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Tef (*Eragrostis tef*) Production and Soil Acidity Problem in Ethiopia: A Review

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Abstract

Tef is a major cereal crop which serving as staple food grain for over 70 million people primarily for human consumption after baking the grain flour into popular cottage bread called "injera" and the straw (*chid*) is an important source of feed for animals. Tef grain has good nutritive value especially iron, calcium and copper compared to other cereals. Because of its gluten-free proteins and slow-release carbohydrate constituents, tef is recently being advocated and promoted as health crop at the global level. The area devoted to tef cultivation is on the increase because both the grain and straw fetch high domestic market prices. But, the national yield per unit area (1.85 t/ha) still remains low, even though the cultivation of tef and its acceptance is become increased in Ethiopia. Soil acidity is one bottle neck from the major several environmental constraints which facing the tef production. The current study aimed to mobilize the reality of the problem and paving the way to alleviate or reduce the problem.

Keywords: Food grain • Feed • Cereal • Cultivation

Introduction

Tef *[Eragrostis tef* (Zucc.) Trotter], is the major Ethiopian cereal grown on more than 3.1 million hectares annually [1] and serving as staple food grain for over 70 million people. Tef grain is primarily used for human consumption after baking the grain flour into popular cottage bread called "*injera*". The straw (*chid*) is an important source of feed for animals. Generally, the area devoted to tef cultivation is on the increase because both the grain and straw fetch high domestic market prices. Tef is also a resilient crop adapted to diverse agro-ecologies with reasonable tolerance to both low (especially terminal drought) and high (waterlogging) moisture stresses. Tef grain has good nutritive value especially iron, calcium and copper compared to other cereals. Because of its gluten-free proteins and slow-release carbohydrate constituents, tef is recently being advocated and promoted as health crop at the global level [2].

Scientific research on tef was started in the late 1950s. Since then, commendable achievements have been made through both basic and applied research endeavors. Of these, about 51 improved varieties were released [1]. Nevertheless, the national yield per unit area (1.85 t/ha) still remains low, even though the cultivation of tef and its acceptance is become increased in Ethiopia, several environmental constraints were facing the production.

Soil acidity is one of the most important factors that affect crop production worldwide. According to Abate E, et al. [3] Acid soils (pH <5.5 in surface layer) constitute 3,950 million ha or 30% of the world"s total ice-free land or about 40% of the arable land [4]. In Africa 22% or 659 million ha of the total 3.01 billion ha land area has soil acidity problem [5]. In Ethiopia strong soil acidity affects more than 28.1% entire country and 43% of the agricultural land in the three high potential regions, mostly in highlands [6,7].

Soil acidity is associated with the presence of hydrogen and aluminum in exchangeable form. The concept of acidity was developed in connection with the behavior of aqueous solutions, which are said to be acid when the activity of hydrogen ions exceeds that of hydroxyl ions. Most soils in the humid areas are acid or "sour" as a result of losses by leaching and crop removal of such basic elements as calcium, magnesium, and potassium; while arid or desert regions soils are usually alkaline or sweet. The degree of acidity or alkalinity of a soil is conveniently expressed in terms of pH values. The pH scale is divided into 14 divisions or pH units numbered from 1 to 14 (Figure 1) [6].

Soil acidity is one of the major abiotic constraints on tef production which dominate especially in western parts of Ethiopia [8-10]. Unlike most globally important cereals, tef has not yet been bred for tolerance to soil acidity [3]. Acid soils cause nutritional disorders, deficiencies or unavailability of essential nutrients such as calcium, magnesium, molybdenum and phosphorus and toxicity of aluminum, manganese and hydrogen ions activity in the soil and perfectly affect the growth and production of crops [11,12].

The promotion of mineral fertilizers, compost and lime use, along with soil and water conservation practices, have been the main strategies promoted by the government extension service to counter the problem of soil acidity. Nonetheless, variability in agro-ecologies, local resource endowment and the limited capacity of small-scale farmers to invest in such options have limited their impact in the management of acid soils [13].

As Legesse HR, et al. [14] report most smallholder farmers in the western parts of the country have been abandoning their land temporarily (fallowing) or even permanently in some areas to mitigate this problem. However, due to the increasing population pressure, abandoning farmland temporarily or permanently has become an untenable option. For these reasons, development of cultivars adapted to acid soil complexes is a promising alternative or supplement to liming and related agronomic practices. Hence, the selection of tef genotypes/varieties adapted to acid soil conditions of western Ethiopia is necessary to ensure economic stability to many farmers who cannot afford application of liming material. tef genotypes with the capacity to tolerate acidic soil conditions will also produce high yields in areas where liming is not feasible due to high acidity conditions in the subsoil. Therefore, the aim of this study was to assess the differential response of tef genotypes of different origin to soil acidity in terms of growth, yield, and yield related traits under field conditions.

The best and economic approach option to reduce the impacts of soil acidity on crop production is the development of tolerant cultivars through selection, hybridization and other breeding methods. The main task of plant breeders to exploiting the genetic variations for the improvement of stress tolerant cultivars is evaluating different genotypes under stress conditions and performs selection practices. As Merga M and Dabi ADA [15] cited many selection indices have been formulated on the basis of yield under stress and non-stress to identify the most stress tolerant genotypes. But the study done so far were not comprised the released varieties [16,17].

