6 with montmorillonite than with kaolinite, the link between pH and percent base saturation is crucial for soils representative of 1:1 and 2:1 clay. According to the sum of cations, pH 8.2 CEC method, soils containing 2:1 clays (fine, mixed, and thermic Vertic Hapludults) had to be 80% base saturated in order to achieve the same pH as soils containing 1:1 clay (fine, loamy, siliceous thermic Typic Hapludult) at 40% base saturation (Kamprath and Adams, 2010).

Alumino-Silicate Minerals

The main hydrous oxides found in soils are Al and Fe, which can be found as interlayer in clay mineral structures or as coatings on other mineral particles in amorphous, crystalline, or colloidal forms. As the soil's pH drops, these oxides dissolve into solution and release H+ ions via a process called stepwise hydrolysis, which causes the soil to become even more acidic (Abebe, 2007; Somani et al., 1996). Plant growth is restricted by acidity of the soil not only because of ionic pollutants such as H, Mn, and P, but also because of shortages in P, Mo, Ca, and Mg. It has been established that one of the most frequent reasons for yield decline in acid soils is the toxicity of these components. The toxicity of acid soil is a complicated phenomenon resulting from a multitude of elements that might impact plant growth via several physiological and biochemical routes. Acid soil infertility is closely linked to growth-limiting elements such as Al^{3+}, Mn^{2+}, and low pH (H+ toxicity). Plant growth may be impacted by these toxicity variables alone, in combination, or both (Sanchez, 1977; Somani, 1996).

Effect of Soil Acidity on Plant Nutrient Availability and Crop Yield

The primary source of the negative effects of soil acidity on plant growth and output is phosphorus deficiency, which is brought on by P adhering to colloidal fractions and converting to insoluble Al and/or Fe compounds as well as the toxicity of iron, manganese, and aluminum (Brady and Weil, 2008). It has also been noted that agricultural output in acidic soils is restricted by deficiencies of calcium, magnesium, potassium, and molybdenum. The pH of the soil has a direct bearing on the availability and solubility of critical nutrients for plants (Marschner, 2011).

The pH of the soil has a direct bearing on the availability and solubility of critical nutrients for plants (Marschner, 2011; Somani, 1996). Plant nutrient availability is influenced by the pH of the soil. High soil acidity can have two effects: on the one hand, an oversupply of soluble Al, Mn, and other metallic ions, and a scarcity of accessible Ca, P, and Mo (Agegnehu and Sommer, 2000a; Somani, 1996). Acid soil impairs the movement of soil organisms that plants require to keep healthy and limits the availability of essential nutrients including P, K, Ca, and Mg. An alkaline chemical must be applied to raise the pH of a soil if it is too acidic for plants to develop in a healthy manner.

Crop productivity on acid soils is limited by the acidity of the soil and the resulting reduced availability of nutrients (Bekele and Hofner, 1993; Beyene, 1987; Mamo and Haque, 1991). Due to its high immobility among the key plant nutrients (Agegnehu and Sommer, 2000b; Sanchez, 1977), phosphate can easily be rendered unavailable to plant roots in soils with pH values below 5.5. Consequently, crop yields in these types of soils are typically very poor. Plants are more able to get P when the pH of the soil is between 5.5 and 7. If the soil reaction is kept within the soil pH range of 5.5 to 7, toxicity and Mn and Fe deficiencies may be prevented; According to Somani (1996), this pH range appears to encourage the most readily available plant nutrients. Since growing crops absorb roughly 0.44-kilogram P ha-1 per day, the amount of P in soil solution required for optimum crop growth is between 0.13 and 1.31 kg P ha-1 (Lawlor, 2004). According to Lawlor (2004), the topsoil layer's labile proportion ranges from 65 to 218 kg P ha-1, which has the potential to replenish soil solution P. Particular adsorption and precipitation reactions cause phosphate sorption, or the removal of orthophosphate from soil solution into solid phases (Sample et al., 1980; Sanchez and Uehara, 1980).

According to Parfitt (1978), precipitation reaction happens when insoluble P compounds develop and precipitate, whereas specific adsorption happens when P anions replace the hydroxyl groups on the surface of Al and Fe oxides as well as hydrous oxides. Al and Fe phosphates may precipitate from soils with very low pH 5.0), while insoluble calcium phosphates may develop at high pH values (>6.5) (Haynes, 1984).

