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Role of lime and compost on soil properties and yield of bread wheat (*Triticum aestivum L.*) in acidic soil of Ethiopia: A Review

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Abstract

Soil acidity has become a serious threat to soil fertility and crop production in most highlands of Ethiopia. Therefore, the objective of this paper was to review integrated use of lime and compost effect on soil properties and yield of bread wheat in acidic soil of Ethiopia. The previous study estimated that about 40.9% of the arable lands of Ethiopia are affected by soil acidity. These might be natural and anthropogenic activities that can cause accelerating soil acidification including the application of artificial fertilizers, removal of elements through the harvest of high-yielding crops, eroded topsoil and depleted nutrients, and high rainfall which are high enough to leach appreciable amounts of exchangeable basic cations. It affects crop growth because it contains toxicity of aluminum, and manganese and is characterized by lack of essential macro and micro plant nutrients such as P, N, K, Ca, Mg and Mo. The essential nutrients are low the plant root growth also poor, and the result is also lower water and nutrient uptake. The pH of soil is less than 5.5 yields of acid susubitable crops produced in the highlands are particularly poor and usually lead to Al, Fe, H, and Mn toxicity plus deficiency of essential nutrients. A review showed that the detrimental effects of soil acidity can be corrected through agricultural liming and compost. The management of acid soils through integrated soil management not only improves the yield but also soil properties, it reduces exchangeable acidity and increases soil pH. Crop productivity of marginal fertile acidic soil can be improved through the integrated use of soil ameliorated by lime and compost. In the case of soil acidity wheat growing areas of the central and southern Ethiopian highlands, farmers have shifted to tolerant crops. Wheat productivity has been declining from year to year in the northwestern Ethiopian highlands, mainly due to intensive soil degradation and depletion of plant nutrients. Generally, combined use of properly managed by lime and compost could be used for soil properties and wheat production in our country.

Keywords: Bread wheat (Triticum aestivum L.), Lime, Organic fertilizer, Soil acidity, Soil pH

Introduction

Soil acidity is one of the main factors that limit and prevent profitable and sustained agricultural productivity in many parts of the country (BereketAyenew*et al*., 2018; Sumner and Noble, 2003). It is a major soil degradation issue, which estimated approximately 50% of the world's potentially arable soils (Kochian *et al*., 2004; Sade *et al*., 2016). In Ethiopia, acidic soils are dominated found in the highlands where rainfall intensity is high, and crop cultivation has gone on for many years (Getachew Agegnehu and Taye Bekele, 2005; Gete Zeleke *et al*., 2010). The major acidic soil rising in climatic factors includes rainfall, temperature, topographic, and morphological features (Brady and Weil, 2016; Mesfin Abebe, 2007). The precipitation is high enough to leach appreciable amounts of exchangeable bases from the soil surface (Achalu Chimdi *et al*., 2012). About 43% of cultivated land in humid and sub-humid highlands of Ethiopia is affected by soil acidity problems (ATA, 2014). As a result, soil acidity has become a serious threat to crop production in most highlands of Ethiopia (Getachew Agegnehu *et al*., 2019; Mesfin Abebe, 2007). In Ethiopia, huge surface areas of the highlands located affected by soil acidity in almost all regions of the country; Some well-known areas affected by acidity have a significant impact on the highlands of Ilubabor, Gamugofa, Sidama, Kembata, Hadya, Siltie, Wolayita, Guragie, Kafa, Wallaga, Jimma, Dawuro, West Shoa, North Shoa, Assosa and Gojjam (Eyob Tilahun *et al*., 2015; Fanuel laekemariam and Kibebew Kibret, 2015). According to Eyasu Elias (2016) that 80% of Nitisol and Luvisols soil types are strongly acidic having pH fall under 4.5-5.5 including Mecha, Semen Achefer, G/Jarso, Jabi Tehnan, Bure, Dera, Chena, Mecha, south Achefer, M/Azenet, Malga, Nada Limuseka, Dedesa, Bedele and Enamor under highly affected acidic soils.