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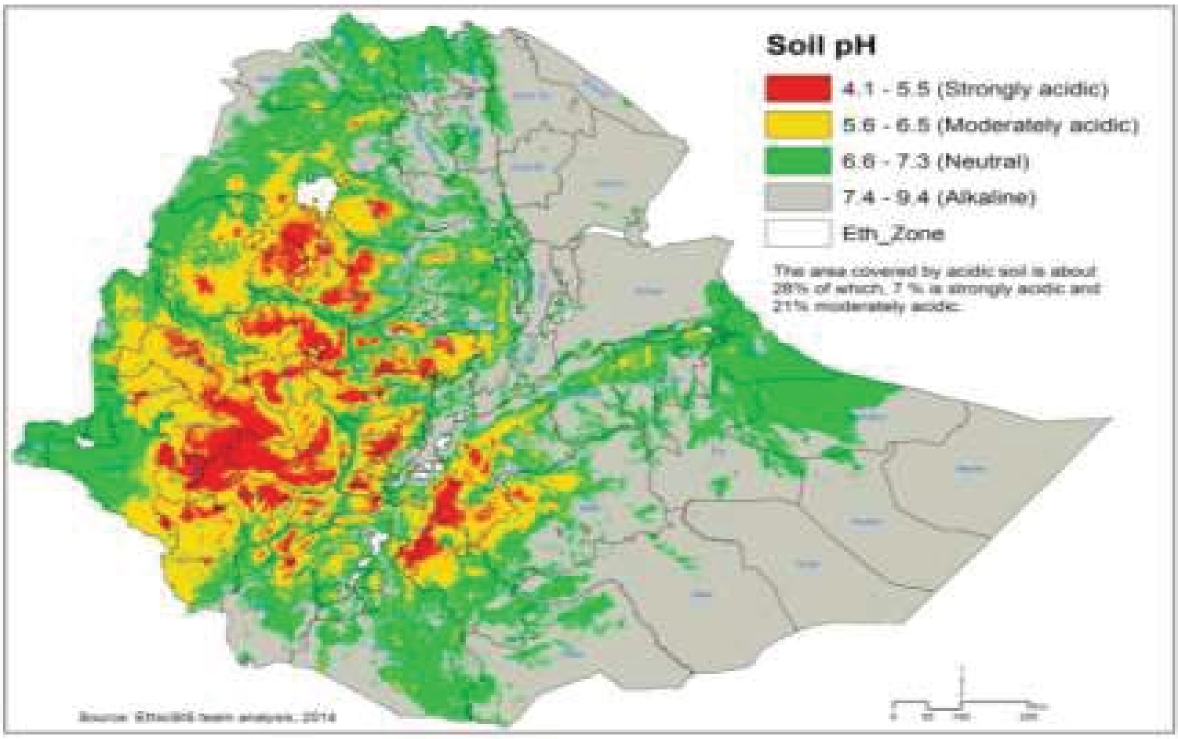

Figure 1. Ethiopian ATA report by Kassahun.

As a result, reviewing the problem is crucial to pave the way and solve the problem; specially identifying acid stress tolerant tef varieties and its management options. This review paper aimed to put together recent achievements made through research on developing soil acid tolerant tef varieties and management options have been taking; then sharing information's for our farmers and researchers living in acid soil prone areas.

Literature Review

Origin, distribution and agro-ecology of Tef

Tef is one of the crops which their center of origin and diversity in Ethiopia [18]. It is endemic to Ethiopia and its major diversity found only in this country. Similar to several other crops, the strict date and location for the domestication of tef is unknown. However, there is no doubt that it is a very ancient crop in Ethiopia, where domestication took place before the birth of Christ [19]. According to Jones BMG, et al. [20], tef introduced to Ethiopia well before the Semitic invasion of 1000 to 4000 B.C. It was probably cultivated in Ethiopia even before the ancient introduction of wheat and barley [21].

In the genus *Eragrostis*, 43% of the species seem to have originated in Africa, 18% in South America, 12% in Asia, 10% in Australia, 9% in Central America, 6% in North America and 2% in Europe [22]. According to Cufodontis G [23], 54 species are found in Ethiopia, out of which 14 (or 26%) are said to be endemic. Recent estimates indicated that only 44 of the 350 *Eragrostis* species found in Ethiopia [24].

Tef was been introduced to different parts of the world through diverse institutions and individuals [25]. However, the sources differ about the date of tef's international footmark. In his monograph Ketema S [19] reported that the Royal Botanical Gardens, Kew, London, United Kingdom, obtained tef seeds from Ethiopia in 1866 and distributed it to some countries in the British colonies, India, Australia, United States of America, South Africa and British Guyana. According to Tadesse [26], tef first introduced to California (USA), Malawi, Zaire, India, Sri Lanka, Australia, New Zealand and Argentina. It also introduced to Zimbabwe, Mozambique, Kenya, Uganda, and Tanzania. Tef being grew in South Africa, India, Australia, the Netherlands, Spain, Israel and Canada for both human consumption and animal feed [19,27,28].

