Journal of Biology, Agriculture and Healthcare
ISSN 2224-3208 (Paper) ISSN 2225-093X (Online)
Vol.8, No.14, 2018

Progress of Soil Acidity Management Research in Ethiopia

Fekadu Mosissa
Ethiopian Institute of Agricultural Research, Holeta Research Center, Ethiopia, P.O.Box: 31

Abstract
This review paper tries to put together soil acidity management research based evidences generated recently. In the context of agricultural problem soils, acid soils are soils in which acidity dominates the problems related to agricultural land use. Soil acidity problems are increasing in the highland areas of Ethiopia. Application of lime coupled with fertilizer improves the productivity of crops in acid affected soils. In Nedjo condition, lime level 5 t ha^{-1} with 69 kg ha $^{-1}$ phosphorus gave best yield (1346.2 kg ha $^{-1}$) and (1635.5 kg ha $^{-1}$) of finger millet and teff respectively. Similarly, yield of faba bean was obtained by applications of 16 .5 (t ha^{-1}) and 13(t ha^{-1}) of lime along with 30 kg ha^{-1} P fertilizer at Bedi and Emdibir respectively. Application of 16.5 t ha $^{-1}$ lime with 30 P (kg ha^{-1}) gave 212% yield increment over the control that has no lime but 30 P (kg ha $^{-1}$). Integrated reclamation approach centring lime-fertilizer and soil nutrients interaction is vital to establish cost effective and sustainable nutrient management of this soil. 50% FYM + 50% NP + 50% lime treatment gave significant yield and yield component of teff at Nedjo testing site, this result showed that proper knowledge and enhanced use of integrated soil fertility management technologies such as combined use of organic and inorganic fertilizers in the presence of a soil- conditioner lime are vital in improving and sustaining crop production. From an experiment conducted to evaluate the effectiveness of limes produced at different locations in Ethiopia no statistical yield difference was observed, and this implies that both lime produced at Senkele (Oromia region) and Dejen (Amhara region) can successfully answer their regional lime needs. When Senkele lime, Dejen lime and Ca(OH)2 from Ghion gas factory were compared with Awash calcite and Awash dolomite, these two Awash products were greatly preferred. The reason might be mainly from the material they are processed and as well the technology under which they were crushed. Research results revealed that in CASCAPE (Capacity building for scaling up of evidence–based best practices in agricultural production in Ethiopia) South, application of 1800 kg ha^{-1} lime with recommended fertilizer rate gave the highest yield (1367 kg ha^{-1}) with a 150% yield advantage over the control. In Amhara, yield showed significant variation among treatments where both lime-applied treatments (2050 kg ha^{-1} lime and 1925 kg ha^{-1} lime) gave grain yields of 3648 kg ha^{-1} and 3643 kg ha^{-1}, respectively. This was over 50% yield advantage over the control.
Keywords: soil acidity, nitosol, lime, pH, phosphorus, exchangeable acidity

INTRODUCTION

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 Abera *et al.*, 2006). In Ethiopia, huge surface areas of the highlands located at almost all regional states of the country are affected by soil acidity. From current ATA report it was estimated that about 43 % of the total arable land in Ethiopia is affected by soil acidity. Soil acidity problem is significant in the north-western, south-western, southern and central regions of the country which receive precipitation high enough to leach down soluble salts and/or basic cations appreciably from the surface layers (root zone) of the soils. Some of the well-known areas severely affected by soil acidity in Ethiopia are Ghimbi, Nedjo, Hossana, Sodo, Chencha, Hagere-Mariam and Awi Zone of the Amahara Regional State (MoARD, 2007).

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 (Abreha, 2013).

Over use of agricultural by products (crop residue) and continuous crop harvest (without proper fertilization), removal of cations (Wang *et al.*, 2006) and continues use of acid forming inorganic fertilizers (Bolan *et al.*, 1991) make important contribution to soil acidity development in most highland areas of Ethiopia.

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 (Brady and Weil, 2008). 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 (Marschner and Rengal, 2007; Sposito, 2008; Fageria *et al.*, 2011). Thus, in Ethiopia, acidity related soil fertility problems are major production constraints reducing the productivity of the major crops grown in the country (IFPRI, 2010).

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 (Sumner, 2000; Hocking, 2001; Brady and Weil, 2008). Deficiencies of calcium, magnesium, potassium and molybdenum have also been reported to limit crop yield in acid soils (Sumner, 2000).

Soil acidity problems are commonly corrected by applying lime. Surface liming ameliorates topsoil acidity in a relatively short term, but is generally slow in ameliorating subsoil acidity (Ernani et al., 2004). Liming is an important practice to achieve optimum yields of all crops grown on acid soils. According to Kaitibie et al. 2002, liming is the most widely used long-term method of soil acidity amelioration, and its success is well documented (Scott et al.,2001). Application of lime at an appropriate rate brings several chemical and biological changes in the soils, which are beneficial or helpful in improving crop yields on acid soils (Fageria et al. 2008).

Liming raises soil pH, base saturation, and Ca and Mg contents, and reduces aluminium concentration in acidic soils (Fageria et al. 2004). The liming of acidic soils result in the release of P for plant uptake; this effect is often referred to as ‘‘P spring effect’’ of lime (Bolan et al., 2003).

Amelioration of soil acidity by surface liming to attain a pH range which is suitable for better crop production is crucial in order to get reasonable yields in acid prone areas. In order to alleviate the soil acidity problem using agricultural lime different research activities have been done with different organizations in different parts of the country.

For a long ago, different stakeholders, Agricultural Research Institutes (both federal and regional), Universities and nongovernmental organizations used lime to reclaim acid soils. A well coordinated research activity on acid soil was started following the restructuring of EIAR in 2008. The soil acidity research project commenced its mission by identifying hot spot soil acidity benchmark sites throughout the country. Holetta Agricultural Research Center was mandated to Bedi, Emdibir and Nedjo benchmark sites that represents low, medium and highly acidic soils of the country respectively. Similarly Jima, Asosa, Pawe, Wendogenet and Tepi research centers are also conducting researches on acid soils.

The objectives of this review were to summarize past lime technology research achievements and recommend future research direction for lime technology.

MATERIALS AND METHODS

Academic publications were searched through both electronic and hard copy literature sources. A large set of keywords were chosen to identify as many publications as possible. These include soil acidity, nitisol, lime, phosphorus, pH, exchangeable acidity. Moreover, publications in hard copies (research reports, articles in journals, proceedings and thesis) were obtained from different institutions such as Ethiopian Institute of Agricultural Research (EIAR), Regional Agricultural Research Institute (RARIs), NGO’s and personal communication. Only publications dealing with a progress of acid soil management research in Ethiopia were selected and arranged together for this review. Articles published only after 2000 were considered.