Acidity affects physical, biological, and chemical soil properties, which in turn affect the sustainability of crop production through its effect on reduced growth and yield of crops (Marschner, 2011; Wang *et al*., 2006). It's a complex of several factors which involves essential plant nutrient deficiencies, toxicities level of Al, low beneficial microorganisms' activity, and poor plant root growth which limits absorption of nutrient and water (Fageria and Baligar, 2003; Marschner, 2011). A high level of soil acidity can cause a decrease in root growth, nutrient availability, and effect crop protection activity (Harter, 2002), reduction and total failure of crops and decline of soil physical properties. As soil pH decreases, the availability of micronutrients such as aluminum, manganese, and iron also increases and vice versa (Agrawal *et al*., 2016). According to Horst *et al*. (2010) reported that aluminum toxicity in plants constrains of root growth.

Acidic soils could be amended by liming, use of organic fertilizers and cultivating acid-tolerant crops. Of these practices, liming adjusts pH levels needed by the crop to be developed. It's a major and effective practice to overcome soil acidity constraints and improve crop production. Effective ameliorate for acidic soils raises soil pH, it results in enhanced availability of essential nutrients for instance P, N, Ca, Mg, Mo etc. and improved crop yields through the reduction of exchangeable acidity and aluminum (Achalu Chimdi *et al*., 2012; Kisinyo *et al*., 2009). The use of organic fertilizer improves soil structure, aeration, increases water holding capacity of the soil and stimulates healthy root development (Edwards and Hailu, 2011; Twarog, 2006). Thus, compost may be one of the interesting options for improving crop productivity for resource poor farmers, especially in developing countries like Ethiopia. The addition of compost reduces soil acidity through different mechanisms during the decomposition process, with the formation of insoluble iron and aluminum hydroxide (Haynes and Mokolobate, 2001). Currently, the use of lime and compost on acidic soils is one of the best options for improving soil fertility and increase crop productivity; its effects are more persistent (Chen *et al.*, 2001). Lime and compost reduce the exchangeable acidity, as the calcium from lime replaces the exchangeable forms of aluminum and iron, which reacts with hydroxide ions released from water in the soil solution to form gibbsite (Adane Buni, 2014). The integrated use of organic and liming requirements may improve and sustain crop yields without degrading soil fertility status (Opala, 2011).

Major crop production constraints in Ethiopian soil include soil chemical degradation such as acidity, salinity, sodicity, low levels of fertilizers, and pesticides (Alemayehu Seyoum *et al*., 2011). Soil acidity is one of soil chemical degradation it affects crop growth because it contains a dangerous amount of aluminum and manganese and is characterized by a lack of crucial plant nutrients such as P, N, K, Ca, Mg and Mo. The essential nutrients low the plant root growth poor resulting in lower water and nutrient uptake so, crop growth and production reduce (Brady and Weil, 2008; Marschner, 2011). The pH of the soil is <5.5 yields of susubitable crops produced in the highlands are particularly poor and usually lead to Al, Fe, H, and Mn toxicity plus deficiency of P, N, S, and other nutrients (Marschner, 2012; Abreha Kidanemariam *et al*., 2013; Harter, 2007). Acidic soils cover a total of 1.66 billion hectares in nations, whereas the total area impacted by soil acidity is around 4 billion hectares (Abu Regasa Gemada, 2021). Primarily affects tropical and subtropical regions, as well as moderate climatic conditions areas (Getachew Agegnehu, 2019). Acid soils are increasing and occupying a bigger amount of cultivated land in Ethiopia. Ethiopia has substantial soil acidity coverage. Ethiopia has a total land area of about111.8million hectares, of which only a 79million hectares are suitable for agriculture, from these about 40.9% of the area is covered by strongly to weak acid soils. About 27.7% of this soil is moderate to weak acid soil and about 13.2% is severe acid soil (Wassie Haile and Shiferaw Boke, 2009; Mesfin Abebe, 2007).