Tef is adapted to a wide range of environments, and is presently cultivated under diverse agro-climatic conditions [29]. It can grow from sea level up to 2800 m.a.s.l, under various rainfalls, temperature and soil regimes. However, according to experience gained so far from national yield trials, conducted at different locations across the country, tef performs excellently at an altitude of 1700-2200 m.a.s.l, annual rainfall of 750 - 850 mm, growing season rainfall of 450-550 mm and a temperature range of 10°C-27°C [30]. Tef grows largely in 11 of the 19 major agro ecological zones of Ethiopia [31].

Tef grain yield in the US averages from 0.7 t/ha dry land to 1.4 t/ha irrigated [27]. In Ethiopia, the national average grain yield of tef is about 1.85 t/ha [1]. However, improved varieties of tef produced a grain yield of 1700-2200 kg/ha on farmers' fields and 2200-2800 kg/ha on research fields and well managed large farms [32] [19]. It suffers less from diseases, gives better grain yield and possesses higher nutrient contents, especially protein, when grown on Vertisoils rather than on Andosols [30].

Tef plants cannot strive with weeds especially during the young growing stage. It is best to start with a weed-free, clean field that ploughed frequently during the appropriate season in order to kill the weeds. The work should also start with clean tef seeds that are free of weed seeds [19]. Depending on variety, tef is ready for harvest three to five months after sowing [33].

Use and nutritional value of Tef

The use of tef traced back to about 3359 B.C [34]. In contrast to amaranth, which utilized by early civilizations throughout the world, tef production and uses have been primarily restricted to the countries of Ethiopia, India and its colonies, and Australia [27]. While tef grain still provides over two-thirds of the human nutrition in Ethiopia, it is relatively unknown as a food crop elsewhere. Late 20th century publications in the United States describes tef grain as being marketed as a health food product, or used as a late planted emergency forage for livestock [35].

Tef is highly nutritious and is an important part of Ethiopia's cultural heritage and national identity. It is an excellent source of essential amino acids especially lysine, the amino acid that is most often deficient in other grain foods. Tef contains more lysine than barley, millet, and wheat and slightly less than rice or oats [2]. It is an important source of water-soluble vitamins especially vitamins B1, B2, B3 and B6, and in contrast to other cereals tef contains vitamin C [36]. Tef is also an excellent source of fiber and high in mineral contents like Fe, Ca, Cu, Zn and Mg [37]. Moreover, it is gluten-free and preferred food for persons with celiac disease, diabetics (slow-release carbohydrates) and anemia [38].

It is the smallest grain in the world, and it takes 150 grains of tef to equal the size of one kernel of wheat. The grain also gives high returns in flour of 99% compared to 60-80% from wheat [39]. There are three types of tef grains known as white, brown and mixed (brown and white) in the market. In Ethiopia, tef traditionally used to make *injera*, which is a soft, porous, thin pancake, with slightly sour taste. Tef commonly consumed with various meat and/or pulse sauces called wot. Its flour also used for the preparation of tef porridge, and un- raised bread called *Kitta* or *anebabero* (two over-laid *injera*). Sometimes, the grain brewed into a native beer called *Tella* or *Fersso* and a more alcoholic traditional liquor, locally known as *arakie,* or *katikalla*. Tef straw also used as animal feed, binder of mud used for plastering local houses or huts, and to make local grain storage silos called *goteras* [19].

There are several recipes that fit western palates was developed from tef flour, particularly in the United States and Europe, where it has found niches in the health food market as a gourmet food. Tef flour used as a thickening agent in a range of products including gravies, casseroles, soups and stews. It also used as an ingredient in puddings, smoothie drinks and in baked goods such as cookies, muffins and crackers. In addition, tef grain, owing to its high mineral content, now used in mixture with soybean, chickpea and other grains in the baby food industry [19] [40].

According to Ketema S [30] tef remained an important crop to Ethiopian farmers because of the prices for its grain and straw are higher than other major cereals. The crop performs better than other cereals under moisture stress and waterlogged conditions; its grain can be stored for a long period without attacked by weevils and the straw is a nutritious and highly preferred feed for cattle compared to other cereals.

Constraints of Tef production in Ethiopia

Tef is the dominant cereal in Ethiopia ranking first in area coverage (accounting for 30% of the area) and second to maize in terms of volume of production (Table 1).

Despite its indispensable importance in the Ethiopian agriculture, the production and productivity of tef is low with the national average standing at 1.85 t ha^{-1} [1]. The major yield limiting factors are lack of cultivar that tolerant to lodging, acidity, drought and pests [41]. Besides, the grains are also often lost in the harvesting and threshing process because of their minute size [26].

Soil acidity problems in Ethiopia

Soil degradation is a global threat. Developing countries are more severely affected by soil degradation than developed countries. Ethiopia is also one of the developing countries in eastern Africa and highly threatened by soil degradation problems [42]. Soil acidity is one of the major constraints to tef production on acid soils. It is one of the chemical soil degradation problems which affect soil productivity especially in the highlands of Ethiopia. According to Golla AS [40] review; Soil acidity is the problem of agricultural activities in Ethiopian highlands (cultivated lands) and is getting an increase. It is a critical issue requiring urgent attention in most highlands of Ethiopia because of its impact on crop production and productivity [44-46]. Most acidic soils have poor chemical and biological properties. Its acidity associated with Al, H, Fe, Mn toxicities to plant roots in the soil solutions and corresponding deficiencies of the available P, Mo, Ca, Mg and K [47,48].