RESULTS AND DISCUSION

Phosphorus status of the reddish-brown soils of Ethiopian highlands

The reddish-brown soils of the Ethiopian highlands are highly deficient in phosphorus. For instance, soil analytical results have indicated that most of the soils in the Walmera area are low in pH and deficient in available P (Table 1).

Table 1. Initial soil chemical properties of the experimental field of Holeta Agricultural Research Centre, 2001 – 2003

	pH				Meq/100 g soil				
Field No	1:1(H2O)	P (ppm)	N (%)	OC (%)	Na	K	Ca	Mg	CEC
Rep I	4.2	5.5	0.19	1.56	0.11	1.66	2.76	2.31	23.44
Rep II	4.3	5.0	o.16	1.48	0.14	1.25	2.73	2.36	28.98
Rep III	4.4	5.0	0.17	1.52	0.07	1.28	2.75	2.20	27.94
Rep IV	4.4	4.2	0.1	1.52	0.08	1.14	2.74	1.48	26.04
Mean	4.3	4.95	0.17	1.52	0.10	1.33	2.74	2.09	26.60

Notes: P determined by Olsen method; CEC = cation - exchange capacity; OC= Organic carbon.
Source: Getachew Agegnehu and Taye Bekele, 2005b.

Table 2. Chemical characteristics of soils of two sites in Walmera area, 2003 – 2004

Soil type	pH 1:1 (H2O)	N (%)	P (mg/kg)	NH_{4+} - N (mg/kg)	NO_3 - N (mg/kg)	Na (Meq/100 g soil)	K	Ca	Mg	CEC
Nitisol/Dila	5.04	0.20	21.26	37.68	21.75	0.15	2.03	12.52	3.29	25.75
	5.09	0.18	18.17	39.85	19.65	0.01	2.13	9.24	2.24	23.97
	5.24	0.24	17.93	27.74	23.68	0.01	2.20	12.76	2.63	29.80
Mean	5.12	0.21	19.12	35.69	21.69	0.66	2.12	11.51	2.72	26.51
Nitisol/Dimile	4.46	0.20	8.40	39.46	9.83	0.01	1.41	8.95	1.76	20.78
	4.62	0.16	10.80	17.26	5.63	0.01	1.82	8.82	1.58	20.35
	4.51	0.17	10.00	34.28	13.58	0.02	1.64	6.85	1.38	19.51
Mean	4.53	0.18	9.73	30.33	9.68	0.01	1.62	8.23	1.57	20.21

Notes: CEC = cation - exchange capacity; Source: Getachew Agegnehu and Taye Bekele, 2005a.

Thus, the amount of available P in the soil is, by and large, insufficient to meet the requirements of barley production. Soil analytical results were found to be suboptimal for the production of crops. Similar to Marschner, 1995 finding, soils with pH values less than 5.5 are deficient in Ca and/or Mg, and also P. As presented in Table 1 and 2, the soil pH, available P and exchangeable cations were found to be far below the optimum.

Management of Acid Soils with Lime application

Due to increasing scope and magnitude of soil acidity problem in Ethiopia, reclamation program focusing on liming has been under taken in seriously affected part of the country. Some of the achievements obtained are presented as follows.

Table 3. Effect of lime on the grain yield (t/ha) of maize at Nedjo

Lime t/ha	**N P_2O_5 (kg/ha) 0-0**	**35-35**	**70-70**	**Mean Yield (t/ha)**
0	5.40	4.95	4.22	4.86
3	3.95	**6.14**	5.49	5.19
Mean	**4.67**	**5.55**	**4.85**	

Source: Holeta Agricultural Research Center (HARC), 2010

Table 4. Effect of Lime and P application on grain yield (kg/ha) of Barley at Bedi

Lime t/ha	**P (kg/ha) 0**	**10**	**20**	**30**	**Mean**
0	1256	2059	2397	3060	2393
0.5	2132	2501	3447	3833	2978
1	2498	3184	4362	4675	3680
1.5	2536	3995	4697	5117	4086
2	2498	3769	4846	4976	4022
Mean	**2184**	**3102**	**3950**	**4332**	

Source: Holeta Agricultural Research Center (HARC), 2010

As indicated in tables 3 and 4, increased rate of lime application from 0 - 3 t/ha resulted in increased yield of Maize when applied with 35-35 N P_2O_5 (kg/ha) and Barely yield also increased with increasing lime (0-1.5 t/ha) and P application (0-30 P_2O_5 kg/ha). This clearly indicated that, application of lime coupled with fertilizer improve the productivity of crops in acid affected soils. This might be related with poor fertility of acid soils prevalent in high rainfall areas where leaching of nutrients is expected to be high.

An experiment was conducted at Nedjo testing site to evaluate the interaction effects of different lime rates and phosphorus levels on yield of teff and finger millet. The lime level which gave best yield of finger millet was 5 t ha^{-1} with 69 kg ha^{-1} of phosphorus (1346.2 kg ha^{-1}). The second best yield of finger millet was recorded by 20t ha^{-1} lime with 46 kg ha^{-1} of phosphorus (Table 5).

Similarly, the best yield of teff was obtained by 5 t ha^{-1} with 69 kg ha^{-1} of phosphorus (1635.5 kg ha^{-1}). The second best yield of teff (1365.8 kg ha^{-1}) was recorded by 10t ha^{-1} lime with 46 kg ha^{-1} of phosphorus (Table 6). Both teff and finger millet grown on extremely acidic soils (Nedjo site) were more responsive to inorganic fertilizer phosphorus rate than lime levels. This might be because of temporary saturation of phosphorus fixation around the plant root zone.

