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Review on the Work Done For the Last Decade on Acid Soil Management for Better Yields in Southwestern Ethiopia

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Abstract: Population is increasing exponentially over time but resources are limited. To support this population, increasing productivity of the resources is importantly inevitable. One of the resources, the base of production, is soil. Its fertility is declining due to expansion of soil acidity and its low inherent fertility status. Soil fertility management is therefore, a key for sustainable crop production for food security. Last10-15 years of research and its achievement in soil acidity management in annual crops by Jimma Agricultural research center have been reviewed. To fulfill the increasing demand for food and raw materials, soil health and fertility has remained as the major factor to increase and sustain crop yields. This calls for proper use of knowledge of soil acidity and its amelioration to maximize agricultural productivity. Farmers require simple and sustainable techniques to amend acid soils and improve yields of crops of their choices. Recommendations on reclamation of acid soils need to change with new developments, such as liming, use of acid-tolerant crop varieties and integrated soil fertility management. Liming has played an important role in raising soil pH and enhancing crop productivity. In Ethiopia, southwestern area the gap between potential and actual yield is very wide because of soil acidity and associated nutrient availability. Acidic soils are not responsive to the application of inorganic fertilizers without amendments-it is simply wastage of resources. Thus, developing effective and efficient acid soil management practices is indispensable for enhancing crop productivity and thereby sustaining yield gains. Natural Resources Management Research process, acid soil management research program of the Jimma Agricultural Research center has been conducting different research activities on soil acidity management to enhance, and sustain agricultural productivity in the country. Using amendments such as lime and organic fertilizer for acid soil management showed good result in maize and soybean productivity in acidic soils in Jimma and Illubabor. This review finding provides important information on management options to amend soil acidity and improve the entire fertility of soils, and other organic amendments that can be applied to remedy soil acidity to the desired pH level and improve soil quality. Integrated acid soil management enhances the stability of yields and maximizes nutrient use efficiency. The information contained in this finding serves the interests of policymakers, researchers, students, agronomists and users associated with acid soils management.

Keywords: Acid Soil, Soil Amendment, Annual Crops, Integrated Soil Fertility Management

1. Introduction

Soil fertility is a base for improving production and productivity. Soil fertility management in Jimma Agricultural Research Center is traced back to the late 1970's and to the early 1980's during which yield responses of coffee to N, P and K application was studied in different coffee growing regions of the country. Since then, it was expanded to mainly grown annual crops in southwestern regions like maize, soybean, common bean and sorghum after soil and water and field crop agronomy research divisions were established at the Center (JARC progress report). These crops play a major role in achieving food security of smallholder farmers in this region.

Soil fertility is declining over time due to low inherent soil fertility and low external inputs. These lead to low and vibrant yields in annual crops. Soil fertility is maintained by applying nutrients from either chemical and/or organic fertilizers. Chemical fertilizers are a type of fertilizer manufactured in industries. They include urea, di-ammonium

phosphate, triple super phosphate and other forms that are readily available. Organic fertilizers on the other hand are a materials ranging from house wastes to manually prepared materials like compost vermin-compost and green manure. The low organic matter input and continuous ammonium based fertilizer use in Ethiopia exacerbate the acid soil formation. Soil acidification is a complex set of processes resulting in the formation of acid soils. The summation of different anthropogenic and natural processes including leaching of exchangeable bases, basic cation uptake by plants, decomposition of organic materials, application of commercial fertilizers and other farming practices produce acidic soils [3]. Acid soils are highly leached soils with high saturation of Al^{+3} and H^{+} cations but very low basic cations such as Ca^{+2}, Mg^{+2}, and K^{+}. It is the most challenging constraint to in crop production in Ethiopia. Soils that affected by acidity is about 43% of the arable [5] and more serious effect is observed in south western, southern, western and northwestern where rainfall intensity is high and to some extent the central highlands of the country is also affected by mild acidity [11]. Aluminum ($Al3^{+}$) toxicity inhibits root cell division and elongation, thereby reducing water and nutrient uptake [15], and cause poor nodulation or mycorrhizal association of roots [4], consequently leading to poor plant growth and yield. Acid soils are poor in fertility and its management should focus towards enriching organic matter in soil. Hand in hand, reclamation of these soils with amendments like lime and organic materials have been believed to be better options for managing such soils. In addition, appropriate type and amount of chemical fertilizer [14], and screening crop varieties for acid soil tolerance are also important practice in making acid soil productive. Jimma agricultural Research Center has been carried out different acid soil and soil fertility management practices since its establishment. Integrated use of lime, leguminous crop and judicious fertilizer are important practices in enhancing soil fertility and improving the productivity of acid soil for annual crops in southwestern and western Ethiopia. Phosphorus nutrition plays important role in legumes and symbiotic N2 fixation. The formation of seeds and fruits is especially depressed in plants suffering from P deficiency. Thus, not only yields but also poor quality seeds and fruits are obtained from P deficient soils [6]. Liming is a major and effective practice to overcome soil acidity constraints and improve crop production on acid soils. Lime is called the foundation of crop production or ‘‘workhorse’’ in acid soils [7].