Table 1. Area planted and production of the main cereals grown in Ethiopia in 2019/20 (2012 E.C).

Crop	Area in Million Hectares	Production Million Tones	Yield (t/ha)
Tef	3.10	5.7	1.85
Maize	2.27	9.6	4.24
Sorghum	1.83	5.2	2.88
Wheat	1.79	5.3	2.97
Barley	0.95	2.3	2.5
Finger millet	0.46	1.1	2.47
Total	10.4	29.2	16.91

Source: CSA; 2020 or [1].

In the humid tropics, soils become acidic naturally due to leaching of basic cations under high rainfall conditions. At pH below 5, Al is easily soluble in water and becomes the dominant ion in the soil solution. Soil acidity is expanding in scope and magnitude in Ethiopia, severely limiting crop production. For example, in tef; barley, wheat and faba bean growing areas of central and southern Ethiopian highlands, farmers have shifted to producing oats which is more tolerant to soil acidity than the others [49,14].

Extent of soil acidity

As Getaneh S and Kidanemariam W [47] cited; Soils tend to become acid because of the leaching mechanism of carbonic acid that is CO_2 dissolved in rainwater. Basic cations like calcium (Ca) and magnesium (Mg) are removed through leaching and crop harvest but at the same time these bases are replaced due to organic matter decomposition and from the weathering of minerals those are formed by naturally [50]. Soil acidity is among the major land degradation problem worldwide. About 30% of the ice-free soils (close to 4 billion ha) in the world are acidic [51]. Tropical and sub-tropical regions as well as areas with moderate climatic conditions are mostly affected by soil acidity. Worldwide, 32% of all arable land is acidic. Almost two-third of all acidic soils in the world belongs to Ultisols, Entisols and Oxisols [52]. Oxisols (also referred to Ferralsols) occupy about 3.75 million km^2 or 14.3% of the total land area of Africa. The Oxisols (dusk red Latosols, dark red Latosols, red, yellow Latosols, and yellow Latosols) are the dominant soils, with about 98 million ha. They are very weathered deep, acid soils, with a low availability of nutrients, but with good physical properties due to the predominance of 1:1 clay mineral, and Fe and Al oxides in the fraction [53].

Land degradation is a critical challenge, substantially affecting agricultural productivity and rural livelihoods in Ethiopia [54], especially serious in the highlands, which is 44% of the total area of the country where human and livestock pressure is high [55]. It is home to 90% of the total human population; 95% of the land under crops and 75% of livestock are also located in this area [55]. The impact of land degradation has put at risk the livelihoods, economic wellbeing, and nutritional status of several people in the country [56]. Land degradation not only reduces the productive capacity of agricultural land, rangelands and forest resources but also considerably impacts on biodiversity [57]. It adversely affects the ecological integrity and productivity of large areas of land, or landscapes under human use. Soil acidity and associated low nutrient availability are key constraints to crop production in acidic soils, mainly Nitisols of Ethiopian highlands;It estimated that around 43% of the Ethiopian cultivated land is affected by soil acidity. The extent of soil acidity in Ethiopia is about 28%, of these soils are dominated by strong acid soils (4.1-5.5 pH) [58,6].

Major acid soils in Ethiopia

Nitosol/Oxisol soils are the main soil classes dominated by soil acidity. Under acidic soil conditions there has been a gradual depletion of soil bases (such as Ca, Mg and K) and soil acidity developed. Soil acidity mainly at soil pH <5.5 affects the growth of crops due to high concentration of aluminum (Al) and manganese (Mn), and deficiency of P, nitrogen (N), sulfur (S) and other nutrients [59].

The dominant soil associations are Dystric Nitisols and Orthic Acrisols with inclusions of Dystric Cambisols and Lithosols on the steepest slopes. Eutric Nitisol is the dominant soil type as Nitisol in the central highlands of Ethiopia where soil acidity is the problem. Nitisol is the major soil unit that covers the western part of Ethiopia. The soil develops on a wide range of parent materials, such as volcanic, metamorphic, granitic, and felsic materials, sandstones and limestone. The soil occurs on the gently sloping to steep land, on flat and undulating lands, usually with other types of soil units such as Gleysols or Vertisols. On the other hand, the [steeper slops are usually covered with shallow soils such as Cambisols and Luvisols [50].

Nitisols have very good potential for agriculture; they have a stable structure and a high-water storage capacity. Workability on these soils does not create any problem even shortly after precipitation or in the dry season, land can be prepared without difficulty. These soils have a rather low CEC for their clay content and available P are usually very low [50]. Nitisols have three sub-soil units, i.e. Eutric, Dystric and Humic Nitisols. Dystric Nitisol contains relatively high organic matter content in the top layer and high base saturation in the soil profile, especially in the A and B-horizons, indicating the high fertility status of the soil. Eutric Nitisol has red to dusky red lower laying horizon, with similar fertility status to that of the Dystric Nitisol. Nitisols are found in areas where the slope is between 2-16% on undulating plains, low plateaus, gentle hills and mountains side slopes of all areas. The problem of acidity is closely related to these soil types due to their geographical location, intensive cultivation, and inappropriate farm management practices [50]. Acrisols are generally developed from acidic parent material, which occur in the high rainfall areas associated with Nitisols and Cambisols. These soils are found on moderate to steep slopes. They are moderately suited for agriculture, partly they are cultivated, and partly they are left under natural vegetation for grazing purposes. Base saturation is generally low, and pH value is generally below neutrality. Acrisols are the results of strong weathering and depletion of bases by leaching.