Table 5. Influence of lime & Phosphorus on Finger millet grain yield (kg ha $^{-1}$), Nedjo 2013

**	P1(0 kg ha $^{-1}$)	P2(23 kg ha $^{-1}$)	P3(46 kg ha $^{-1}$)	P4(69 kg ha $^{-1}$)
0 lime (control)	459.6 L	494.6 KL	826.1 G	699.3 HI
0.5 (5 t ha^{-1})	459.3 L	931.4 EF	1230.6 B	1346.2 **A**
1 (10 t ha^{-1})	507.1 KL	790.9 GH	861.4 FG	982.0 DE
1.5 (15 t ha^{-1})	580.1 JK	647.5 IJ	881.8 FG	797.2 G
2 (20 t ha^{-1})	673.0 IJ	1046.0 CD	1269.7 AB	1111.7 C
CV				6.98
LSD				68.95

Source: HARC Progress Report (2015)

Table 6. Influence of lime & Phosphorus on teff grain yield (kg ha $^{-1}$), Nedjo 2013

**	P1(0 lime)	P2(23 kg ha $^{-1}$)	P3(46 kg ha $^{-1}$)	P4(69 kg ha $^{-1}$)
0 lime (control)	192 ^{K}	1142.9 ^{DEF}	1169.8 ^{DE}	1328.6 ^{C}
0.5 (5 t ha^{-1})	268.9 ^{J}	1136.3 ^{EFG}	1348.8^{C}	1635.5 ^{A}
1 (10 t ha^{-1})	485.1 ^{I}	1205.6 ^{D}	1365.8 ^{BC}	1426.6 ^{B}
1.5 (15 t ha^{-1})	484.5 ^{I}	1144.8 ^{DE}	1155.4 ^{DE}	1176.9 ^{DE}
2 (20 t ha^{-1})	500.6 ^{I}	964.1 ^{H}	1177.3 ^{DE}	1107.8 ^{FG}
CV				11.7
LSD				104.3

Source: HARC Progress Report (2015)

Research work has been done on integrated soil fertility management (i.e., organic fertilizer sources combined with inorganic fertilizers) under limed /unlimed condition on teff yield at Nedjo testing site. The experiment was conducted for two consecutive years without changing plots that received the organic fertilizer sources farmyard manure (FYM) and compost only in the first year but received the inorganic fertilizers every year. TSP and Urea were used as source of phosphorus and nitrogen.

Result obtained from two years data and the over years aggregate (Table 7, 8 and 9) clearly showed that superior grain yield, biomass weight and plant height were recorded with treatment 50% FYM + 50% NP + 50% lime. The second best result was obtained with treatment 50% compost + 50% NP + 50% lime. Similar result was obtained by Chilimba et al., (2004) evaluated the response of maize grain yield to applied compost and farmyard manure in combination with inorganic fertilizer materials. Both organic fertilizer sources (FYM & Compost) combined with equal amount of NP inorganic fertilizers in the absence of a soil conditioner lime gave statistically similar teff grain yield, biomass and plant height. This might be probably happened due to the inorganic fertilizers thus increase the above ground and root biomass due to immediate supply of plant nutrients in sufficient quantities as stated by Sarkar et al., 2003; Bostick et al., 2007

The obtained results clearly assured that proper knowledge and enhanced use of integrated soil fertility management technologies such as combined use of organic and inorganic fertilizers in the presence of lime are vital in improving and sustaining crop production.

Table 7. Effect of organic fertilizer sources on teff grain yield and yield components (kg ha $^{-1}$) on acidic soil at Nedjo 2014

No	Treatment	PLHT	Pnkln	BM	GY
1	Control (no amendment)	33.1	19.2	463.0	87.9
2	Recommended NP	34.1	22.6	722.2	193.1
3	100 % FYM	53.9	35.1	1685.2	547.1
4	100% compost	51.9	38.0	1425.9	381.9
5	50% FYM + 50% NP	67.2	40.0	3425.9	890.4
6	50% compost + 50% NP	63.7	45.5	3277.8	833.2
7	100% FYM + 100 % lime	58.7	39.5	2611.1	747.0
8	100% Compost + 100 % lime	60.1	39.1	1759.3	529.2
9	NP + 100% lime	65.8	40.9	3203.7	740.2
10	50% FYM + 50% NP + 50% lime	73.8	41.0	4611.1	1191.6
11	50% compost + 50% NP + 50 % lime	67.3	38.4	3870.4	1011.3
12	Rock phosphate as a treatment combination	48.6	30.3	1685.2	462.1
	Mean	56.5	35.8	2395.1	634.6
	CV	8.6	15.2	22.5	25.1
	LSD	8.3	9.2	911.4	269.8

Source: HARC Progress Report (2015)

Table 8. Effect of organic fertilizer sources on teff grain yield (kg ha $^{-1}$) on acidic soil at Nedjo 2015

No	Treatment	PLHT	Pnkln	BM	GY
1	Control (no amendment)	0.0	0.0	0.0	0.0
2	Recommended NP	0.0	0.0	0.0	0.0
3	100 % FYM	25.3	11.5	256.7	155.0
4	100% compost	23.3	10.5	220.0	127.6
5	50% FYM + 50% NP	77.1	33.9	1155.0	657.1
6	50% comp + 50% NP	77.5	35.8	898.3	489.9
7	100% FYM + 100 % lime	72.9	33.0	825.0	488.1
8	100% Compost + 100 % lime	75.0	31.9	1155.0	650.0
9	NP + 100% lime	51.2	23.5	843.3	427.3
10	50% FYM + 50% NP + 50% lime	80.6	35.6	1796.7	907.5
11	50% compost + 50% NP + 50 % lime	80.7	37.2	1228.3	730.7
12	Rock phosphate as a treatment combination	40.4	18.5	330.0	197.9
	Mean	50.3	22.6	725.7	402.6
	CV	4.5	3.0	19.2	16.3
	LSD	39.0	36.5	51.3	49.2

Source: HARC Progress Report (2015)

Table 9. Over year aggregate effect of organic fertilizer sources on teff grain yield (kg ha $^{-1}$) on acidic soil at Nedjo (2014 – 2015)

		cropping season			over year
No	Treatment	2013	2014	2015	means
1	Control (no amendment)	43.4	87.9	0.0	43.8
2	Recommended NP	66.8	193.1	0.0	86.6
3	100 % FYM	1367.6	547.1	155.0	689.9
4	100% compost	1163.0	381.9	127.6	557.5
5	50% FYM + 50% NP	806.2	890.4	657.1	784.6
6	50% comp + 50% NP	771.7	833.2	489.9	698.3
7	100% FYM + 100 % lime	1258.8	747.0	488.1	831.3
8	100% Compost + 100 % lime	1075.5	529.2	650.0	751.6
9	NP + 100% lime	415.3	740.2	427.3	527.6
10	50% FYM + 50% NP + 50% lime	1053.4	1191.6	907.5	1050.8
11	50% compost + 50% NP + 50 % lime	911.4	1011.3	730.7	884.5
12	Rock phosphate as a treatment combination	407.1	462.1	197.9	355.7
	Mean	778.4	634.6	402.6	605.2
	CV	203.5	269.8	49.2	405.8
	LSD	15.4	25.1	16.3	39.6

Source: HARC Progress Report (2015)

An experiment was conducted to observe the interaction of Lime and P on seed yield of faba bean at Bedi and Emdibir. The results of these experiments are presented in tables below. The highest significant ($P \leq 0.05$) yield of faba bean was obtained by applications of 16 .5 (t ha^{-1}) and 13(t ha^{-1}) of lime along with 30 kg ha^{-1} P fertilizer at Bedi and Emdibir respectively (Table 10 and 11). Application of 16.5 t ha $^{-1}$ lime with 30 P (kg ha $^{-1}$) gave 212% yield increment over the control that has no lime but 30 P (kg ha $^{-1}$).