Bread wheat *(Triticum aesativum L.)* is an important primary food in Ethiopia, to meet the consumers demand and other food productsparticularly in urban areas (Anbessie Debebe, 2021). After South Africa, Ethiopia is the second-largest wheat producer in sub-Saharan Africa in terms of total wheat area and production (Bekele Hundie *et al*., 2000; Asfaw Negassa *et al*., 2013; FAO, 2015). Ethiopian wheat yields have been below the East African and worldwide average yields, indicating low productivity crops (Schneider and Anderson, 2010). It is the fourth-largest cereal crop produced by close to 5 million smallholder farmers, which makes up about 35% of all small farmers in the country (Bekele Hundie, 2000; Anbessie Debebe, 2021). It ranks fourth after maize, tef and sorghum both in area coverage and production (CSA, 2018). As a result, in wheat and barley growing areas of the central and southern Ethiopian highlands, farmers have shifted to producing oats which are more tolerant crops (Wassie Haile and Shiferaw Boke, 2009). However, wheat productivity has been declining from year to year in the northwestern Ethiopian highlands, mainly due to soil degradation (soil acidity) and depletion of plant nutrients (Mekonnen Asrat *et al*., 2014). It's a serious and present threat, has been needed in the highlands of Ethiopia for crop production (Wassie Haile *et al*., 2009). Therefore, the objective of this paperwas to review integrated use of lime and compost effect on soil properties and yield of bread wheat in acidic soil of Ethiopia

Methods of the review

Literature search was conducted through the Web of Science (apps.webofknowledge.com), Google Scholar (scholar.google.com) and Research Gate. We searched the literaturepublished up to 2022, using 'soil acidity', 'acid soil management', 'improved bread wheat crop', 'organic fertilizer and liming' as key terms on the effect of lime and compost in acid soil of Ethiopia, as well as its influence on wheat crop production was used.

Distribution of Soil Acidic in Ethiopia

The distribution of acidity in Ethiopia had increased from time to time, with the total area of Ethiopia 111.8 million hectares. Out of these 79 million hectares of land is suitable for agriculture, from these about 40.9% of the area is covered by strongly to weak acid soils. 27.7% of these are moderate to weakly acidic with a pH 5.8-6.7 and 13.2% have strong to moderately acidic soil with a pH less than 5.5 (Taye Belachew, 2007; Mesfin Abebe, 2007). As a result, according to ATA (2014) estimates, about 43% of the total cultivate d lands in Ethiopia where major staple food cropare grown affected by acidity. The known area affected by acidity has a significant impact on the highlands of Ilubabor, Gamugofa, Sidama, Kembata, Hadya, Siltie, Wolayita, Guragie, Kafa, Wallaga, Jimma, Dawuro, West Shoa, North Shoa, Assosa and Gojjam (Eyob Tilahun *et al*., 2015; Fanuel laekemariam and Kibebew Kibret, 2015). Similarly, according to Biyensa Gurmessa (2020), acid soil more dominate lies in the western region of the country, predominantly covering most parts of Wollega, Jimma and Ilubabor from the Oromia Region and Gojjam (Southern Amhara Region). Soils types of more dominate in acidic soil are not well defined and mapped; but according to Eyasu Elias (2016), the dominant acidic soil is Nitisols with reddish color, deep horizon, and high proportion of clay content.

Acidic soil exists in H^+ and Al^{3+} ions. Aluminum is the third most common element in the earth's crust and the most abundant metal (Vitorello *et al*., 2005). In acidic soils, Al^{3+} mostly exists as a structural constituent of primary and secondary aluminosilicate minerals (Miyasaka *et al*., 2007). Aluminum nutrient concentration is one of the indicators of soil acidity (Rengel, 2003). It is generally present in soils in a variety of forms and bound to soil constituents, particularly clay particles and organic matter. When soil pH drops, Al^{3+} becomes soluble and the amount of aluminum in the soil solution increased. Aluminum tends to bond with P in a less available and insoluble due to phosphorous reacting with Al and Fe, and precipitated as a form of $AlPO_4$ and $FePO_4$, resulting in creating of phosphorous deficiency for plant growth (Mesfin Abebe, 2007). If the current land mismanagement practices are not rehabilitated, the areas of acidic soil expand, creating conditions for the occurrence of wider aluminum toxicity. In western and eastern Wollege zones, the large proportion of exchangeable acidity is due to exchangeable Al^{3+}, while in west Shoa zone dominate exchangeable H^+, So the east and west Wollega zone of the Oromia region is serious in acidity problem (Abdenna Deressa *et al*., 2007) (Figure 1)

