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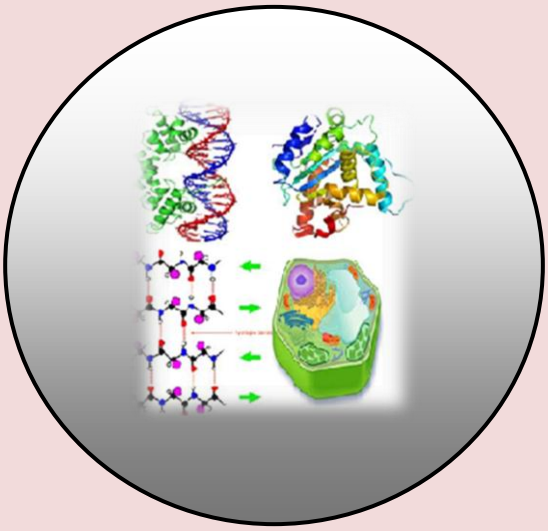

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Review on Causes, Effects and Management Method of Soil Acidity in Ethiopia

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ABSTRACT

A variety of processes can degrade soils, causing them to lose the functions that make them healthy and able to effectively provide multiple services. Indicators of soil acidity were measuring soil pH and symptom of plant. Current status of soil acidity in Ethiopia indicated that 43% total arable land affected from those 15% strongly acidic and 28% moderately acidic. Soil acidity often found in Oxisols, Nitosols, and Ferralsols soils and could be some Inceptisols, quite a few Alfisols, most Oxisols and Ultisols in Ethiopia. Causes of acidity, parent material, Land use, Soil texture, Climate, Rainfall, Nitrogen Fertilizers, Plants, Product removal, Organic Matter Decay, Subsoil Acidity, Nitrification and dry summer conditions. To manage soil acidity (pH), the addition of amendments liming and Sulfur amendment, fertilization (appropriate use of nitrogen) and tillage practices including shift cultivation, SOM levels and crop selection (acid tolerant varieties) should all be considered were found to be effective in reducing soil acidity and Al toxicity in different areas. Access of lime in Ethiopia, EthioSIS team analysis, 2014 indicated that Goal for 2020, from total cultivated land 226,000ha of acid soils to be treated. Plan for next five years 450,000-900,000 tons of lime needs to be produced, distributed and applied to acid soils to meet the goal. GTP (Growth and Transformation Plan). The lime initiative laid the foundation for much broader dissemination and impact of agricultural lime in Ethiopia through: Groundwork, Capacity building and Infrastructure building. Challenges of soil acidity management in Ethiopia are all acidity affect soil not known, accessibility of lime and limited awareness of acidity effect. Future line work for acidity soil remedy in Ethiopia includes Characterization and mapping of soil acidity, awareness creation and accessing the lime in Ethiopia. The aim of the paper was to review Potential, Cause, effect, and management method of Soil acidity in Ethiopia.
Key words: Soil, Acidity, PH, lime and Ethiopia.

INTRODUCTION

A variety of processes can degrade soils, causing them to lose the functions that make them healthy and able to effectively provide multiple services. With soil degradation, crop yields fall, soil organic carbon is depleted, soil biodiversity decreases, the capacity to sequester carbon decreases, etc. (Ethiopian Soil Campaign, 2015). Soil acidity is one of the chemical soil degradation problems which affect soil productivity in the Ethiopian highlands (Aboytu Sisay, 2019). Many soils, especially in humid regions, were acidic before they were ever farmed parent materials (SARE, 2012), the another causes of soil acidity could be leaching of basic cations such as Ca^{2+}, Mg^{2+}, and K^+, and continuous use of acid-forming mineral fertilizer sources such as urea (CO $(NH_2)_2$) and Diammonium phosphate($(NH_4)_2HPO_4$) which produce hydrogen ion (H^+) through oxidation of ammonium ion (NH_4^+) to nitrate ion(NO_3^-) (Cook, 1982, Obiri-Nyarko, 2012). Soil acidity associated to Al toxicities, soil erosion and soil nutrient depletion are the main soil related constraints to agricultural development in parts of developing countries relying on agricultural to feed their growing population (Tolera, et al, 2006, Fekadu Mosissa, 2018).