Table 10. The interaction effect of Lime and P on seed yield of Faba bean in (kg ha^{-1}) during 2009/10 cropping season at Bedi.

	P (kg ha^{-1})				
Lime (t ha^{-1})	0	10	20	30	Mean
0	1338.5	2071.2	2332.8	2355.8	2024.6
0.5 (0.55 t ha^{-1})	2275.6	2817.4	3242.2	3310	2911.3
1 (1.1 t ha^{-1})	2804.2	3886.2	4081.9	4330.6	3775.7
1.5 (1.65 t ha^{-1})	3119.9	3769.9	4924.2	5007.4	4205.4
2 (2.2 t ha^{-1})	3466.3	4489.7	4647.7	4997.6	4400.3
Mean	3251.1	4258.6	4807.2	5000.4	

Source: HARC Progress Report (2015)

Table 11. The interaction effect of Lime and P on seed yield of Faba bean in (kg ha^{-1}) during 2009/10 cropping

season at Emdibir.

Lime (t ha^{-1})	P (kg ha^{-1}) 0	10	20	30	Mean
0.5 (3.25 t ha^{-1})	64.8	93	92.2	105.1	89
1 (6.5 t ha^{-1})	190	193.4	256	324.1	240.9
1.5 (9.75 t ha^{-1})	236.6	260.7	374.5	383.5	313.8
2 (13 t ha^{-1})	241.8	318.5	381.3	420.1	340.4
Mean	202.86	228.8	306.1	311.5	

Source: HARC Progress Report (2015)

To discern the effects of liming on root nodulation and grain yield of soybean an experiment was conducted at Bako area, western Ethiopia. The finding from the experiment with regard to growth and yield attributes revealed that liming acid soil in soybean production had significantly influenced the number and dry weight of nodule, the plant height, the above ground biomass and grain yield (Table 15, 16). The nodule number and nodule dry weight increased linearly with increase of liming rate until it reached the recommended level (Derib Kifile, 2014). The optimum value of nodule number and weight obtained is 113 and 963.3 mg /plant which were improved remarkably by 73.84% and 71.04% respectively due to liming (Table 12).

Table 12. Nodulation of soybean as influenced by liming, Bako Agricultural Research Center, western Ethiopia (Derib Kifile, 2014)

Trt No	Lime rate in (t ha^{-1})	Nodule Number/plant	Nodule Volume (in ml)/plant	Nodule Dry wt. (mg)/plant
1	0	65d	2.16	563.33d
2	1.56	85c	3.76	633.33cd
3	2.34	97b	4.3	713.33b
4	3.13	113a	4.43	963.33a
5	3.91	84c	2.93	650bc
6	4.69	93bc	3.26	653.33bc
	LSD (0.05)	11.185	NS	79.693

Table 13. Yield and Yield Related Traits as influenced by Liming, Bako Agricultural Research Center, western Ethiopia. (Derib Kifile ,2014).

Trt No	Lime rate in (t ha^{-1})	SC/plot	plant height (cm)	Biomass weight in (t ha^{-1})	Grain yield weight in (t ha^{-1})	HI
1	0	540	45.93c	6.46c	3.92c	0.43
2	1.56	604	50.93b	7.3b	4.38ab	0.45
3	2.34	617	55.26b	7.66ab	4.36ab	0.42
4	3.13	564	60.23a	7.46b	4.2bc	0.4
5	3.91	593	51.66b	8.27a	4.69a	0.43
6	4.69	605	53.5b	7.3b	4.14bc	0.4
	LSD (0.05)	NS	4.36	0.74	0.41	NS

Sc = Stand count, HI = Harvest Index. Means within a column followed by the same letter(s) or with no letter are not significantly different, NS =Non significant at p>0.05

A field experiments were conducted at the two locations on acidic soil to study the effect of lime and phosphorus application on haricot bean varities at Dolla and Gununo in Wolaita Zone, Southern Ethiopia. The research work was initiated to evaluate the response of haricot bean varieties to liming on acid soils. The experiment was laid out in factorial randomized complete block design with three replications. Hawasa dume and Omo-95 were treated by 0 and 0.4 t ha^{-1} of lime. There was a significant increase on growth parameters of the two varieties as rates of lime increased both at Dolla and Gununo sites. Maximum values of plant height, leaves and branches number were recorded at application rates at both location with liming in year 1 and 2. Similarly, the highest grain yield and yield components were obtained at 20 kg P ha^{-1} with lime (0.4 t ha^{-1}) on both varieties at two locations. Furthermore, application of lime improved soil conditions and in turns varieties performance at both locations (Table 14).

Table 14: Mean value of lime on yield and yield components performance of haricot bean varieties at Gununo and Dolla in 2012-2013 (Mesfin et al., 2014)

		Gununo				Dolla			
Lime (t ha^{-1})	Varieties	Pod No	Seed No	Pod length	Seed yield	Pod No	Seed No	Pod length	Seed yield
0	Omo - 95	8.80	5.42	8.35	826.32	8.85	5.62	8.72	875.17
	Hawassa dume	9.25	5.17	8.47	930.20	8.62	5.22	8.72	972.96
0.4	Omo - 95	8.77	5.02	8.17	1079.40	7.77	4.91	8.52	1122.58
	Hawassa dume	9.35	5.17	8.47	1282.49	8.67	5.22	8.40	1416.99
CV		27.70	17.14	9.50	34.27	22.70	11.90	0.79	46.00
LSD		1.43	0.44	0.57	201.00	1.65	0.65	3.11	200.00

An experiment was also carried out on acid soils of Jima and Ilubabore zones of south-western Ethiopia to know the effect of split application of lime on the basis of maize-soybean rotation system in two sets. Treatments of split lime applications were control, full dose of recommended lime applied at one time during the cropping season, two splits in which 50% of the dose applied in the first year and the rest 50% in the second year, three splits in which 33% of the dose applied in the first year, 33% in the second year and the rest 33% in the third year and four splits in which 25% of the dose applied in the first year, 25% in the second year, 25% in the third year and the rest 25% in the fourth year. Recommended rate of N, 46 kg ha $^{-1}$ and 92 kg ha $^{-1}$ were uniformly applied for soybean and maize, respectively. However, 20 P kg ha^{-1} was uniformly applied for all treatments and for both test crops.