However, in many cases, the primary controllers of P concentrations in soil solutions are particular adsorption reactions (Parfitt, 1978). Numerous variables, such as pH, the background electrolyte's ionic strength, and anion competition, influence the specific adsorption of P (Barrow, 1984). The crop being grown determines the ideal pH since different crops react differently to acidic soil. For instance, Uchida and Hue (2000) reported that nodules in the roots of food and forage legumes, such beans, peas, and desmodium fodder, allow bacteria to absorb nitrogen from the atmosphere and transform it into a form that the plant can use. For the legumes that need those specific strains of bacteria, a pH of 6 or above is ideal because some strains of the bacteria cannot survive at pH levels lower than 6. While potato plants can grow well at higher pH levels, the ideal soil pH range for potato growth is 5.0 to 5.5 because potato scab disease is more common when soil pH is over 5.5. Conversely, plants with pH levels above 5.5 experience iron (Fe) and magnesium deficits, whereas plants like camelia and azalea thrive exclusively at pH levels below 5.5. For optimal crop yields and nutrient availability, soil pH should be between 6.0 and 7.0. which popular field crops prefer as their range (Duncan, 2002). Legumes can only produce so much due to acidic soil (Fageria et al., 2012). It is currently one of the main things preventing Ethiopia from producing enough faba beans (Endalkachew et al., 2018; Mesfin et al., 2019). While neutral soils with a pH range of 7-8 are thought to be ideal for growing cotton, alfalfa, oats, and cabbage, acid soils are not tolerated by these crops. Soils with a pH of 6-7 are ideal for the growth of wheat, barley, corn, clover, and beans. Since grasses can withstand acidic soils more than legumes can, liming to a pH of 5.5 may regulate acidity without affecting yield.

Conversely, legumes thrive in pH ranges between 6.5 and 7.5 and require more calcium. Millet, sorghum, sweet potatoes, potatoes, tomatoes, flax, tea, rye, carrots, and lupine are among the crops that can withstand acidic soils (Somani, 1996). The main signs of elevated soil acidity that might result in lower yields are poor plant vigor, uneven crop growth, poor legume nodulation, stunted root growth, the persistence of weeds that can withstand acidic conditions, an increase in disease incidence, and aberrant leaf colors (Kang and Juo, 1986; Somani, 1996). Poor plant growth and water use efficiency are likely to result from increased acidity because of nutritional imbalances and deficiencies, as well as induced toxicity from aluminum and magnesium. High Al concentrations also have an impact on plant respiration, cell division, glucose phosphorylation, nitrogen mobilization, and the uptake and translocation of nutrients, particularly the immobilization of P in the roots (Baquy et al., 2017; Fageria and Baligar, 2008). (Fox, 1979; Haynes and Mokolobate, 2001). Even at pH lower than 4, insensitive plant species are not greatly affected by soil acidity, whereas sensitive plant species can be inhibited in their growth at pH 5.5 or lower. Al and Mn toxicity, as well as Ca and Mo insufficiency, exacerbate and frequently outweigh this pH effect (Baquy et al., 2017; Fox, 1979; Somani, 1996). When Al poisoning causes acidity, the roots are frequently the first organs to suffer damage; they become stunted and stubbly. Acid soils can have low levels of immobile nutrients, which stunted roots find difficult to obtain. There is a significant reduction in the plant's capacity to absorb water and nutrients, especially those that are stationary like P (Fox et al., 1979). As a result, plants are vulnerable to both nutritional deficits and drought.

In addition to the common red discolorations linked to P shortage, micronutrient deficiency symptoms are also commonly noted. Furthermore, because Al directly opposes magnesium absorption, magnesium deficiency symptoms serve as a helpful marker for acidity issues (Marschner, 2011). The main cation linked to the acidity of soil is exchangeable Al. The presence of more than 1 mg kg-1 of Al in the soil solution damages the root growth of sensitive crop species. When Al occupies 60% or more of the soil's exchangeable capacity, this frequently occurs. Mn can potentially be harmful since it becomes highly soluble at pH values below 5.5 (Somani, 1996).

Nutrient availability for plants is influenced by the pH of the soil. Excess soluble Al, Mn, and other metallic ions and a lack of accessible Ca, P, and Mo are the results of excessive soil acidity (Agegnehu and Sommer, 2000a). The movement of soil organisms that plants require for good health is impacted by acid soil, which also restricts the availability of essential nutrients including P, K, Ca, and Mg.