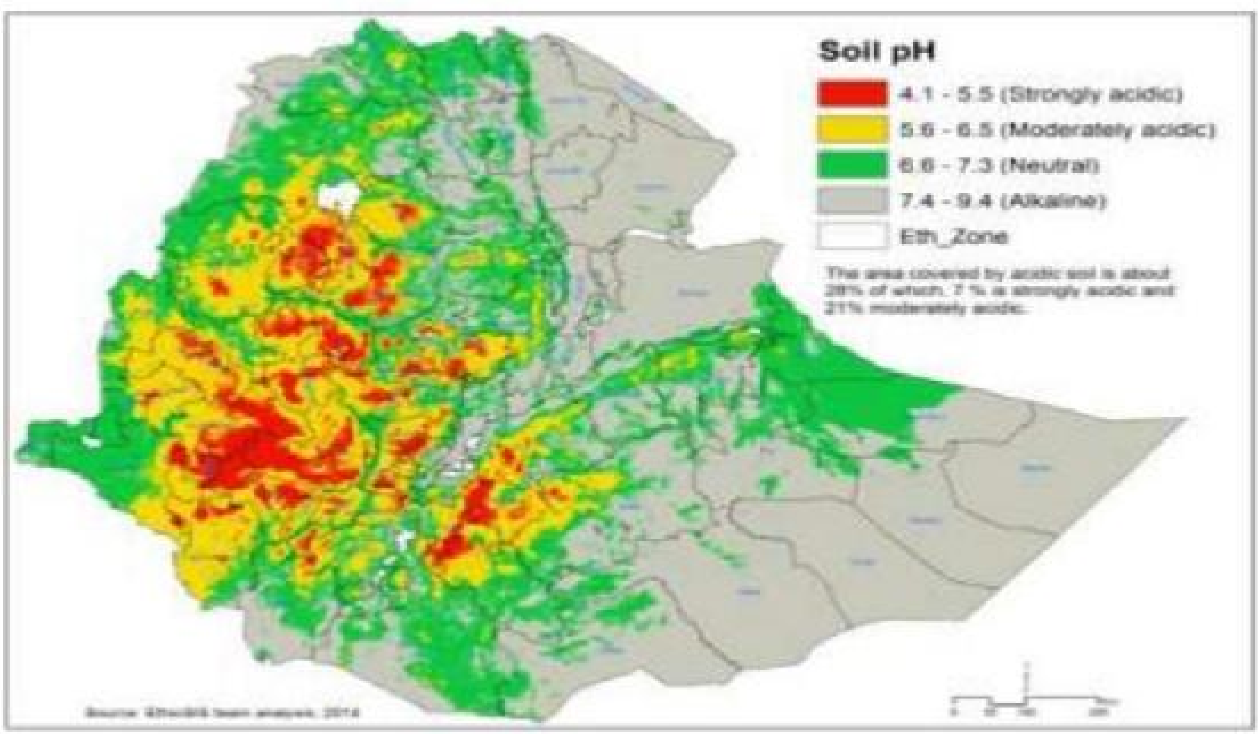

Figure 1: Extent and Distribution of Soil Acidity in Ethiopia (EthioSIS, 2014)