A rapidly growing population, Currently about 85-90 percent of the population (68-70 million, or around12 million households), lives on, agriculture of Ethiopia needs to increase food production in grain equivalent, by at least one million metric tons, but total cultivated land is around 12 million hectares, majority as semi-commercial or subsistence farming system Population growth and agricultural production are not growing at par, Due to Land degradation and result, nutrient depletion (ATA, 2013). Soil acidity and low availability of phosphorous (P) are among the major problems limiting crop production in the highlands of Ethiopia where high rainfall, nutrient leaching, and soil erosion are more prevalent (Asmare et al. 2015). Soil acidity affects the growth crop because acidic soil contain toxic levels of aluminum and manganese and characterized by deficiency of essential plant nutrients such as P, Ca, K, Mg, and Mo (Wang et. al., 2006; Tisdale et. al., 1985). Due to this reason, In September 2013, the 68^{th}UN General Assembly declared the year 2015 as the International Year of Soils. In preceding years, it had become apparent that the world-wide rate of soil depletion was coming to jeopardize the capacity of farmers to meet the food needs for the projected global population of 20 billion by 2050.

Soil pH is a measure of soil acidity (USDA-NRCS, 2018). Achieving optimum soil pH is essential for field crop production, because it affects many soil properties and processes, including nutrient cycling, soil microbial activity, and soil structure. Soil acidity affects root development, leading to reduced nutrient and water uptake and deficiency in essential plant nutrients, such as K, Ca, and Mg (Abdenna, et al., 2007, Negash Teshome, 2017). Low soil P availability due to its high fixation in acidic soils is limiting crop production. A study also showed that soil acidity increased on cultivated lands in western part of Ethiopia because of the intensity of the high rainfall (Achalu et al., 2012). Moreover, different reports indicated that most cultivated lands of the Ethiopian highlands in general and western parts in particular are prone to soil acidity due to removal of ample amount of nutrients by leaching, crop mining and runoff as compared with grazing and forest lands (IFPRI. 2010).

The use of lime, acid tolerant varieties, application of compost, and manure were found to be effective in reducing soil acidity and Al toxicity in different areas [T. W. Crawford, 2008, Endalkachew Fekadu et al., 2019].

Objective

- To review on Potential, Causes, effects, and management method of Soil acidity in Ethiopia: Current status and future perspective.

INDICATORS OF SOIL ACIDITY

Soil acidification is the result of a complex set of processes caused both naturally and by human activity (Amede Tilahun et al, 2019). It limits plant growth because of conditions that increase base element deficiencies, Phosphorus-fixation and toxicities of Aluminum, Manganese and Hydrogen ions. Common acid-forming cations are hydrogen (H^+), aluminum (Al^{3+}), and iron (Fe^{2+} or Fe^{3+}) (Ann McCauley et al, 2017), according to (Negash Teshome, 2017, Jackson, 1967), easily understood when we consider that a soil is acidic when there is an abundance of acidic cations, like hydrogen (H^+) and aluminum (Al^{3+}) present compared to the alkaline cations like calcium (Ca^{2+}), magnesium (Mg^{2+}), potassium (K^+), and sodium (Na^+). Soil acidity indicator is by the measurement of soil reaction (pH) and Symptoms of soil acidity in crop.

The term pH stands for the potential (p) of the hydrogen ion (H^+) in water. pH is actually a way of reporting the amount of hydrogen ion in solution using an electrical "potential" expressed as the negative logarithm of hydrogen ion activity/concentration of a soil which means that for each unit increase in pH there is a 10 times change in acidity (so a soil with a pH of 5 is 10 times more acid than a soil with a pH of 6 and 100 times more acid than a soil with a pH of 7 (Negash Teshome, 2017, Brady and Weil, 2002, USDA_NRCS, 2018,). Acidic solutions have a pH less than 7 (Ann et al, 2017).

Symptoms of soil acidity in crop

Poor plant vigor, uneven crop growth, Persistence of acid-tolerant weeds, Yellow/red leaf discoloration, increased disease incidence, Poor nodulation of legumes, and stunted root growth (Amede Tilahun et al., 2019).