Causes of soil acidity

Soil acidification is a multipart set of process resulting in the formation of an acid soil. In the broadest sense, it can be considered as the summation of natural and anthropogenic processes that lower down the pH of soil solution [60].

Removal of agricultural by products (crop residues) and continuous crop harvest (without proper fertilization), removal of cations and continues use of acid forming inorganic fertilizers make important contribution to soil acidity development in most highland areas of Ethiopia[12]. Continuous application of chemical fertilizers with N and/or P nutrients only in the form of DAP and urea, in the country, has adversely affected soil physical properties such as soil structure and bulk density [60]. Besides, the practice can aggravate soil acidification and depletion of macro and micro plant nutrients to amounts below critical level needed for optimal crop growth and production [61,62]. Thus, in Ethiopia, acidity related soil fertility problems are major production constraints reducing the productivity of the major crops grown in the country [10]. In efficient use of nitrogen is one of the causes of soil acidification, followed by the export of alkalinity in produce [63]. Ammonium based fertilizers are major contributors to soil acidification. Ammonium nitrogen is readily converted to nitrate and hydrogen ions added in to the soil. It has been recognized that there are several causes for soils to become acidic. The following factors are the major causes of soil acidity.

a) Climate: It has been well known that in soils of dry region a large supply of bases is usually present, since little water passes through the soil. With an increase in rainfall, the contents of soluble salts are reduced to a low level, and any calcium carbonate and gypsum present are removed. With further increase in rainfall, a point is reached at which the rate of removal of bases exceeds the rate of their liberation from nonexchangeable forms. Wet climates have a greater potential for acidic soils [56]. Over time, excessive rainfall leaches the soil profile's basic elements (Ca, Mg, Na, and K) that prevent soil acidity. High rainfall leaches soluble nutrients such as Ca and Mg which are specifically replaced by Al from the exchange sites [64].

b) Acidic parent material: Rocks containing an excess of quartz or silica as compared to their content of basic materials or basic elements are categorized as acid rocks; for example, granite and rhyolite. When rocks that are deficient in bases are disintegrated or decomposed in the process of the accumulation of soil material is acidic, despite no loss of base during the process of soil formation. Soils that develop from weathered granite are likely to be more acidic than those developed from shale or limestone. There are large areas of siliceous and sandy soils produced from acid parent rocks, which have always been in need of lime. However, most acid soils have been developed as a result of leaching losses and crop removal of bases [64].

The inherent fertility of Ethiopian soils developed under varied parent materials and climate varies depending on the origin and composition of the materials. For instance, soils developed from sandstones are poor sandy soils, whereas the inherent soil fertility developed over basic parent materials is relatively high. In alluvium plains, alluvium becomes rich and fertile if it originates from relatively young materials, and less fertile if it originates from highly weathered surfaces. The pH values in the majority of soils are in the range of 4.5 to 6.5. In most cases, soils found in high altitude areas of the country are acidic in reaction, poor in exchangeable cations and low in base saturation [65].

c) Application of ammonium fertilizers: Continuous application of inorganic fertilizer without soil test and amendment, in the end increase soil acidity. The use of N fertilizers in form of ammonia is a source of acidification [66,63]. When ammonium fertilizers are applied to the soil, acidity is produced, but the form of N removed by the crop is similar to that found in fertilizer. Hydrogen is added in the form of ammonia-based fertilizers (NH_4), urea-based fertilizers [(CO $(NH_2)_2$], and as proteins (amino acid) in organic fertilizers. Transformation of such sources of N fertilizers into nitrate (NO_3) releases hydrogen ions (H^+) to create soil acidity. In reality, N fertilizer increases soil acidity by increasing crop yields, thereby increasing the amount of basic elements being removed by crop harvest without incorporation. Hence, application of fertilizers containing NH_4 or even adding large quantities of organic matter to a soil can ultimately increase soil acidity and lower pH [63].

d) Decomposition of organic matter: The decomposition of organic matter produces H^+ ions, which are responsible for acidity. The development of soil acidity from the decomposition of organic matter is insignificant in the short-term. Large quantities of carbonic acid produced by microorganisms and higher plants including through other physicochemical and biological processes are the causes of soil acidity although the effect from its dissociation is relatively small as most of it is lost to the atmosphere as CO_2 [67]. Soil organic matter or humus contains reactive carboxylic, enolic and phenolic groups that behave as weak acids. During their dissociation they release H^+ ions. Further, the formation of CO_2 and organic acids during the decomposition also results in replacement of bases on exchange complex with H^+ ions.

e) Removal of major cations through crop harvest: Removal of elements, especially from soils with small reservoir of bases due to the harvest of high yielding crops is responsible for soil acidity. When soils are worked mechanically and crops are grown the balance is disturbed and the soils become more acid. This is the result of base cations being removed with crops and the simultaneous increase of leaching which takes place when soils are disturbed and worked [64,68]. During growth, crops absorb basic elements such as Ca, Mg, and K to satisfy their nutritional requirements. As crop yields increase, more of these lime-like nutrients are removed from the field. Compared to the leaf and stem portions of the plant, grain contains minute amounts of these basic nutrients. Therefore, harvesting high-yielding forages such as Bermuda grass and alfalfa affects soil acidity more than harvesting grain does [69,52].

f) Land use or land cover change: Changes in land use and management practices often modify most soil physical, chemical and biological properties to the extent reflected in agricultural productivity [70]. Previous studies indicated that soil properties deteriorate due to the conversion of native forest and range land into cultivated land [71,72]. Such practices result in an increase in bulk density, decline in Soil Organic Matter (SOM) content and CEC, which in turn reduce the fertility status of a certain soil type. In addition, change in land use associated with deforestation, continuous cultivation, overgrazing, and mineral fertilization can cause significant variations in soil properties and reduction of output [72,73].