Effect of soil acidity on bread wheat production

Wheat grows best when the soil pH is between 6.0-7.0. Growing wheat at a pH below 6.0 often results in magnesium (Mg) deficiency, slower mineralization of organic nitrogen (N), reduced availability of phosphorus (P), and increases the possibility of aluminum (Al) and manganese (Mn) toxicity.Acidic conditions enhance the presence of trivalent cation (Al^{3+}) (Merino *et al*., 2010), which is the most toxic of all Al^{3+}species available to plants (Kochian *et al*., 2004). Soils affected by acidity convert available into unavailable forms and are poor in basic cations such as calcium, potassium, magnesium, and some micronutrients which are essential to crop growth and development (Wang *et al*., 2006). This results in alterations in the physiological and biochemical processes of plants and consequently loss of productivity (Sumner and Noble, 2003). Under acidic conditions, some vital nutrients such as P, Ca, K, and Mg are made unavailable in the soil solution for plant uptake due to the richness of elements such as Al and Mn (Mesfin Abebe, 2007). The major wheat-producing areas in Ethiopia are located Arsi, Bale, Shewa, Ilubabor, Western Hararghe, Sidama, Tigray, Northern Gonder and Gojjam (Bekele Hundie *et al*., 2000). Most soils are exposed to nutrient leaching over a long period, resulting in low organic matter content and requiring careful management to support good crop yields (Jafer Dawid and Gebresilasie Hailu, 2018).

Mechanisms of Amendment Acidic Soil in Ethiopian

The management of acid soils should aim at improving production potential by the addition of amendments to correct soil acidity and manipulate the agricultural practices to obtain optimum crop yields by liming, acid-tolerant crop variety, and addition of organic fertilizer. The balance of acidity and alkalinity is very important in maintaining the optimum availability of soil nutrients and minimizing potential toxicities. Acid soils are phytotoxic due to nutritional disorders, deficiencies, unavailability of essential nutrients such as Ca, Mg, Mo, P, and toxicity of Al^{3+}, Mn^{2+} and H^{+} activity (Taye Bekele, 2007). At very low soil pH, aluminum may become more soluble and can be taken up by roots, becoming toxic. Phosphorous may become unavailable, and calcium levels can be low or not available for plants, at low pH, Fe, $Al^{3+,}$ and other micronutrients are toxic or available since they are locked up as insoluble hydroxides and carbonates (Slattery and Hollier, 2002). So, soils amended by lime and compost are very crucial in acidic soil.

Effect of liming and compost on soil properties

Liming material has two forms: calcium carbonate ($CaCO_3$) and calcium oxide (CaO) called “calcitic lime’’ and magnesium carbonate ($MgCO_3$) is called “dolomitic lime” it can be used to reduce acidity (Wegene Negese, 2019). Liming is the most common and effective practice for reducing soil acid-related problems directly supplying many cations that are important for crop production (Fageria and Nascente, 2014; Mesfin Kassa *et al*., 2014; Tiritan *et al*., 2016; Holland *et al*., 2018). Lime is made up of largely calcium content and is a base, therefore; it has a neutralizing effect on acid soil and improves the availability of nutrients in the plants (Edmeades *et al*., 2003; Holland *et al*., 2018). Liming can also influence both transformation and uptake of nutrient by plants through its indirect impact on the soil stimulates of microbial activity, enhances nitrogen fixation and mineralization and hence, legume crops greatly benefit from liming (Fageria, 2002; Fageria and Baligar, 2008; Cheng *et al*., 2013). The pH of the soil increased due to the use of lime, while exchangeable acidity and aluminum also decreased (Geremew Taye *et al*., 2020). Similarly, in addition to lime, it has a positive influence on soil pH (Sultana *et al*., 2019). Application of lime tends to raise soil pH and improve plant nutrient availability by displacement of H^{+}, Al^{3+}, $Fe^{3+,}$ and Mn^{2+} from soil adsorption sites (Onwonga *et al*., 2010; Ristow *et al*., 2010; Jafer Dawid and Gebresilassie Hailu, 2017).