Measuring pH

Examples of soils	pH	Acid range
	0	-
	1	-
Acid sulfate soil	2	-
	3	v/strong acid
Forest soil	4	Strong acid
	5	Moderate acid
Humid climate arable soil	6	Slight acid
	7	Neutral
Calcareous soil	8	Base/alkaline
Sodic soils	9	
	10	
	11	
	12	
	13	
	14	

Source: Brady (1980)

SOIL ACIDITY POTENTIAL IN ETHIOPIA

Current status of soil acidity in Ethiopia

Acid soils constitute 30% of the world's total ice-free land. In Africa, 22% or 659 million ha of land has a soil acidity problem (von Uexk¨ull and Mutert 1995). Soil acidity is estimated that approximately 50% of the worlds' arable soils are acidic and may be subjected to the effect of aluminum (Al) toxicity of which the tropics and subtropics account for 60% of the acid soils in the world (Sumner and Noble, 2003).

Desta Beyene, 1988, Taye 2007 and Abdenna Deressa et al., 2007, reported the coverage of acidity estimated that about 40% of the total arable land of Ethiopia is affected by soil acidity. Of this land area, about 27.7% is moderately acidic (pH in KCl) 4.5 - 5.5) and about 13.2% is strongly (pH in KCl) < 4.5) acidic. Two years later, Tolessa Debele and Beshir Abdulahi, (2009), reported chemical degradation of soil especially soil acidity indicates about 40.9% of Ethiopia is covered by acid soils, from this total land 28% by moderately acidic soils (pH 4.5 -5.5), and 13% by strongly acidic soils (pH <4.5) which covers 95% of the cropped area and contain almost 85% of the Ethiopian population.

A recent soil mapping exercise, conducted by the Ethiopian Soil Information System (EthioSIS) under the administration of the Ethiopian Agricultural Transformation Agency (ATA), estimated that 43% of arable lands were affected by acid soils and that 3.6 million people, about 10% of the total rural population, live in areas with acidic soils (Jerome, et al,2019). Schlede (1989), ATA reported that from 43% total affected land 15% strongly acidic and 28% moderately acidic.

In Ethiopia in different region soil acidity amount and the land affected different. In SNNPR (Southern Nations, Nationalities and Peoples' Region), the highlands of Gamo Gofa specially in Chencha, Sidama, Kambata, Hadiya, Guragie, and South western areas are affected by soils acidity seriously (Wassie Haile and Shiferaw Boke,2009). In Amhara region Awi Zone and in Oromia Hagere-Mariam, Gimbi, Nejo, virtually all soils around Asosa and Welega were moderate to very strongly acidic.

In Ethiopia, acid soils extend from south-west to north-west with east to west distribution and are limited by the eastern escarpments of the Rift Valley, Western and to South-Western Ethiopia including the lowlands. There are also indications that soil acidity has begun to be visible in the northwestern and northern parts of the country (Sahlemedhin and Ahmed, 1983; Mesfin, 2007.

Soil class affected by acidity in Ethiopia

Tolessa Debele and Beshir Abdulahi (2009) report indicated that Ethiopia has a total land area of 1.13 million km2 and more than 18 soil associations. The major soil types are ‹Lithososls 17.1%, ‹Nitisols 12.2%, ‹Cambisols 11.6%, ‹Regosols 10.9%, ‹Vertisols 10.0% ‹Fluvisols 8.3%. When only arable lands are considered the important once are: ‹Nitosols 23% ‹Vertisols 19% ‹Cambisols 18%. Soil acidity often found in Oxisols, Nitosols, and Ferralsols (Amede Tilahun et al, 2019). Acid soils in Ethiopia could be some Inceptions, quite a few Alfisols, most Oxisols and Ultisols. These are found in association with others as Chromic Vertisols, Mollisolsetc (Mesfin Abebe, 2007). The Dystric Nitisols that is relatively high in organic matter and greater base saturation in the top layer. The Acrisols are generally developed from acidic parent material in the high rainfall areas where strong weathering has led to depletion of bases due to leaching. Therefore The Dystric Cambisols occur at relatively high altitudes on very steep slopes wherever conditions are not favorable for soil forming processes. Greater than 80% of the landmasses originating from Nitisols are acidic, (Sahlemedhin and Ahmed, 1983; Mesfin, 2007).

Table 1. Status of soil acidity in different types of soils from different regions (Paulose Dubale, 2001).