Studies have emphasized the negative effect of land use or land cover change on soil properties. For example, the study of Agoume and Agoumé

V and Birang AM [74] on the impact of land use systems on some physical and chemical soil properties of an Oxisol in the humid forest zone of southern Cameroon showed that land use systems significantly affected the clay, silt and sand fractions. Sand and silt decreased with soil depth, but clay increased. Soil pH, total N, organic carbon, available P, exchangeable cations, exchangeable Al, effective cation exchange capacity and Al saturation significantly differed with the land use systems.

The Al saturation increased with soil depth, and the top soils presented acidity problems while the sub soils exhibited Al toxicity. According to Chimdi A, et al. [72] indicated also a decline in total porosity in the soils of grazing and cultivated land in comparison to soils of forest land was attributed to a reduction in pore size distribution and the magnitude of SOM loss which in turn depends on the intensity of soil management practices. Bore G and Bedadi B [68] also reported that the amount of SOM in grazing and cultivated lands has depleted by 42.6 and 76.5%, respectively, compared to the forest soil.

g) Low buffer capacity of the soil: Another source of soil acidity is contact exchange between exchangeable hydrogen on root surfaces and the bases in exchangeable form on soils. Where leaching is limited, microbial production of nitric and sulfuric acids also occurs. The lime requirement of acid soil is related not only to the soil pH but also to the buffer or CEC. The buffering or CEC is related to the amount of clay and organic matter present, the larger the amount, the greater the buffer capacity. Soils with higher buffer capacity (clayey, peats), if acid, have high lime requirement. Coarse textured soils with little or no organic matter will have low buffer capacity and, even if acid, will have low lime requirement. The indiscriminate use of lime on coarse textured soil could lead to over-liming injury. Therefore, the relationship between pH and percent base saturation is important for soils representative of 1:1 and 2:1 clays, because a much higher base saturation was required to raise the pH to 6 with montmorillonite than with kaolinite. For instance, soils with 2:1 clays (fine, mixed, and thermic Vertic (Hapludults) had to be 80% base saturated to give the same pH as the soils with 1:1 clays (fine, loamy, siliceous thermic Typic Hapludult) at 40% base saturation as determined by the sum of cations, pH 8.2 CEC method [75,76].

Effect of soil acidity on nutrient availability and crop yield

The detrimental effect of soil acidity on plant growth and yield is mainly attributed to the deficiency of phosphorus, which is caused by adsorption of P to colloidal fractions and conversion to insoluble Al and/or Fe compounds and toxicity of aluminum, iron and manganese [60]. Deficiencies of calcium, magnesium, potassium and molybdenum have also been reported to limit crop yield in acid soils [77].

The solubility and availability of important nutrients to plants is closely related to the pH of the soil [78]. Soil pH affects the availability of plant nutrients. Effects of high acidity in a soil are shortage of available Ca, P and Mo on the one hand, and excess of soluble Al, Mn and other metallic ions on the other [79]. Acid soil limits the availability of crucial nutrients such as P, K, Ca and Mg, and affects the movement of soil organisms plants need to stay healthy. If a particular soil is too acidic for plants to grow healthy, it is necessary to raise the pH by applying an alkaline substance.

Soil acidity and associated low nutrient availability is one of the constraints to crop production on acid soils. If a pH of a soil is less than 5.5 phosphate can readily be rendered unavailable to plant roots as it is the most immobile of the major plant nutrients [80], and yields of crops grown in such soils are very low. In soil pH between 5.5 and 7, P fixation is low and its availability to plants is higher. Toxicity and deficiency of Fe and Mn may be avoided if the soil reaction is held within a soil pH range of 5.5 to 7; this pH range seems to promote the most ready availability of plant nutrients. The quantity of P in soil solution needed for optimum growth of crops lies in the range of 0.13 to 1.31 kg P ha^{-1} as growing crops absorb about 0.44 kg P ha^{-1} per day [81]. The labile fraction in the topsoil layer is in the range of 65 to 218 kg P ha^{-1}, which could replenish soil solution P [81].

Soil acidity managements

The management of acid soils should aim at improving the production potential by the addition of amendments to correct the acidity, manipulate the agricultural practices and using acid tolerant crops to obtain optimum crop yields. Farmers require simple and sustainable techniques to amend on acid soils and improve yields of crops of their choices. Recommendations on reclamation of acid soils need to change with new developments, such as liming, use of acid-tolerant crop varieties, integrated soil fertility management, and using of organic fertilizers. Liming has played an important role in raising soil pH and enhancing crop productivity. In Ethiopia, the gap between potential and actual yield is very wide because of soil acidity and associated nutrient availability. For Example, if we take tef the actual yield is 1.85 ton/ha but it's yield potential is up to 6 ton/ha [30]. Acidic soils are not responsive to the application of inorganic fertilizers without amendments-it is simply wastage of resources.