The addition of organic fertilizers to add acidic soils can be effective in reducing phytotoxic levels of Al^{3+} content in the soil solution (Wong and Swift, 2001). The major mechanisms responsible for these improvements are thought to be the formation of organo Al complexes that reduce Al^{3+} toxicities or direct neutralization of Al^{3+} from an increase in soil pH caused by increased organic matter (Wegene Negese, 2019). Possible alternative use of organic fertilizer sources such as crop residue, compost and manure (Getachew Agegnehu and Tilahun Amede, 2017) and the potential to ameliorate acidic soil (Wong and Swift, 2003). The amendment of acid soils through integrated soil fertility and plant nutrient management not only improves the yields of crops, but also the soil physical and chemical properties. Regular application of organic residues can induce a long-term increase in soil organic matter and nutrient contents. It improves soil aggregation, increasing microbial biomass, improves water holding capacity, raising CEC and pH of soils (Martínez B.J *et al*., 2013). The organic acids in compost or manure also raise the soil pH, and reduce the exchangeable forms of Al through oxidation of organic acid anions, chelation, ammonification, specific ion adsorption, and reduction reactions of metal oxides surfaces (Haynes and Mokolobate, 2001).

The use of composted organic wastes is recommended for improvement of soil quality and soil fertility in tropical regions which slowly release significant amounts of nitrogen, phosphorus and potassium (Mohammad H *et al*., 2004). The application of manure in acidic soil reduces Al^{3+} toxicity and improves soil fertility by supplying essential nutrients like P, K, Ca, and Mg (Whalen *et al*., 2000; Amlinger *et al*., 2007). Soil acidity decreased with increase in manure and lime application (Harun I.G *et al*., 2015). The combined use of lime and organic amendement is more effective against soil acidity problem (Tiritan *et al*., 2016). Management of soil organic matter by using composted organic waste is the key to sustainable agriculture (Nyamangara *et al*., 2003). The disease-suppressing quality of compost is just beginning to be widely recognized and appreciated. High quality of compost has more fertile and sustainable than commercial fertilizer (Mohammad H *et al*., 2004). The use of composted organic material as fertilizer and soil amendment not only results in an economic benefit for the small-scale farmer, but also reduces pollution and nitrogen leaching (Nyamangara *et al*., 2003). The use of lime and compost can improve soil properties (Table 1).

Effect of lime and compost application on bread wheat yields

The major limitations to agricultural production in the Ethiopian highlands are declining soil organic matter, nutrient imbalances, as well as soil acidity problems (Getachew Agegnehu *et al*., 2014). The optimum pH-H_2O for best growth in wheat production is 6.0 to 7.0 (Somani, 1996) and soil pH below these value affect its growth. The combined application of lime and manure in acid soils has the potential to contribute overall increase yields because it reduces exchangeable acidity and increases soil pH and fertility (Onwonga *et al*., 2010). Crop productivity of marginal fertile acidic soil can be improved through the integrated use of soil ameliorants in lime and compost. The yield of bread wheat increased with increased application of lime (Geremew Taye *et al*., 2020, Mesfin Kuma *et al*., 2022), and organic manure (Efthimiadou *et al*., 2010). Positive changes in the quality of wheat flour, because of increasing the amount of gluten protein after compost treated (Gopinath *et al*., 2008). Surface liming, which is incorporating lime into the topsoil, may not have long lasting impact on the subsurface soils, and as a result frequent application of liming may be required to bring about a meaningful improvement in crop yield. The yield highin those treated with lime and compost than in the control (untreated) in acid soils as shown in (Table 2).

Table 1: Effect of lime and compost application on selected soil properties in Ethiopia