Over years mean showed that split application of lime significantly affected maize and soybean yield at Doyo (Jima). In this line, splitting into two and applying in two consecutive years as well as splitting of lime into three and applying in three consecutive years gave similar yield with full rate application of lime for maize. Splitting into four was even gave similar maize grain yield with splitting lime into two and three (Tesfu Kebede et al., 2010). This is due to the less acidity of Doyo area. Result of this experiment revealed that splitting the required amount of lime into 33%and 50% is possible if maize to be grown on this soil (Table 15).

Table 15. Effect of Split Application of Lime on Maize Yield (kg ha^{-1}) at Doyo in 2009 - 2013 growing seasons (Tesfu Kebede et al., 2010)

Treatments	2009	2010	2011	2012	2013	Over year Mean
Control	1656b	2524b	4259	2762c	1910	2622c
25% every year	1730b	3370ab	4464	3671ab	1792	3005bc
33% every year	1756b	3412ab	4677	4221a	2180	3249ab
50% every year	2176ab	3640ab	4936	3491ab	2256	3300ab
Full dose	2798a	4163a	5101	3192bc	2149	3481a
$LSD_{0.05}$	780	1441	ns	784	ns	466
CV (%)	20.48	22.36	14.83	12.01	35.88	11.09

Means with in a column with the same letter(s) are not significantly different at 0.05 probability level.
ns =Not significantly different at 0.05 probability level

Split application and full rate application gave almost similar soybean yield at the testing site (Table 16). However, resource poor farmers who cannot afford the price of full dose lime can split in to two, three and four and apply every year without significant yield loss for both crops compared to one time application of full dose.

Table 16. Effect of split application of lime on soybean seed yield (kg ha^{-1}) at Doyo in 2009 - 2013 growing seasons (Tesfu Kebede et al., 2010)

Treatments	2009	2010	2011	2012	2013	Over year Mean
Control	1259	1185	1219b	1705	2416	1557b
25% every year	1454	1541	1978a	1977	2441	1878a
33% every year	1674	1662	2270a	1739	2441	1957a
50% every year	1848	1694	2275a	1880	2108	1961a
Full dose	1944	1780	2286a	1850	2408	2054a
$LSD_{0.05}$	ns	ns	638	ns	ns	294
CV (%)	22.86	20.77	16.91	8.92	7.91	11.62

Means with in a column with the same letter(s) are not significantly different at 0.05 probability level.
ns =Not significantly different at 0.05 probability level

Similar to Doyo soil, Hurumu's soil was also responsive to split lime application. Splitting into two and three gave similar maize and soybean yield with full rate application of lime at once (Tables 17 and 18). Depending on the availability of lime and affordability of maize and soybean growers, it is possible to use either of the above frequencies.

Table 17. Effect of split application of lime on maize grain yield (kg ha^{-1}) at Hurumu in 2009-2013 growing seasons (Tesfu Kebede et al., 2010)

Treatments	2009	2010	2011	2012	2013	Over years Mean
Control	5226c	4654b	6804	5868d	5993	5709b
25% every year	5851bc	5082ab	7115	6975b	5643	6133ab
33% every year	6579ab	5337ab	7127	7875a	5755	6535a
50% every year	7157ab	5812ab	7914	6678bc	5794	6671a
Full dose	7439a	5864a	8069	6204c	5616	6638a
LSD $_{0.05}$	1337	1202	ns	485	ns	725
CV (%)	11.01	11.94	9.96	3.85	12.96	8.60

Means with in a column with the same letter(s) are not significantly different at 0.05 probability level.
ns =Not significantly different at 0.05 probability level.

Table 18. Effect of Split Application of Lime on Soybean seed Yield (kg ha^{-1}) at Hurumu in 2009-2013 Growing seasons (Tesfu Kebede et al., 2010)

Treatments	2009	2010	2011	2012	2013	Over year Mean
Control	1382b	1530	1344b	1436b	2077	1554b
25% every year	1421b	1539	1953a	1766ab	2390	1814ab
33% every year	1674ab	1631	2024a	1858a	217 0	1871a
50% every year	1848ab	1709	2004a	1752ab	2327	1867ab
Full dose	1944a	1734	2050a	1727ab	2188	1929a
LSD $_{0.05}$	497	ns	470	384	ns	218
CV (%)	15.97	10.06	13.33	11.86	10.17	8.98

Means with in a column with the same letter(s) are not significantly different at 0.05 probability level.
ns =Not significantly different at 0.05 probability level

Another study was conducted at Megele-33 kebele, Assosa area of north western Ethiopia from 2012 – 2015 on the basis of cereal food legume/oil crops rotation system in two sets. Treatment with 50% lime in split application gave the highest mean grain yield (3143.3kg/ha) of sorghum (Table 19), and as clearly observed from Table 19 the ANOVA result showed a significant difference of grain yield between treatments (Dessalegn Tamene and Bekele Anbesa, 2015).

Table 19. Effect of Split Application of Lime on Soybean seed Yield (kg ha^{-1}) at Asosa

Treatment	PLH (m)	Gy kg/ha
Control	91.1	573.5
Full dose of lime	99.1	2378.7
50% lime each year	121.3	3143.3
33% lime each year	105.4	2315.0
25% lime each year	110.1	2402.3
CV	29.7	78.4
LSD	NS	1618.8

To evaluate different agricultural lime materials produced in Ethiopia for their agronomic effectiveness on acid soils an experiment was conducted at Holeta agricultural research centre for three years. The agricultural lime materials were brought from Senkele (Oromia), Dejen (Amhara) and both Awash Dolomite and Awash calcite from Awash 7 kilo. Statistically no yield difference was observed among different agricultural limes produced in Ethiopia, and this implies that both limes produced at Senkele (Oromia) and Dejen (Amhara) can successfully answer their regional lime needs. When Senkele lime, Dejen lime and $Ca(OH)_2$ from Ghion gas factory were compared with Awash calcite and Awash dolomite, these two Awash products were greatly preferred (Table 20 and 21). The reason might be mainly from the material they were processed and as well the technology under which they were crushed.