2. Methodology

This paper reviews various acid soil management practices in annual crops that were conducted by Jimma Agricultural Research Center in the previous decades. It also highlights the major achievements and the future research directions of soil acidity management for sustainable food crop production in the regions.

Table 1. *Effect of lime and phosphorus rates on soybean grain yield (ton ha^{-1}) at Hurumu.*

Lime (t ha^{-1}) & P (kg ha^{-1}) rate	2009	2010	2011	2012	2013	Mean
L0 P0	1.44	1.16	0.38^{h}	0.57^{g}	0.62^{i}	0.84^{g}
L0P10	1.73	1.54	1.21^{fg}	1.63^{a-d}	1.39^{e-g}	1.50e
L0P20	1.37	1.34	1.78^{a-e}	1.84^{a-c}	2.25^{ab}	1.72^{b-e}
L0P30	1.60	1.55	1.93^{a-d}	1.73^{a-d}	1.74^{c-e}	1.71^{b-e}
$L_{1.41}$ P0	1.84	1.51	0.61^{h}	0.92^{fg}	0.73^{hi}	1.12^{f}
$L_{1.41}$P10	1.83	1.88	1.54^{d-f}	1.49^{c-e}	1.81^{b-e}	1.71^{b-e}
$L_{1.41}$P20	1.57	1.34	1.38^{ef}	1.71^{a-d}	2.16^{a-d}	1.63^{c-e}
$L_{1.41}$P30	1.57	1.47	2.05^{ab}	1.78^{a-d}	2.17^{a-d}	1.81^{a-c}
$L_{2.82}$ P0	1.43	1.28	0.57^{h}	0.73^{g}	1.21^{f-h}	1.05^{fg}
$L_{2.82}$P10	1.89	1.64	1.69^{b-e}	1.21^{ef}	1.78^{b-e}	1.64^{c-e}
$L_{2.82}$P20	1.68	1.28	1.86^{a-d}	1.79^{a-d}	2.16^{a-d}	1.76^{a-e}
$L_{2.82}$P30	1.72	2.09	1.89^{a-d}	1.86^{a-c}	2.16^{a-d}	1.95^{ab}
$L_{4.23}$ P0	1.74	1.53	0.79^{gh}	0.67^{g}	1.02^{g-i}	1.15^{f}
$L_{4.23}$P10	1.55	1.49	1.59^{c-f}	1.40^{de}	1.53^{e}	1.51^{de}
$L_{4.23}$P20	1.76	1.21	2.09^{ab}	1.65^{a-d}	2.23^{a-c}	1.79^{a-d}
$L_{4.23}$P30	1.79	1.94	2.00^{a-c}	2.03^{a}	2.30^{a}	2.01^{a}
$L_{5.64}$P0	1.46	1.23	1.21^{fg}	0.68^{g}	0.91^{g-i}	1.10^{fg}
$L_{5.64}$P10	2.28	2.02	1.79^{a-e}	1.54^{b-e}	1.68^{d-f}	1.86^{a-c}
$L_{5.64}$P20	1.55	1.71	2.11^{ab}	1.90^{ab}	2.11^{a-d}	1.88^{a-c}
$L_{5.64}$P30	1.72	1.39	2.13^{a}	1.97^{a}	2.13 $^{a-d}$	1.87^{a-c}
LSD	NS	NS	0.44	0.41	0.49	0.29
CV	22.65	42.57	17.22	16.86	17.43	25.1

Means with in a column with the same letter (s) are not significantly different at 0.05 probability level. Ns=Not significantly different.
Source: Soil fertility and plant nutrient management proceeding, Ethiopian Institute of Agricultural Research (EIAR), 2018 ISBN: 978-99944-66-52-8.