Location	Lime (t ha^{-1})	OF(t ha^{-1})	Combined		Untreated			Treated			Change in soil pH over control (%)	References
			Lime	OF	Soil pH	Exc. acidity	Ava. P	Soil pH	Exc. acidity	Ava. P		
HARC	4.68	-	-	-	4.82	1.65	6.8	5.22	0.63	7.59	7.7	
Robgebeya	4.68	-	-	-	4.67	1.97	7.22	5.40	0.14	8.15	13.5	
Watabacha Minjaro	4.68		-	-	4.61	3.29	7.09	5.20	0.30	8.04	11.35	(Germaye Taye, 2020)
Embu	-	-	10Mg ha^{-1}	12.5Mg ha^{-1}	4.1	-	-	6.3	-	-	34.9	(Harun I.G *et al*., 2015)
Assosa	-	-	3t ha^{-1}	5t ha^{-1}	-	2.41	-	-	0.51	-	-	(Biruk Teshome *et al*., 2017)
Lay Gayint	-	-	5t ha^{-1}	8t ha^{-1}	4.95	3.95	6.76	5.56	0.55	9.35	10.97	(Endalkachew Fekadu *et al*., 2017)
Ebantu	-	-	4t ha^{-1}	5t ha^{-1}	4.83	2.38	4.5	5.98	1	6.9	30	(Abdissa Bekele *et al*., 2018)
Cheha	-	-	11.5t ha^{-1}	5t ha^{-1}	4.68	1.37	-	6.71	0.03	-	30.25	(Bereket Ayenew and Asmare Melese, 2021)
Sodo	3.75				5.01	1.67	6.3	6.72	0.36	6.7	25.4	(Adane Buni, 2014)
Assosa	3	-	-	-	5.4	1.27	-	5.95	0.35	-	9.2	
	-	5	-	-	5.4	1.27	-	5.92	0.32	-	8.7	(Biruk Thosome*et al*., 2017)
Mecha	3.5	-	-	-	4.85	2.54	18.03	6.21	0.07	31.3	21.9	(Erkihun Alemu*et al*., 2022)

Table 2: Effect of untreated and treated soil yield change in acid soil affected areas of Ethiopia

Location	Lime rate (t ha^{-1})	OF (t ha^{-1})	Combined		Untreated grain yield (t ha^{-1})	Treated grain yield(t ha^{-1})	Change of yield increase over the control (%)	References
			Lime	OF				
Loma	10	-	-	-	2.44	3.28	26.6	(Getahun Bore and Bobe Bedadi, 2016)
HARC	4.68	-	-	-	1.61	2.83	43.1	(Geremew Taye *et al*, 2020)
Robgebeya	4.68	-	-	-	1.97	3.33	40.84	
Banja	4.60	-	-	-	0.44	1.12	60.7	(Mesfin Kuma *et al*., 2022)
Gozamin	3.3	-	-	-	0.898	1.787	49.75	(Mekonnen Asrat *et al*., 2004)

Conclusion and Recommendation

Soil acidity is one of the main factors that limit and prevent profitable and sustained agricultural productivity in many parts of the country. Soil acidity is one of the most important soil factors which affect plant growth and ultimately limit bread wheat production in Ethiopia. In acidic soils, the high content of Al^{3+} and Fe^{3+} hydroxides are the main factors accounting for strong macronutrients consequently, limits crop production. The original ecology of the major crop-producing growing areas in Ethiopia is being disturbed by soil chemical degradation. The prevailing high rainfall has resulted in low organic matter, exposure to the less fertile sub-soils, and increased soil acidity in major crop-producing areas.

The current crop production potential in Ethiopia is being negatively affected by the passive treating acidity of the soils along with the low implementation rate of other agricultural technologies. Liming has been one of the best options for treating acid soils, although it is not being well taken and practiced by farmers due to factors related to transportation and application cost. This sheds light on the requirement of incentives for full scale implementation of liming. On the other hand, the effect of liming does not last long, and the need for treating the starting point problem may be required. Organic amendments are effective to treat acid soils in integration with liming material

Based on the current review, further research is recommended on the following:

✓ Optimizing the amount of lime required for at least the major main crops grown in Ethiopian

✓ Evaluating the significance of integrating with lime and organic amendments in reducing soil acidity and increasing crop yields

✓ Determining the frequency of applying the liming and organic amendment

✓ Conducting profitability or economic analysis on liming and organic amendments

✓ Understanding and prioritizing mechanisms affecting soil acidity management motivate farmers more to practice liming and organic fertilizer amendments.

✓ When organic fertilizer has applied before sowing, because a different researcher has different applied time recommendation

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