Location	Soil Types	Soil pH
Bako	Chromic Vertisol	4.2
	PellicVertisol	5.8
	Humic Vertisol	4.6
Metahara	MollicAndosol	5.4
N.Eastern Escarpment	Humic/MollicAndoso	5.2
Anno (East Wellega)	Humic Acrisol	4.7
AletaWondo	Nitosol	5.35
Dale (Yirgalem)	Nitosol	5.49
Chorra (Illubabor)	Nitosol	5.42
Metu(Illubabor)	Nitosol	5.24
	Nitosol	5.07
GimbiHarru	Nitosol	5.07
Anfillo	Nitosol	5.36
Kosa (Limu)	LuvicPhaeoze	5.8
	EutricNitosol	5.4
Gumer(Limu)	EutricNitosol	5.2
	LuvicPhaeozem	5.2
Suntu (Limu)	Nitosol	5.2

CAUSE OF ACID SOIL

Several researchers reported (Crompton E.1967, Dawit Degefu-1966, Fissen itenna-1992, Mesfin Abebe, 1998, Murphy H.F-1963, Mesfin Abebe, 2007) that, Cause of soil acidity is several internal and external factors related to changes in the entire ecosystem have acted upon the parent material of these soils and have given rise to chemically and physically heterogeneous acid soils with various causes for their inherent poor fertility. These could be due to the:

- high rainfall that leached soluble nutrients such as calcium and magnesium;
- removal of lime elements especially from soils with small reservoir of bases due the harvest of high yielding crops;
- biological decomposition of organic materials to produce humus and thereby the formation of organic acids;
- large quantities of carbonic acid produced by microorganisms and higher plants though much of it is eventually lost as carbon dioxide;
- dissociation of iron and aluminum from acidic parent material through physico-chemical and biological processes;

- replacement of calcium and magnesium specifically by aluminum and iron from the exchange sites; or their presence in exchangeable form;
- low buffer capacity from little clay and organic matter, especially under the use of acidulating fertilizers; e contact exchange between exchangeable hydrogen on root surfaces and the bases in exchangeable form on soils; and,
- microbial production of nitric and sulfuric acids where leaching is limited from cyclic reduction-oxidation of iron compounds such as pyrite

Parent material

Due to differences in chemical composition of parent materials, soils will become acidic after different lengths of time. Thus, soils that developed from granite material are likely to be more acidic than soils developed from calcareous shale or limestone (Hailin Zhang, 1990).

Land use

Soil pH is affected by land use and management. The type of vegetation on a soil impacts pH levels. For example, areas of forestland tend to be more acidic than areas of grassland. Conversion of land from forestland or grassland to cropland can result in drastic changes in pH over time. These changes are a result of loss of organic matter, removal of soil minerals when crops are harvested, and erosion of the surface layer (USDA_NRCS, 2018).

Soil texture

Soils that have a high content of clay and organic matter are more resistant to changes in pH (higher buffering capacity) than are sandy soils. Although clay content cannot be altered, organic matter content can be altered by management practices. Sandy soils commonly have a low content of organic matter, resulting in a low buffering capacity and a high rate of water percolation and infiltration. Thus, they are susceptible to acidification (USDA_NRCS, 2018).

Climate

Temperature and rainfall affect the intensity of leaching and the weathering of soil minerals. In warm, humid environments, soil pH decreases over time through acidification due to leaching from high amounts of rainfall. In dry environments where weathering and leaching are less intense, soil pH may be neutral or alkaline (USDA_NRCS, 2018.

Climate Annual temperature range between the warmest and coldest month, Precipitation of warmest quarter (mm), Mean annual precipitation, Temperature ˚C Mean annual temperature (Zhang, et al., 2019).

Rainfall

Rainfall contributes to a soil's acidity. Water (H_2O) combines with carbon dioxide (CO_2) to form a weak acid — carbonic acid (H_2CO_3). The weak acid ionizes, releasing hydrogen (H^+) and bicarbonate (HCO_3). The released hydrogen ions replace the calcium ions held by soil colloids, causing the soil to become acidic. The displaced calcium (Ca^{++}) ions combine with the bicarbonate ions to form calcium bicarbonate, which, being soluble, is leached from the soil. The net effect is increased soil acidity.