3. Major Achievements

3.1. Lime and P Fertilizer for Maize and Soybean Production

At Hurumu the findings of experiments show that application of different levels of lime and P fertilizer revealed that individual year as well as combined over years brought about significant ($P \leq 0.05$) interaction effect on grain yield of maize due to different levels of lime and P fertilizer. As the level of P increases, grain yield of maize considerable increased. The observed increase in grain yield with increasing P rate, in non-limed confirmed that P was a limiting nutrient to maize production. Similar findings were reported [12].

According to Nekessa, [12] maize grain yields increased due to liming of the acid soils and improved nutrition of added N and P. However, there is no evidence that shows increasing in lime level increased grain yield of maize at Mettu (Hurumu). Generally at Mettu/ Hurumu, applications of 20 and 30 P kg $ha^{-1}$with and without lime gave significantly the high grain yield of maize as compared to the other treatments. However, it could be argued that application of lime for maize at Hurumu could not benefit the crop. Similar result was reported by Brown *et al*. [8]. The lack of yield response due to liming can probably be attributed to the anticipated high acid buffering capacity of the soil and rendering the lime application levels relatively ineffective [2]. Similarly, Hachalu *et al* (2012) showed that deficiency of P could be corrected thought liming acid soil to increase the pH more than 6 [1].

Similar experiment at the same location on soybean (2009-2013) revealed that, seed yield was influenced by the interaction of lime and phosphorus fertilizer. The highest and significant seed yield was obtained by application of 1.41, 2.82, 4.23 & 5.64 t lime ha^{-1} along with 30 kg P ha^{-1}; 2.82, 4.23 and 5.64 t lime ha^{-1} along with 20 kg P ha^{-1} and 5.64 t lime ha^{-1} along with 10 kg P ha^{-1}. So, this result indicated that liming improves availability of P for crops and also external P application improved crop performance. The result further indicate that applying phosphorus fertilizer increases crop growth and yield on soils which are naturally low in P and in soils that have been depleted [13].

3.2. Split Application of Lime

In Jimma/Doyo and Hurumu, responses of maize and soybean to split lime application was also investigated by Acid soil management team of JARC for five consecutive cropping seasons.. Accordingly, the results at Doyo showed that, split application of lime significantly affected maize and soybean yield at Doyo (Table 2). The results showed that application of lime into four equal split gave similar maize grain yield with splitting lime into two and three. This might be due to the less acidity of Doyo area. Result of this experiment revealed that splitting the required amount of lime into two and three for growing maize at this area. At the same location, split and full dose application gave almost similar soybean seed yield (Table 3). Therefore, resource poor farmers who cannot afford the price of full lime requirement at once can split in to two, three or even into four and apply every year without significant yield reduction for growing soybean.

Table 2. *Effect of split application of lime on maize grain yield (kg ha-1) at Doyo.*

Treatment	2009	2010	2011	2012	2013	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 (0.5)	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.

Table 3. *Effect of split application of lime on maize grain yield (kg ha-1) at Hurumu.*

Treatment	2009	2010	2011	2012	2013	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 (0.5)	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.

Table 4. *Effect of split application of lime on soybean seed yield (kg ha-1) at Doyo.*

Treatment	2009	2010	2011	2012	2013	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

Treatment	2009	2010	2011	2012	2013	Mean
50% every year	1848	1694	2275a	1880	2108	1961a
Full dose	1944	1780	2286a	1850	2408	2054a
LSD (0.5)	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.
Source: Soil fertility and plant nutrient management proceeding, Ethiopian Institute of Agricultural Research (EIAR), 2018 ISBN: 978-99944-66-52-8.

Similar to Doyo site, Hurumu soil was also responsive to split lime application (Tables 4 & 5). All splits gave statistically comparable maize and soybean yield with full dose of lime application. Therefore, depending on the availability of lime and affordability of maize and soybean growers, it is possible to use either of the above split application frequencies.