Table 20: Effects of different agricultural limes on yield & yield components of barley, combined analysis (Year I) -2014

Treatment	PLHT (cm)	Spkln (cm)	Spkpsp	BM (kg ha^{-1})	GY (kg ha^{-1})	HLW (%)	TSW (g)
1	114.39	6.25	49.40	17911.1	6146.7	61.5	41.87
2	114.83	6.30	49.40	18788.9	6524.7	63.5	42.27
3	115.11	6.39	50.27	18611.1	6879.2	62.1	41.64
4	113.22	6.58	51.40	18266.7	6975.3	61.1	42.02
5	113.78	6.14	49.67	18233.3	6577.4	62.1	41.78
Mean	114.27	6.33	50.03	18362.22	6620.66	62.08	41.92
CV (%)	3.15	5.55	11.54	10.44	12.62	4.39	4.73
LSD(0.05)	NS	NS	NS	NS	797.26	NS	NS

Source: HARC Progress Report 2016

Trt. 1= control, 2= Dejen lime, 3= Awash Dolomite, 4= Awash Calcite, 5= Senkele lime, 6= Ca $(OH)_2$, PLHT=plant height, Spkln = Spike length, Spkpsp = No of Spikelet per Spike, BM=Biomass (kg ha^{-1}) , GY= Grain yield (kg ha^{-1}), HLW=hectolitre weight, TSW= Thousand seed weight.

Table 21. Effects of different agricultural limes on yield & yield components of barley, R/Gebeya (Kifile) - 2016

Treatment	PLHT (cm)	Spkln (cm)	Spkpsp	BM (kg ha^{-1})	GY (kg ha^{-1})	HLW (%)	TSW (g)
1	90.13	6.33	45.80	7389.0	3261.0	61.33	47.60
2	88.30	6.87	52.13	8389.0	3642.5	61.03	47.00
3	88.93	6.60	50.33	8537.0	3653.6	62.13	47.73
4	89.73	7.00A	49.53	8019.0	3582.5	61.87	47.53
5	86.33	6.20	49.20	7796.0	3420.1	61.83	47.07
Mean	88.69	6.60	49.40	8025.92	3511.94	61.64	47.39
CV (%)	3.33	6.40	5.70	15.81	15.92	1.69	2.09
LSD(0.05)	NS	0.79	5.30	NS	NS	NS	NS

Source: HARC Progress Report 2016

Trt. 1= control, 2= Dejen lime, 3= Awash Dolomite, 4= Awash Calcite, 5= Senkele lime, 6= Ca $(OH)_2$, PLHT=plant height, Spkln = Spike length, Spkpsp = No of Spikelet per Spike, BM=Biomass (kg ha^{-1}) , GY= Grain yield (kg ha^{-1}), HLW=hectoliter weight, TSW= Thousand seed weight.

The Capacity building for scaling up of evidence–based best practices in agricultural production in Ethiopia (CASCAPE) project conducted research in selected woreda's in the Southern and Amhara regions with the aim of reclaiming acid soils for crop production. In both regions different treatments with varying quantities of lime per hectare were tested. In the South region six treatments used were, (i) 900 kg ha^{-1} lime (ii) 900 kg ha^{-1} lime plus the recommended fertilizer rate (iii) 1800 kg ha^{-1} lime (iv) 1800 kg ha^{-1} lime plus the recommended fertilizer rate (v) application of recommended fertilizer (100 kg DAP and Urea per ha) only; (vi) control (no treatment); where as in CASCAPE Amhara (i) 1925 kg ha^{-1} lime (ii) 2050 kg ha^{-1} lime and (iii) control (no lime application) were used. All three treatment plots followed the recommended fertilizer dosage. Barley was the experimental crop used. Grain yield was measured on each treatment and was analyzed using SAS software.

Grain yield of barley increased with lime application. The highest grain yield of 1367 kg ha^{-1} was obtained with application of 1800 kg lime and recommended fertilizer, as opposed to application of 900 kg lime and recommended fertilizer (1283.5 kg ha^{-1}) (Table 22). These yield levels were significantly higher than the control (554.0 kg ha^{-1}). Barley grain yield in *Dera* & *Jabi Tehnan* woredas of Amhara region showed significant differences between lime treated plots and non treated plots. Lime rates based on the buffer method (1925 kg ha^{-1} on average of four sites) and the exchangeable acidity method (2050 kg ha^{-1}) on average of four sites) gave grain yields of 3648 and 3643 kg ha^{-1} of barley, respectively and the difference were not significant (Table 23). The non – treated (control) plot gave a grain yield of 2452 kg ha^{-1}, and this was significantly lower than the other treatments. Biomass (straw) yield of barley was highest (10058 kg ha^{-1}) for a lime rate of 2050 kg, but the difference between the treatments was not significant.

Table 22. Mean grain yield of barley across different liming treatments in Bule woreda, Southern Ethiopia (Wondwosen Bekele et al., 2014)

Treatments	Mean grain yield across replications (kg ha^{-1})
Control	554.00
RFR	778.00
900 kg ha^{-1} lime + 0 Fertilizer	891.50
900 kg ha^{-1} lime + RFR	1283.50
1800 kg ha^{-1} lime + 0 Fertilizer	924.75
1800 kg ha^{-1} lime + RFR	1367.67

RFR: recommended fertilizer rate (100 kg DAP & 100 kg Urea)

Table 23. Grain yield of barley across liming treatments following buffer and exchangeable acidity in Amhara region (Wondwosen Bekele et al., 2014)

Treatments	Lime rate (kg)	Mean grain yield (kg ha^{-1})	Mean biomass yield (kg ha^{-1})	Grain yield advantage over the control (kg ha^{-1})
Control	0	2432^{b}	6385^{a}	
Buffer method	1925	3648^{a}	9151^{a}	50%
Exchangeable-acidity method	2050	3643^{a}	10058^{a}	50%
Mean	3241	8531		
CV	16.2	24		

**As the trial in CASCAPE Amhara were conducted at two districts, Dera and Jabi: the data on the table combined over the two woredas.*

Comparison of soil pH level changes before planting and after harvest at CASCAPE south showed that after harvest the pH levels consistently increased from 4.68 in the control (T_1) to 5.33 (T_5) due to the treatment with 1800 kg ha^{-1} lime plus no fertilizer. For the control, pH after harvest showed a reduction by 0.03 compared to the pH level before planting, which might be associated with the macronutrient mining of test crops from the native soil.