Nitrogen Fertilizers

Nitrogen levels affect soil pH. Nitrogen sources — fertilizers, manures, legumes — contains or form ammonium. This increases soil acidity unless the plant directly absorbs the ammonium ions. The greater the nitrogen fertilization rate, the greater the soil acidification. As ammonium is converted to nitrate in the soil (nitrification), H ions are released. For each pound of nitrogen as ammonium, it takes approximately 1.8 pounds of pure calcium carbonate to neutralize the residual acidity. Also, the nitrate that is provided or formed can combine with basic cations like calcium, magnesium and potassium and leach from the topsoil into the subsoil. As these bases are removed and replaced by H ions, soils become more acidic.

Plants

Legumes like soybeans, alfalfa and clovers tend to take up more cations in proportion to anions. This causes H ions to be released from plant roots to maintain the electrochemical balance within their tissues. The result is a net soil acidification. Root respiration and decomposition of organic matter by microorganisms releases CO_2 which increases the carbonic acid (H_2CO_3) concentration and subsequent leaching.

Product removal

Removal of produce (grain, animal, pasture and trees) from a given area of land will take alkaline material with it, which if not replaced leads to soil acidification (Slattery et al. 1991, Moody and Aitken 1997, Noble et al. 1999). The most striking example here is if a lucerne pasture is cut for hay. Should 8t/ha of lucerne be removed in one year it requires 0.5 t/ha of lime, representing 2030% of production costs, to replace the lost alkalinity in the surface soil (Slattery et al. 1991).

The removal of trees and shrubs over large areas of the landscape has made a significant contribution to product removal and thus accelerated acidification on many high rainfall soil types.

Harvesting of crops has its effect on soil acidity development because crops absorb the lime-like elements, as cations, for their nutrition. When these crops are harvested and the yield is removed from the field, then some of the basic material responsible for counteracting the acidity developed by other processes is lost, and the net effect is increased soil acidity. Soil acidity will develop faster under continuous wheat pasture than when grain only is harvested. High yielding forages, such as Bermuda grass or alfalfa, can cause soil acidity to develop faster than with other crops (Hailin Zhang, 1990).

Subsoil Acidity

Even if the top 6 inches of soil show a pH above 6.0, the subsoil may be extremely acidic. When subsoil pH's drop below 5.0, aluminum and manganese in the soil become much more soluble, and in some soils may be toxic to plant growth. Cotton and, to some extent, soybeans are examples of crops that are sensitive to highly soluble aluminum levels in the subsoil, and crop yields may be reduced under conditions of low subsoil pH. If you've observed areas of stunted plants in your field, take a subsoil sample in these areas. If the soil pH is extremely acidic (below 5.2), lime should be applied early in the fall and turned as deeply as possible.

Organic Matter Decay

Decaying organic matter produces H+ which is responsible for acidity. The carbon dioxide (CO_2) produced by decaying organic matter reacts with water in the soil to form a weak acid called carbonic acid. This is the same acid that develops when CO_2 in the atmosphere reacts with rain to form acid rain naturally. Several organic acids are also produced by decaying organic matter, but they are also weak acids. Like rainfall, the contribution to acid soil development by decaying organic matter is generally very small, and it would only be the accumulated effects of many years that might ever be measured in a field (Hailin Zhang, 1990).

Nitrification

Most high land Ethiopia Soils are deficient in nutrients such as nitrogen (N) and phosphorous (P), essential for the production of agricultural crops. Modern farming systems therefore require the addition of N fertilizer to crops to maintain yield, particularly where continuous cropping is practiced and high value crops like wheat, barely, and teff are grown. The use of fertilizers, especially those supplying nitrogen, has often been blamed as a cause of soil acidity. Acidity is produced when ammonium containing materials are transformed to nitrate in the soil. Some forms of N fertilizer are more acidifying than others. Ammonium sulphate for example acidifies the soil as it is biologically transformed to nitrate. If any excess nitrate is not utilized by the plants, then it is available for leaching (Helyar 1990); (nitrate fertilizer applied directly and not used by plants also faces this same fate). The more ammoniacal nitrogen fertilizer is applied, the more acidic the soil gets, as a Cation (Al3+), the amount of dissolved aluminum is 1000 times greater at pH 4.5 than at 5.5 and 1000 times greater at 3.5 than at 4.5 (Hailin Zhang, 1990).

Dry summer conditions

Hot environments where there are dry summer months; result in the buildup of nitrate nitrogen due to the mineralization of nitrogen in decomposing plant matter. When the season breaks in the autumn months, annual plants regenerating in crops and pasture systems have insufficient plant roots to capture all the nitrate in the soil before it leaches below the root zone; this results in increased acidification (Helyar, 1990).