Table 5. *Effect of split application of lime on soybean seed yield (kg ha^{-1}) at Hurumu.*

Treatment	2009	2010	2011	2012	2013	Mean
Control	1382b	1530	1344b	1436b	2077	1554b
25% every year	1421b	1539	1953a	1766ab	2390	1814ab
33% every year	1674ab	1631	2024a	1858a	2170	1871a
50% every year	1848ab	1709	2004a	1752ab	2327	1867ab
Full dose	1944a	1734	2050a	1727ab	2188	1929a
LSD (0.5)	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.
Source: Soil fertility and plant nutrient management proceeding, Ethiopian Institute of Agricultural Research (EIAR), 2018 ISBN: 978-99944-66-52-8.

3.3. Organic Fertilizer as Amendment for Acid Soil Amelioration

The use of farm yard manure (FYM) alone, compost alone, ½ compost + NP, FYM + lime, compost + lime and ½ compost + NP + lime significantly improved soil pH. This approach is important in reducing the acid forming effect of chemical fertilizers. Continuous addition of FYM along with NPK also increases the soil pH as compared to the use of NPK alone [14].

Table 6. *Effect of inorganic and organic fertilizers and lime on chemical properties of Acid soil.*

Treatment	pH	Exc. Acidity (Cmol kg-1)	Available P (mg kg-1)	CEC (Cmol kg-1)	OC (%)
Control	4.6c	3.4a	0.9bc	35.9a	1.5b
NP	4.6c	2.9ab	1.4a	27.1ab	1.8ab
FYM	4.8ab	2.5bc	1.1abc	29.0ab	1.9a
Compost	4.9a	1.6ed	1.2abc	34.1a	1.8a
½ (FYM+NP)	4.6c	3.0ab	1.2abc	33.3ab	1.7ab
½(compost+ NP)	4.8ab	2.0cde	1.4a	33.9a	1.7ab
FYM + Lime	4.8ab	2.3bc	0.9bc	30.3ab	1.8a
Compost + lime	5.0a	1.6e	1.4a	34.7a	1.9a
NP + lime	4.7bc	2.3bcd	1.1abc	23.1 b	1.9a
½ (FYM+NP) + Lime	4.7bc	2.6bc	1.1abc	28.4ab	1.9a
½ (compost+ NP + lime)	4.8ab	2.0cde	1.3ab	31.5ab	1.9a
LSD0.05	0.2	0.7	0.4	10.6	0.3
CV (%)	2.5	17.9	20.1	20.0	8.8

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

Organic fertiliser application has been reported to improve crop growth by supplying plant nutrients as well as improving soil physical, chemical, and biological properties [10]. Application of organic fertilizers along with recommended rates of chemical fertilizer increased the maize productivity to the maximum level, which might be due to the improvement in soil health i.e. microbial activity, pH, CEC, OM etc and release of organic acids that bind aluminum (Al) and iron (Fe), thereby reducing P fixation and increasing its availability [10].

Over year analysis indicated that recommended NP, 50% FYM + 50% NP, recommended NP + lime and 50% FYM + 50% NP +50% lime gave significantly (P≤ 0.05) superior grain yield of maize as compared to the other organic fertilizers. This could be due to the provision of readily available plant nutrients from chemical fertilizers. Application of organic fertilizers along with recommended rates of fertilizers increased the maize productivity to the maximum level, which might be due to the improvement in soil health i.e. microbial activity, pH, CEC, OM etc and release of organic acids that bind aluminum (Al) and iron (Fe), thereby reducing P fixation and increasing its availability [10]. This investigation suggests recommending the use of organic fertilizer alongside with lime and mineral fertilizers to increase maize yields. Similar results were reported by Verde *et al*. (2013) who found that the use of

manure together with lime and mineral fertilizers to increase soybean yields [14]. The high yields observed under combination of manure, NP fertilizer and lime application might be as a result of its ability for improving soil biological and physical properties which increase soil water retention and enhance nutrient uptake [8].