Similarly, from an experiment conducted at Chencha and Hagerselam areas of southern Ethiopia application of lime together with other macro-nutrients (nitrogen, phosphorus and potassium) significantly increased yield of barley. It is clearly observed that the relative barley yield increased due to application of 0.85 and 1.75 Mg lime alone or with different combinations of NPK in 2007 was promisingly high. Application of 0.85 and 1.75 Mg lime gave 64 and 100% higher yield, respectively than absolute control; whereas 7 and 64%, 52 and 37%, 116 and 100% and 24 and 22% higher yields were observed by combining with NP, NK, PK and NPK, respectively as compared to application of respective fertilizer alone. Application of half and full doses of lime alone or with NPK gave statistically similar barley yield both at Chencha and Hagerselam. These results suggested that lime application increased the effect of fertilizer on barley yield at both sites, the highest being on NP in Chencha soils and on PK in Hagerselam soils (Table 24).

Table 24. The effect of lime and NPK fertilizer application on the grain yield of Barley (kg ha^{-1}) in acidic soils of Chencha and Hagerselam (Wondwosen Bekele et al., 2014)

Treatment	Chencha		Hagerselam	
	2007	2008	2007	2008
Control	517.4c	763.9bc	1171.2b	617.9d
NP	1271.0b	701.2c	1988.0ab	1985.0b
NK	1285.0b	941.0abc	1447.4b	1081.5cd
PK	1479.0b	1531.2a	1669.7b	1468.4bc
NPK	2333.0a	1357.6ab	2816.8a	2614.3a
LSD (0.05)	479.5	604.1	1170	582.2
L1	975.0b	593.8b	1369.4	1159b
L2	1508.3a	1210.3a	1978.4	1576ab
L3	1648.0a	1372.9a	2108.1	1925a
LSD (0.05)	371.4	467.9	NS	451.8
Control	83.3g	312.5ef	738.7	499.1f
L2	666.7efg	708.3cdef	765.8	677.4ef
L3	802.1defg	1270.8abcde	1009.0	677.2ef
NP + L1	541.7defg	125.0f	1441.4	1640.0bcde
NP + L2	1271cdef	874.3bcdef	1567.6	1818.0bcd
NP + L3	2000abc	1104.2abcdef	2955.0	2496.0abc
NK + L1	791.7defg	583.3cdef	1117.1	677.4ef
NK + L2	1604.2bcd	1083.3abcdef	1693.7	1141.0def
NK + L3	1458.3bcde	1156.0abcdef	1531.5	1426.0cde
PK + L1	1479.2bcde	1447.9abcd	900.9	1087.0def
PK + L2	1208.3cdef	1812.5ab	1585	1604.0cde
PK + L3	1750.0bc	1333.3abcde	2522.5	1711.0bcd
NPK + L1	1979.2abc	1156.3def	2648.6	1889.0bcd
NPK + L2	2792.0a	1572.9abc	3279.3	2638.0ab
NPK + L3	2229.3ab	2000.0a	2522.5	3315.0a
LSD(0.05)	830.5	1046	NS	1010
CV (%)	36.06	39.1	40.2	38.9

Lime rate for barley at Hagerselam --- L_1 = 0 lime, L_2 = 0.85 Mg ha^{-1} lime, L_3 = 1.75 Mg ha^{-1} lime,
Lime rate for barley at Chencha --- L1 = 0 lime, L_2 = 3.84 Mg ha^{-1} lime, L_3 = 7.68 Mg ha^{-1} lime

Conclusion

Crop development and potential yield depend on different environmental and soil factors. Soil acidity problems are increasing in the highland areas of Ethiopia. Different experiments confirmed that and suggested that lime is essential but must be complimented with balanced plant nutrients in order to get adequate crop yield in acid prone areas. In Nedjo condition, lime level 5 t ha^{-1} with 69 kg ha $^{-1}$ phosphorus gave best yield (1346.2 kg ha $^{-1}$) and (1635.5 kg ha $^{-1}$) of finger millet and teff respectively. Similarly, yield of faba bean was obtained by applications of 16 .5 (t ha^{-1}) and 13(t ha^{-1}) of lime along with 30 kg ha^{-1} P fertilizer at Bedi and Emdibir respectively. Application of 16.5 t ha $^{-1}$ lime with 30 P (kg ha^{-1}) gave 212% yield increment over the control that has no lime but 30 P (kg ha $^{-1}$).

Around Bako area liming significantly influenced the number and dry weight of nodule, plant height, above ground biomass and grain yield of soybean. The nodule number and nodule dry weight increased linearly with increase of liming rate until it reached the recommended level.

The study of lime and phosphorus application on haricot bean varieties at Dolla and Gununo in Wolaita Zone, Southern Ethiopia showed that the highest grain yield and yield components were obtained at 20 kg P ha^{-1} with lime (0.4 t ha^{-1}) at two locations.

Split application of lime on the basis of maize-soybean rotation system in two sets on acid soils of Jima and Ilubabore zones of south-western Ethiopia has showed that splitting into two and three parts gave similar maize and soybean yield with full rate application of lime at once. However, resource poor farmers who cannot afford the price of full dose lime can split in to two, three and four parts and apply every year without significant yield loss for both crops compared to one time application of full dose. Similarly, from an experiment conducted at Megele-33 kebele, Assosa area of north western Ethiopia on the basis of cereal food legume/oil crops rotation system showed that splitting full dose of lime into two parts gave the highest mean grain yield of sorghum without significant yield loss.

From research work done on integrated soil fertility management (i.e., organic fertilizer sources combined with inorganic fertilizers) under limed /unlimed condition on teff yield at Nedjo testing site, two years data and the over years aggregate clearly showed that superior grain yield, biomass weight and plant height were recorded with treatment 50% FYM + 50% NP + 50% lime.

Similarly, an experiment was conducted at Holeta station and on-farm to evaluate different agricultural lime materials produced in Ethiopia for their agronomic effectiveness on acid soils. Statistically no yield difference was observed among different agricultural limes produced in Ethiopia, and this implies that both limes produced at Senkele (Oromia) and Dejen (Amhara) can successfully answer their regional lime needs. When Senkele lime, Dejen lime and $Ca(OH)_2$ from Ghion gas factory were compared with Awash calcite and Awash dolomite, these two Awash products were greatly preferred. The reason might be mainly from the material they were processed and as well the technology under which they were crushed.

Soil acidity limits crop production in many tropical soils. Lime and inorganic phosphate fertilizers are used to remedy these problems. However, due to increasing costs and unavailability when needed, their use among our farmers in our country is not widespread. Thus the government should give an attention to the supply of lime where it is prudently needed.

ACKNOWLEDGEMENTS
I would like to acknowledge all researchers contributed for soil acid management to fetch a solution to minimize its adverse impact and foster its contribution to the country's food security.