One of the factors limiting crop productivity in acid soils is the acidity of the soil and the resulting reduced nutrient availability. Since phosphate is the most immobile of the primary plant nutrients, it can easily be rendered unavailable to plant roots in soils with pH values below 5.5 (Agegnehu and Sommer, 2000b). Crop yields in these types of soils are often quite poor. P fixation is low and P availability to plants is higher in soil pH ranges of 5.5 to 7. If the soil reaction is kept within the pH range of 5.5 to 7, which appears to encourage the readiest availability of plant nutrients, toxicity and deficiencies of Fe and Mn may be avoided.

Given that developing crops absorb roughly 0.44 kilogram of P ha-1 per day, the ideal range of P concentrations in soil solutions for crop growth is 0.13 to 1.31 kg P ha-1 (Lawlor, 2004). Between 65 and 218 kg P ha-1 make up the labile fraction in the topsoil layer, this has the potential to replenish soil solution P (Lawlor, 2004).

Soil Acidity Management

The goal of managing acidic soils should be to increase their potential for production by adding amendments to neutralize the acidity and adjusting farming techniques to provide the highest possible crop yields. Maintaining the ideal availability of soil nutrients and reducing potential toxicities depend greatly on the acid/alkali balance (measured by pH) of the soil. For instance, at very low pH levels, Ca levels can be low, P can become unavailable, and Al can become more soluble and absorbed by roots, making it poisonous. Due to their lock-up as insoluble hydroxides and carbonates at high pH, Fe and other micronutrients (apart from Mo) become inaccessible (Slattery and Hollier, 2002).

Liming

The process of liming involves adding materials rich in calcium and magnesium to soil. These materials might take several forms, such as hydrated lime, chalk, marl, or limestone. When multicropping with acid-sensitive crops is used in highly acidic soil, it is a favorable approach. When lime is at its purest, it mostly consists of calcium. Due to its basic nature, calcium carbonate neutralizes acid (Edmeades et al., 2003).

Lime enhances Ca and Mg availability and base saturation. By deactivating the reactive components, fixation of P and Mo is decreased. Root growth is encouraged and nutrient uptake is enhanced as a result of the correction of toxicity caused by excess soluble Al, Fe, and Mn. According to Fargeria and Baligar (2008), liming has several benefits for legumes, including increased microbial activity, improved N fixation, and enhanced N mineralization. The bioavailability of micronutrients, such as zinc, copper, iron, manganese, and boron, can be significantly decreased by overliming, albeit this effect is pH-pH-dependent (Fageria and Baligar, 2008).

Plant nutrient deficits, especially in Fe, may result from this. The primary way that soil acidity limits or lowers crop output is by hindering root growth, which lowers nutrient and water intake (Marschner, 2011). Acidity of the soil changes available soil nutrients into unavailable forms. Acidity of the soil also affects basiccations, which are necessary for crop growth and development and include calcium, potassium, magnesium, and several micronutrients. There are times when soil acidity causes a crop to fail completely, and the amount of damage that acidity causes vary from place to location based on a number of factors.

Liming therefore has the following key effects: it raises pH, accessible P, exchangeable cations, percent base saturation, and the growth density and length of root hairs for uptake of P. It also increases available P by inactivation or precipitation of exchangeable and soluble Al and Fe hydroxides (Marschner, 2011). The acidity of the soil can be readily adjusted by introducing basic materials to neutralize the acid present or by liming the soil.

Dolomitic or calcitic agricultural limestone is the most affordable and manageable liming material. Agricultural limestone needs to be very finely crushed in order to be extensively mixed with the soil and given time to react with the acidity of the soil because these products are naturally occurring and are somewhat insoluble in water. 90% of calcitic limestone is composed of $CaCO_3$ (calcium carbonate). Rocks with a mixture of magnesium and calcium carbonates ($CaCO_3$+$MgCO_3$) are used to make dolomitic limestone.

Burnt lime (CaO), hydrated lime ($Ca(OH)_2$), and wood ashes are additional liming ingredients that are less commonly utilized (Rengel, 2011).Agegnehu et al. (2006) report that the application of lime at rates of 1, 3, and 5 t ha-1 produced a substantial linear response with mean advantages in faba bean seed production of 45, 77, and 81% over the control. According to Desalegn et al. (2017), applying 0.55, 1.1, 1.65, and 2.2 t lime ha-1 raised soil pH by 0.48, 0.71, 0.85, and 1.1 units and lowered Al^{3+} by 0.88, 1.11, 1.20, and 1.19 mill equivalents per 100 g of soil. Additionally, Agegnehu et al. (2006) reported that when the lime rate increased, the pH of the soil constantly rose from 4.37 to 5.91. On the other hand, because lime was applied, the exchangeable acidity decreased dramatically from 1.32 to 0.12 cmol (+) kg-1. Increases in yield were directly correlated with soil pH levels and inversely correlated with exchangeable acidity; that is, yield rose in tandem with pH increases, whereas faba bean yield increased in response to decreases in exchangeable acidity and vice versa. Additionally, it was shown that the ideal range for legume seed yields was between 5.7 and 7.2 pH values. Moreover, adding lime to soils with pH values below 5.4 enhanced pea yields by 30%.