Nitrogen and Phosphorus Requirements of Maize under Limed Conditions of Acid Soils

Nitrogen and phosphorus requirement of maize was estimated after liming the soil. In this investigation different combinations of nitrogen and phosphorus significantly ($P < 0.05$) influenced grain yield of maize in 2011 and 2012 cropping seasons. There was no difference between 69/10, 46/20, 46/30 and 69/20 N/P Kg ha^{-1} combinations and they resulted in significantly higher yield than the control in 2011 at Jimma (Table 6). However, the yield of the crop grown in 20 and 30 kg P ha^{-1}combined with 46 and 69 kg N ha^{-1} resulted in better yield than other combinations. The significant increment of maize grain yield by the combined application of NP fertilizers along with lime, and to some extent, only N and P together with lime might show liming does not only enhance soil organic N and P mineralization in the experimental soils but it facilitates uptakes of the applied inorganic N and P fertilizers by the crop. Hachalu *et al*. (2012) also highlighted the possibility of increasing the crop yield by improving soil acidity through the application of lime, N and P fertilizers [1].

Table 7. *Grain yield of maize (kg ha^{-1}) as influenced by combinations of lime, organic and inorganic fertilizers at Jimma.*

Treatment	Grain yield (q ha^{-1})				
	2010	2011	2012	2013	Mean
Control	20.73d	17.64c	14.39d	26.22e	19.75f
Recommended NP	50.83a	36.51b	31.91a	38.20abc	39.36ba
100% FYM	25.27cd	25.62bc	15.64cd	29.89de	24.11ef
100% compost	31.98bcd	25.64bc	15.95cd	37.22bcd	27.70ed
½ (FYM+NP)	37.27bc	34.50b	28.41ab	43.95ab	36.03bac
½(compost+ NP)	33.19bcd	41.21ab	26.90abc	40.08ab	35.35bc
FYM + Lime	27.90bcd	27.45bc	16.26cd	31.63cde	25.81edf
Compost + lime	35.45bc	26.33bc	20.09bcd	41.73ab	30.90dc
NP + lime	35.69bc	52.96a	35.62a	43.35ab	41.91a
½ (FYM+NP) + Lime	39.18ab	32.02bc	29.54ab	44.56ab	36.33bac
½ (compost+ NP + lime)	33.73bcd	3613b	2632abc	45.38a	35.39bc
LSD0.05	13.33	16.39	11.68	8.15	6.41
CV (%)	23.19	29.73	28.89	12.48	13.84

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

Table 8. *Effect of nitrogen and phosphorus on maize yield (kg ha-1) under limed acid soil at Jimma in three consecutive seasons.*

N (kg ha-1)	P (kg ha-1)	Season			Mean
		2012	2013	2014	
0	0	2888c	2856e	2386	2710.0
23	10	4207abc	3227e	2615	3349.7
46	10	4218abc	3485e	3066	3589.7
69	10	5035ab	3718de	3239	3997.3
23	20	3902abc	4550bdc	2551	3667.7
46	20	5231ab	5477a	2958	4555.3
69	20	5331a	4416dc	3150	4299.0
23	30	3719bc	4483bdc	3369	3857.0
46	30	4701ab	4760abc	2670	4043.7
69	30	5244ab	5337ab	3249	4610.0
LSD (0.05)		1593	883	Ns	
CV (%)		20.87	12.16	20.99	

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

At Hurumu in Ilubabor, application of the highest dose of nitrogen and phosphorus, (P30 + N 69) Kg ha^{-1}, to the soil of gave the highest maize grain yield (Table 7). In this line, Tadesse *etal* (2012) reported an increase in maize grain yield in Wollega by the application of nitrogen and phosphorus fertilizers along with the use of 3 t ha^{-1} calcium Carbonate [1].

Table 9. *Effect of nitrogen and phosphorus on maize yield (kg ha-1) under limed condition at Hurumu.*

N (kg ha-1)	P (kg ha-1)	Season			Mean
		2012	2013	2014	
0	0	2075c	2850c	2630b	2740d
23	10	5390ab	4030a	3170b	4200bc
46	10	5790ab	3680bc	3380ab	4290bc
69	10	5810ab	4690ab	3310ab	4600bac

N (kg ha-1)	P (kg ha-1)	Season			Mean
		2012	2013	2014	
23	20	6390ab	4860a	3060b	4770a
46	20	5160b	3840bc	3150b	4050c
69	20	5780ab	4280ab	3320ab	4460bac
23	30	6540a	4240ab	3070b	4620bac
46	30	5780ab	4180ab	3640ab	4530bc
69	30	6230ab	4590ab	4360a	5060a
LSD (0.05)		124	103	107	68
CV (%)		12.94	14.52	18.92	14.79