REFERENCE:

Abreha Kidanemariam, Heluf Gebrekidan, Tekalign Mamo, Kindie Tesfaye, 2013. Wheat Crop Response to Liming Materials and N and P Fertilizers in Acidic Soils of Tsegede Highlands, Northern Ethiopia. *Agriculture, Forestry and Fisheries.* Vol. 2, No. 3, 126 -135.

Bolan, N.S., Hedley, M.J., 2003. Role of carbon, nitrogen and sulfur cycles in soil acidification. In"Handbook of soil acidity". New York: Rengel. Z; p. 29-56.

Bolan, N.S., Hedley, M.J., and White, R.E., 1991. Process of soil acidification during nitrogen cycling with emphasis on legume based pastures. *Plant and soil,* 134:53-63.

Bostick, W.M.N., Bado, V.B., Bationo, A., Solar, C.T., Hoogenboom, G., Jones, J.W., 2007. Soil carbon dynamics and crop residue yields of cropping systems in the Northern Guinea Savanna of Burkina Faso. Soil Till. Res. 93, 138 –151.

Brady, N. C. and R. R. Weil, 2008. Nature and Properties of Soils (14th edn.). Prentice Hall, Upper Saddle River. 992p.

Chilimba, A.D.C., Chigwenembe, S., Lungu, B.W. and Sonjera, P.A., 2004. The effects of different organic fertilizers and their interactions with inorganic fertilizer on maize yield. In: Annual report of the Soils Fertility and Plant Nutrition Commodity Team, Ministry of Agriculture, Lilongwe, Malawi.

Derib Kifile, 2014. Effect of liming on root nodulation and grain yield of soyabean at Bako Agricultural Research Center, Western Ethiopia, MSc Thesis, Haramaya University

Dessalegn Tamene and Bekele Anbesa, 2015. Split Application of Lime for Acid Soil Amelioration and better Sorghum performance in Asosa area. EIAR/Assosa Agricultural Research Centre Progress Report.

Ernani, P.R., Ribeiro, M.F.S., Bayer,C., 2004. Chemical modifications caused by liming below the limed layer in a predominantly variable charge acid soil. Communications in Soil Science and Plant Analysis, v.35, p.889-901.

Fageria, N.K and Baligar, V.C, 2008a. Ameliorating soil acidity of tropical oxisols by liming for sustainable crop production. Advances in Agronomy. 99.345-389.

Fageria, N.K, Stone, L.F., 2004. Yield of common bean in no-tillage system with application of lime and zinc. Pesq Agropec Braas. P. 73-78.

Fageria, N. K., Baligar, V. C., and Jones, C. A., 2011. Growth and Mineral Nutrition of Field Crops. Boca Raton, FL: CRC Press.

Getachew Agegnehu & Taye Bekele, 2005a. On-farm integrated soil fertility management in wheat on nitisols of central Ethiopia high lands. *Ethiopian Journal of Natural Resources, 7:141-155*

Getachew Agegnehu & Taye Bekele, 2005b Phosphorus fertilizer and farm yard manure effects on the growth and yield of faba bean and some soil chemical properties in acidic nitisols of the central highlands of Ethiopia. *Ethiopian Journal of Natural Resources, 7:23-39.*

HARC (Holeta Agricultural Research Center), 2010. Research Progress Report.

HARC (Holeta Agricultural Research Centre), 2015. Soil and Water Research Process Progress Report.

Hocking, P.S., 2001. Organic acids exuded from roots in phosphorus uptake and aluminum tolerance of plants in acid soils. In: D.L. Sparks (ed.). Advances in Agronomy. Academic

IFPRI (International Food Policy Research Institute), 2010. Fertilizer and Soil Fertility Potential in Ethiopia Constraints and Opportunities for Enhancing the System. Working Paper.

Kaitibie, S., Epplin, F.M., Krenzer, E.G., Zhang, H., 2002. Economics of lime and phosphorus application for dual purpose winter wheat production in low pH soils. Agron J. p.1139-1145.

Marschner, H., 1995. Mineral Nutrition of Higher Plants. Institute of Plant Nutrition, University of Hohenheim /Academic Press/Harcourt Brace, London, UK.

Marschner, P. and Rengel, Z., 2007. Nutrient Cycling in Terrestrial Ecosystems, , Springer-Verlag, Heidelberg, Germany

Mesfin Kassa, Belay Yebo and Abera Habte, 2014. Liming Effects on Yield and Yield Components of Haricot Bean *(Phaseolus vulgaris* L.) Varieties Grown in Acidic Soil at Wolaita Zone, Ethiopia. *International Journal of Soil Science, 9: 67-74.*

MoARD, 2007. Ministry of agriculture and rural development crop development department, crop variety registrar. Issue No.10.

Sarkar, S., Singh, S.R., Singh, R.P., 2003. The effect of organic and inorganic fertilizers on soil physical condition and the productivity of rice – lentil cropping sequence in India. J. Agric. Sci. 140, 419 – 425

Scott, B. J., Fisher,J.A., Cullins, B.R., 2001. Alluminium tolerance and lime increase wheat yield on the acidic soils of central and southern. Aust J Exp Agric. p 523-532.

Sposito, G., 2008. The Chemistry of Soils. 2nd Ed. Oxford University Press, New York. 330 p.

Sumner, M.E., 2000. Handbook of Soil Science. CRC Press Washington, D.C. USA.

Tesfu Kebede, Jafar Dawd, workineh Tola and Tolessa Amenu, 2010. Split application of lime for acid soil amelioration and better maize and soybean performance in southwestern Ethiopia. EIAR/Jima Agricultural Research Centre Progress Report.

Tolera Abera, Adamu Molla, Abriham Feyissa, Minale Liben, Abdo Woyema, Legesse Admasu and Agedew Bekele, 2006. Barely Research and development in Ethiopia: Proceedings of the 2nd National Barely Research and Development Review Workshop, Holetta Agricultural Research Center , Ethiopia 28-30 November 2006.

Wang J., H. Raman, G. Zhang, N. Mendham and M. Zou, 2006. Tolerance in barely (*Horidiumvulgarie L.*): Physiological mechanisms, genetics and screening methods. *Journal of Zhejiang University Science*. 7: 769-787.

Wondwosen Bekele, Asresie Hassen, Tesfaye Abebe, Yehenew G/Selassie,Tewdros Tefera and Firew Tegene, 2014. Effect of liming on yield of barley in the Ethiopian highlands. Scaling innovations and Agricultural best practices in Ethiopia, Experiences and Challenges. In: Proceedings of the CASCAPE National Stakeholder Conference 23-24 April 2014. Eyasu Elias and Christy van Beek (eds). Addis Ababa, Ethiopia. Pp 186-199.