Complimentary Management Strategies/Using Acid Tolerant Crop Varieties

Using tolerant species/varieties of pasture and crops can lessen the effects of soil acidity if the pH of the soil is low. Without liming treatment, the soil will continue to get more acidic, therefore this is not a long-term fix. The rate of soil acidity can be slowed down by a variety of management techniques. In places with significant rainfall, controlling the use of nitrogen fertilizer is the most crucial strategy to prevent nitrate leaching. Hay that has been cut can be fed back into paddocks to decrease product export. It will also be beneficial to use less acidifying crop rotation choices; for example, swap out legume hay for a pasture or crop that is less acidifying (Bolland et al., 2004).

The majority of economically significant plant species are thought to be resistant to acidic soil conditions. Since many of them originated in areas with acid soil, it is possible that adaptation to soil limitations occurred during the evolutionary process. Certain species' variations can withstand acidic soil, even while the species doesn't survive it overall. Plant tolerance to high concentrations of Al or Mn, as well as to shortages in Ca, Mg, P, and other elements, is measured quantitatively.

There has been significant variance observed in the tolerance of different species to Al and Mn, as well as between genotypes within the same species. Practically speaking, it is crucial to choose species or types that do well at high Al saturation levels and require a small amount of lime. Barley is typically produced on Nitisols, which have low soil pH, in Ethiopia's highlands. This indicates that barley is already acclimated to acidic soil. On light of this, five released barley cultivars were assessed in acidic soils at Endibir in both limed and unlimed conditions. The barley varieties Dimtu and HB-42 fared well in limed conditions, that is to say.

yield increases above matching yields of the same barley kinds under unlimed conditions of 366 and 327%, respectively, were noted. Whereas the corresponding yields of the same barley types obtained under limed conditions were 48 and 49%, respectively, the barley varieties HB-1307 and Ardu performed better under unlimed conditions (Kochian et al., 2004).

Addition of Organic Fertilizers to Acidic Soils

Crop leftovers and farmyard manure (FYM) are two examples of organic plant nutrition sources that can improve the chemical and physical characteristics of soils. In order to recycle plant nutrients, for instance, Lal (2009) stated that crop residues must be returned to the soil as amendments. This results in 118 million mg of N, P, and K in residues produced annually worldwide (83.5% of global fertilizer usage), or 20 60 kg of N, P, K, and Ca per mg of crop residues.

A spectrum of organic acids that can form stable complexes with Al and Fe and block the P retention sites are released by applying FYM to acid soils where P fixation is a issue. This improves the availability and usage efficiency of P (Agegnehu and Amede, 2017). On the basis of cation exchange between root surfaces and soil colloids, manure's beneficial effects on crop yields have been described. It has been successful in lowering the phytotoxic levels of Al in acidic soils by adding organic fertilizers, leading to an increase in yield.

The main processes that are assumed to be in charge of these benefits are the direct neutralization of Al from the increase in pH brought on by the organic matter or the development of organo-Al complexes that make the Al less poisonous. Agegnehu and Amede (2017) suggest that an organic source such as agricultural wastes, compost, manures, and biochar could be used in place of lime. The authors showed that, after accounting for the acidity created during the oxidation of the N in the material, organic sources elevate pH and precipitate Al in direct proportion to their basic cation or ash alkalinity. In contrast to rice husk biochar, cacao shell biochar was reported by Cornelissen et al. (2018) to have a higher pH (9.8 vs. 8.4), CEC (197 vs. 20 cmol kg-1), and acid neutralizing capability (217 vs. 45 cmol kg-1). As a result, it had a stronger potential for liming.

Additionally, Haile and Boke (2011) observed that, in comparison to applying NP fertilizer alone, the combined application of FYM and NP fertilizer on the acid soil of Chencha, southern Ethiopia, considerably boosted potato tuber output and some soil chemical parameters. Crop yields in tropical climates typically diminish with time, in part because of a decrease in the amounts of exchangeable bases connected to the acidity of the upper soil layers. In addition to increasing crop yields, managing acidic soils with integrated soil fertility and plant nutrition management also improves the chemical composition of the soil. A sustained rise in SOM and nutritional content can be achieved with the regular application of organic wastes.