Several practices have been recommended to reclaim soil acidity and upgrade the productivity of strongly acidic soils. These include the cultivation of acid tolerant plants, covering the surface with non-acidic soil, the use of organic fertilizers, and liming. Of these practices, liming and the application of organic fertilizers are considered being the best measures, because their effects are more persistent [82]. However, the unaffordability of fertilizers and lime, and unsustainable crop production calls for use of locally available low-cost organic sources through manures, green manures, and mineral fertilizers in a harmonized combination for sustainable production and soil quality. Farming in the highlands of Ethiopia is characterized by low agricultural productivity as compared with developed countries for progressive soil fertility decline over the years, and inadequate applications of amendments. The overall objective of the this paper is to see soil acidity status and what management practices are taking place to reduce the impact on soil fertility which can be one factor of agricultural productivity.

The management of acid soils should aim at improving the production potential by the addition amendments to correct the acidity and manipulate the agricultural practices to obtain optimum crop yields. The soil's acid/alkali balance (measured by pH) of the soil is very important in maintaining optimum availability of soil nutrients and minimizing potential toxicities. For example, at a very low pH Al may become more soluble and can be taken up by roots - becoming toxic, P may become unavailable and Ca levels can be low. At high pH, Fe and other micronutrients (except Mo) are rendered unavailable since they are locked up as insoluble hydroxides and carbonates [83].

a) Liming: Liming is the application of calcium- and magnesium-rich materials to soil in various forms, including marl, chalk, limestone, or hydrated lime. It is a desirable practice where soil is highly acidic and multi-cropping involving acid sensitive crops is adopted. Lime, in its most pure form, is made up largely of Ca. Calcium carbonate is a base, and therefore, has a neutralizing effect on acid [84]. Lime improves base saturation and availability of Ca and Mg. Fixation of P and Mo is reduced by inactivating the reactive constituents. Toxicity arising from excess soluble Al, Fe and Mn is corrected and thereby root growth is promoted and uptake of nutrients is improved. Liming also stimulates microbial activity and enhances N fixation and N mineralization and hence, legumes are highly benefited from liming [69,85]. However, over-liming can considerably reduce the bioavailability of micronutrients, such as Zn, Cu, Fe, Mn and B, which decreases with increasing pH [69]. This can produce plant nutrient deficiencies, particularly that of Fe.

Soil acidity limits or reduces crop productivity mainly by impairing root growth thereby reducing nutrient and water uptake [78]. Soil acidity converts available soil nutrients into unavailable forms and soils affected by soil acidity are poor in their basic cations, such as Ca, K, Mg, and some micronutrients, which are essential to crop growth and development [12]. The extent of damage posed by soil acidity varies from place to place depending on several factors, and there are occasions where total crop failure occurs due to soil acidity. Thus, the main effects of liming are increasing the available P through inactivation or precipitation of exchangeable and soluble Al and Fe hydroxides, increase in pH, available P, exchangeable cations and percent base saturation, and enhancing the growth density and length of root hairs for uptake of P [78].

Soil acidity can be corrected easily by liming the soil, or adding basic materials to neutralize the acid present. The most economical liming materials and relatively easy to manage are calcitic or dolomitic agricultural limestone. Since these products are natural they are relatively insoluble in water, agricultural limestone must be very finely ground so it can be thoroughly mixed with the soil and allowed to react with soil's acidity. Calcitic limestone is mostly calcium carbonate ($CaCO_3$). Dolomitic limestone is made from rocks containing a mixture of Ca and Mg carbonates ($CaCO_3$+ $MgCO_3$). Other liming materials which are less frequently used include burned lime (CaO), hydrated lime [$Ca(OH)_2$] and wood ashes [85,52].

According to Agegnehu [86] the application of lime at the rates of 1, 3 and 5 t ha^{-1} resulted significantly in linear response with mean faba bean seed yield advantages of 45, 77 and 81% over the control. Desalegn et al. (2017) showed that application of 0.55, 1.1, 1.65 and 2.2 t lime ha^{-1} decreased $Al^{3+}$by 0.88, 1.11, 1.20 and 1.19 mill equivalents per 100 g of soil, and increased soil pH by 0.48, 0.71, 0.85 and 1.1 units, respectively. Agegnehu [86] also indicated that soil pH consistently increased from 4.37 to 5.91 as lime rate increased. Conversely, the exchangeable acidity was significantly reduced from 1.32 to 0.12 cmol (+) kg^{-1} because of lime application. Yield increments showed direct relationship with the soil pH values and inverse relationship with exchangeable acidity, i.e. as the pH increased the yield also increased, but as the exchangeable acidity decreased the yield of faba bean increased and vice versa. There is also found that seed yields of legumes were optimal between soil pH values of 5.7 and 7.2 and yields of pea could be increased by 30% due to lime application to soils with pH values less than 5.4.