ACID SOIL MANAGEMENT METHOD IN ETHIOPIA

Complementary approaches are often employed in the management of acid soils: Liming – application of calcium and magnesium-rich materials from local sources, Integrated Soil Fertility Management (ISFM) and Acid-tolerant crops and varieties (Getachew Agegnehu et al., 2018; James Warner et al. 2018).

Amendment of Lime on acid soil

Liming acid soil calls for application of calcium- and magnesium-rich materials to soil in the form of: Marl, Chalk, Limestone, and Hydratedlime (Tilahun Amede, 2019).

Correcting soil acidity by the use of lime is the foundation of a good soil fertility program. Liming raises the soil pH and causes the aluminum and manganese to go from the soil solution back into solid (non-toxic) chemical forms (Hailin Zhang, 1990). Lime does more than just correct soil acidity. It also: Supplies essential plant nutrients, Ca and Mg, if dolomitic lime is used.

Amendment of Sulfur on acid soil

A common amendment used to lower the pH of basic soils is sulfur (Salton N.A.et al, 2001, Ann, et al 2017). Elemental sulfur is oxidized by microbes to produce sulfate (SO42-) and H+, causing a lower pH. Ferrous sulfate ($FeSO_4$) and aluminum sulfate ($Al_2[SO_4]_3$) can also be used to lower pH, not due to sulfate), but because of the addition of acidic cations (Fe_2+, Al_3+). Application rates for these amendments vary depending upon product properties (particle size, oxidation rate) and soil conditions (original pH, buffering capacity, minerals present). Because calcium carbonate ($CaCO_3$) consistently buffers soil to pH values near 8, soils high in calcium carbonate would need larger quantities of sulfur amendments to lower pH than generally economical.

Crop selection

Crops vary in their ability to raise or lower soil pH. For example, harvest of high yielding leafy crops such as forage or corn can reduce soil pH because leaves and stems contain large amounts of base-forming cations (Ca_2+, K+, Mg_2+) (Ann McCauley, et al., 2017).

Organic material level

Soil organic matter is the combination of plant and animal residues at various stages of decomposition and cells and tissues of soil organisms. The consistent benefit of SOM is that it buffers soil pH change (Ann McCauley, et al. 2017).

Fertilizer

Nitrate-based nitrogen fertilizers, such as calcium nitrate (15.5-0-0 +19% Ca) may increase soil pH at both the surface and deeper levels but only if the nitrate gets taken up by the plant and is not lost to leaching. The method to minimize soil acidification due to fertilizer nitrogen were Increase efficiency of nitrogen, Reduce nitrate loss (Use slow-release nitrogen sources, Use nitrogen sources with nitrification inhibitors' and Plant deep rooted crops to 'catch' deep nitrate, and Consider non-ammonium based nitrogen sources - Legume rotations - Calcium ammonium nitrate (27-0-0) (Ann McCauley, et al, 2017).

ACCESS OF LIME IN ETHIOPIA

Ethio-SIS team analysis, 2014 indicated that Goal for 2020, from total cultivated land 226,000ha of acid soils to be treated. Plan for next five years 450,000-900,000 tons of lime needs to be produced, distributed and applied to acid soils to meet the goal GTP (Growth and Transformation Plan). The lime initiative laid the foundation for much broader dissemination and impact of agricultural lime in Ethiopia through: Groundwork, Capacity building and Infrastructure building.

Successfully created awareness of, and demand for, agricultural lime among smallholder farmers in acid soil areas of the highlands. The Trained development agents and district agricultural experts in critical skills of soil sampling, lime application and in conducting demonstrations, and popularizations.

To access lime in Ethiopia establishment of lime crushers in selected locations is a plan to ATA. There are currently five lime crushers in three locations, with a total annual capacity of just under 20,000 tons (Getachew Agegnehu et al., 2018; James Warner et al. 2018).

CHALLENGES OF SOIL ACIDITY MANAGEMENT IN ETHIOPIA

- All acidity affect soil not known
- Accessibility of lime
- Limited awareness of acidity effect

FUTURE LINE WORK

- Characterization and mapping of Ethiopia soil acidity
- Awareness creation for the people
- Accessing the lime

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