Haynes and Mokolobate (2001) state that the concentrations of exchangeable and soluble Al tend to decrease as a result of Al complexation with the recently generated organic matter. P is produced during the breakdown of organic wastes and can adsorb to oxide surfaces. This may increase the availability of P by reducing the amount of P that is subsequently added through adsorption. These processes have the practical consequence of allowing organic residues to be strategically employed to lower the rates of lime and fertilizer P needed for the best crop yield on acidic, P-fixing soils.

Agegnehu and Bekele (2005b) discovered that, in comparison to the control, the treatment of 4 and 8 t FYM ha-1 with 26 kg P ha-1 on acid Nitisols of Holetta, Ethiopia, improved the yield of faba bean seeds by 97 and 104%, respectively. Soil pH increased from 4.5 to 5.0, N from 0.09 to 0.15%, P from 4.2 to 6.0 mg kg-1, and K, Ca, and Mg from 1.25 to 1.45, 4.77-7.29, and 0.83-1.69 cmol (+) kg-1, respectively, at the same rates.

CONCLUSION

Acidity in soil is a naturally occurring process that arises from a combination of certain climatic, topographical, vegetative, parent material, and rainfall circumstances. It is the primary cause of agricultural productivity limitations and interruptions in many regions of the world, including Ethiopia. Ethiopia's highland regions are experiencing an increase in soil acidity issues. Crop productivity is primarily limited by acidity of the soil and the resulting inadequate availability of nutrients. One of the physiological properties of the soil solution that is expressed in terms of pH is soil response, which shows whether the soil is neutral, acidic, or alkaline. It has an important impact on a variety of soil characteristics, such as the availability of nutrients, biological activity, and physical state of the soil. Soil acidity usually has negative impacts when the pH of the soil drops below 4.5. The phytotoxicity of aluminum (Al) and deficits in phosphorus (P), calcium (Ca), and magnesium (Mg) are the two main reasons that restrict the fertility of acid soils.

A key component of agricultural sustainability is the preservation of soil quality and the use of sustainable soil management techniques. Lime is a potentially better alternative for sustainable soil management than other options since it improves the habitat for leguminous plants and related microbes and increases the concentration of vital minerals by boosting soil fertility and health. This widely used technique raises crop yields on acidic soils by raising the pH of the soil and causing exchangeable aluminum to precipitate.

It has been shown that the best crop performance in acid soils requires liming the soil to lessen soil acidity and lower phytotoxic levels of Mn and Al. But lime treatment should be viewed as a strategy to raise the pH of the soil in order to maximize nutrient availability for the best possible plant growth and yield; it is not a means to an end in and of itself to reach potential output. The best rates of inorganic and organic fertilizers, especially P and K fertilizers, should be used in conjunction with liming. Furthermore, it's important to pinpoint the regions where applying lime significantly improves crop productivity.

To elevate soil pH to a level appropriate for maximum nutrient availability, plant growth, and crop output, liming should be viewed as a soil amendment. Generally speaking, it is extremely important from a practical standpoint to utilize all of the resources at hand, including crop species and acid-tolerant varieties that enhance and maintain soil and agricultural output. All things considered, acid soil management must prioritize strategic research, combining enhanced crop types with soil and water management to create environmentally benign prototype technologies for sustained food production within the parameters of sensible socioeconomic and regulatory concerns.

The solutions for these issues include lime and fertilizers with inorganic phosphate. Unfortunately, our nation's farmers do not use them frequently due to rising costs and unavailability when needed. For this reason, the government need to focus on the availability of where it is prudently required. Ethiopia's declining soil fertility can be attributed to poor nutrient inputs, soil erosion, and an existing nutrient deficit. Integrated soil fertility management is the greatest solution to these issues. When alternative methods of soil amendment are not easily implemented, genotypes that are acclimated to acid soil conditions can also be grown to address issues with soil acidity. Liming, the application of integrated soil fertility management, and crop varieties resistant to Al toxicity are therefore the mechanisms employed for management of acid soils and should be proven and popularized on farmers' fields for sustainable agricultural systems within Ethiopian small-scale farming.

CONFLICT OF INTEREST

The author here declares that there is no conflict of interest in the publication of this article.

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Citation: Amanuel Tadesse 2024. Soil Acidity Causes in Ethiopia, Consequences and Mitigation Strategies-A Review. *International Journal of Agricultural and Applied Sciences*, 5(1): 86-100. https://doi.org/10.52804/ijaas2024.5113