b) Complimentary management strategies/using acid tolerant crop varieties: If soil pH is low, using tolerant species/varieties of crops and pasture can reduce the impact of soil acidity. This is not a permanent solution because the soil will continue to acidify without liming treatment. A number of management practices can reduce the rate of soil acidification. Management of nitrogen fertilizer application is the most important practice to reduce nitrate leaching in high rainfall areas. Product export can be reduced by feeding hay back onto paddocks from where it has been cut. Less acidifying options in crop rotations will also help, e.g. replace legume hay with a less acidifying crop or pasture [87].

eThe number of plant species of economic importance are generally regarded as tolerant to acid soil conditions. Many of them have their center of origin in acid soil regions, suggesting that adaptation to soil constraints is part of the evolutionary process. Although the species as a whole does not tolerate, some varieties of certain species also possess acid soil tolerance. Quantitative assessments of plant tolerance to acid soil stresses include tolerance to high levels of Al or Mn, and to deficiencies of Ca, Mg, P, etc. Species and genotypes within a species have been reported to have considerable variation in their tolerance to Al and Mn. The selection of varieties or species that perform well at high Al saturation levels and thus need only a fraction of the normal lime requirement is of great practical importance. In the highlands of Ethiopia, barley is mainly grown on Nitisols, where soil pH is low. This means that barley has been already adapted to acid soil conditions. With this understanding five released barley varieties were evaluated under limed and unlimed condition on acidic soils at Endibir. Barley varieties (HB-42 and Dimtu) performed well under limed condition, i.e. yield increments of 366 and 327%, respectively over the corresponding yields of the same barley varieties under unlimed condition were recorded. In contrast, barley varieties (HB-1307 and Ardu) performed better under unlimed condition, i.e. lower yields of 48 and 49% compared to the corresponding yields of the same barley varieties achieved under limed condition [67].

c) Addition of organic fertilizers to acidic soils: Farmyard manure (FYM) and crop residues are among organic plant nutrient sources, which could ameliorate the physical and chemical properties of soils. For example, Lal [88] indicated that returning crop residues to soil as amendments is essential for recycling plant nutrients (20–60 kg of N, P, K, Ca per Mg of crop residues) amounting to 118 million Mg of N, P, K in residues produced annually in the world (83.5% of world's fertilizer consumption). In acid soils, where P fixation is a problem application of FYM releases a range of organic acids that can form stable complexes with Al and Fe thereby blocking the P retention sites, and as a result, the availability and use efficiency of P is improved [89]. The positive effects of manure on crop yields have been explained on the basis of cation exchange between root surfaces and soil colloids [90].

The addition of organic fertilizers to acid soils has been effective in reducing phytotoxic levels of Al resulting in yield increases. The major mechanisms responsible for these improvements are thought to be the formation of organo-Al complexes that render the Al less toxic or direct neutralization of Al from the increase in pH caused by the organic matter. The possible alternative of using organic sources such as crop residues, manures, compost and biochar are substitutes for lime [89]. The authors demonstrated that organic sources raises pH and precipitate Al in direct proportion to its basic cation or ash alkalinity with a correction for the acidity produced during the oxidation of the N in the material. For instance, Cornelissen G [88] found that cacao shell biochar exhibited a higher pH(9.8 vs. 8.4), CEC (197 vs. 20 cmol kg^{-1}) and acid neutralizing capacity (217 vs. 45 cmol kg^{-1}) and thus had a greater liming potential than rice husk biochar. Haile and Boke [49] also reported that the combined application of NP fertilizer and FYM on acid soil of Chencha, southern Ethiopia significantly increased potato tuber yield and some soil chemical properties relative to application of NP alone.

In tropical regions, crop yields generally decrease with time, partly due to a decline in the levels of exchangeable bases linked to acidification of the upper layers of the soil. The management of acid soils through integrated soil fertility and plant nutrient management not only improve the yields of crops but also the chemical properties of soils. Regular applications of organic residues can induce a long-term increase in SOM and nutrient content. According to Haynes RJ and Mokolobate MS [89] complexation of Al by the newly formed organic matter tends to reduce the concentrations of exchangeable and soluble Al. As organic residues decompose, P is released and can be adsorbed to oxide surfaces. This can reduce the extent of adsorption of subsequently added P thus increasing P availability. The practical implication of these processes is that organic residues may be used as a strategic tool to reduce the rates of lime and fertilizer P required for optimum crop production on acidic, P-fixing soils. Agegnehu G and Bekele T [90] found that the application of 4 and 8 t FYM ha-1 with 26 kg P ha-1 on acid Nitisols of Holetta, Ethiopia, increased faba bean seed yield by 97 and 104%, respectively, compared to the control. The same rates increased soil pH from 4.5-5.0, N from 0.09-0.15%, P from 4.2-6.0 mg kg-1, and K, Ca and Mg from 1.25-1.45, 4.77-7.29 and 0.83-1.69 cmol ($^+$) kg-1, respectively.

Conclusion

Tef is the major Ethiopian cereal grown on more than 3.1 million hectares annually. However, it's productivity relatively low (1.85 t/ha). Nonetheless, it gained recently global popularity "Super grain" as healthy and performance food due to its gluten free especially for celiac disease, diabetic and gluten allergy people. It has also high mineral contents like iron for anemia, bone and heart health as well as brain function. Soil acidity is one of the most important factors that affect tef production. The current study is also to show the strictness of the problem from time to time relating to tef (main food of Ethiopian) production.

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