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

Integrated Nutrient Management on Maize Grown on Acid Soils

A study on Integrated Nutrient Management of soil on maize showed that in South western Ethiopia showed that application of organic, inorganic fertilizers and lime significantly affected soil properties such as pH, exchangeable acidity, available phosphorus, organic carbon content and cation exchange capacity (Table 8). The use of farm yard manure (FYM) alone, compost alone, ½ compost + NP, FYM + lime, compost + lime and ½ compost + NP + lime significantly improved soil pH as compared to other treatments. It is well known that the organic manure and lime application in acid soil are increase the degree of base saturation and buffering capacity of the soil. This approach is important to reduce unfavorable effect of acid forming chemical fertilizers. The ameliorating effect of lime on soil acidity has been reported by Obiri-Nyarko [10]. Continuous addition of FYM along with NPK also increases the soil pH as compared to the use of NPK alone [10].

Table 10. *Effect of inorganic and organic fertilizers and lime on chemical properties of Acid soil.*

Treatment	pH	Exc. Acidity (Cmol kg-1)	Available P (mg kg-1)	CEC (Cmol kg-1)	OC (%)
Control	4.6c	3.4a	0.9bc	35.9a	1.5b
NP	4.6c	2.9ab	1.4a	27.1ab	1.8ab
FYM	4.8ab	2.5bc	1.1abc	29.0ab	1.9a
Compost	4.9a	1.6ed	1.2abc	34.1a	1.8a
½ (FYM+NP)	4.6c	3.0ab	1.2abc	33.3ab	1.7ab
½ (compost+ NP)	4.8ab	2.0cde	1.4a	33.9a	1.7ab
FYM + Lime	4.8ab	2.3bc	0.9bc	30.3ab	1.8a
Compost + lime	5.0a	1.6e	1.4a	34.7a	1.9a
NP + lime	4.7bc	2.3bcd	1.1abc	23.1 b	1.9a
½ (FYM+NP) + Lime	4.7bc	2.6bc	1.1abc	28.4ab	1.9a
½ (compost+ NP + lime)	4.8ab	2.0cde	1.3ab	31.5ab	1.9a
LSD0.05	0.2	0.7	0.4	10.6	0.3
CV (%)	2.5	17.9	20.1	20.0	8.8

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

Over year analysis indicated that recommended NP, 50% FYM + 50% NP, recommended NP + lime and 50% FYM + 50% NP +50% lime gave significantly (P≤ 0.05) superior grain yield of maize as compared to the other organic fertilizers. This could be due to the provision of readily available plant nutrients from chemical fertilizers. Application of organic fertilizers along with recommended rates of fertilizers increased the maize productivity to the maximum level, which might be due to the improvement in soil health i.e. microbial activity, pH, CEC, OM etc and release of organic acids that bind aluminum (Al) and iron (Fe), thereby reducing P fixation and increasing its availability [14]. this investigation suggests recommending the use of organic fertilizer alongside with lime and mineral fertilizers to increase maize yields. Similar results were reported by Verde *et al*. (2013) who found that the use of manure together with lime and mineral fertilizers to increase soybean yields [14]. The high yields observed under combination of manure, NP fertilizer and lime application might be as a result of its ability for improving soil biological and physical properties which increase soil water retention and enhance nutrient uptake [10].

Table 11. *Grain yield of maize (kg ha^{-1}) as influenced by combinations of lime, organic and inorganic fertilizers at Jimma.*

Treatment	Grain yield (q ha^{-1})				Mean
	2010	2011	2012	2013	
Control	20.73d	17.64c	14.39d	26.22e	19.75f
Recommended NP	50.83a	36.51b	31.91a	38.20abc	39.36ba
100% FYM	25.27cd	25.62bc	15.64cd	29.89de	24.11ef
100% compost	31.98bcd	25.64bc	15.95cd	37.22bcd	27.70ed

Treatment	Grain yield (q ha^{-1})				Mean
	2010	2011	2012	2013	
½ (FYM+NP)	37.27bc	34.50b	28.41ab	43.95ab	36.03bac
½(compost+ NP)	33.19bcd	41.21ab	26.90abc	40.08ab	35.35bc
FYM + Lime	27.90bcd	27.45bc	16.26cd	31.63cde	25.81edf
Compost + lime	35.45bc	26.33bc	20.09bcd	41.73ab	30.90dc
NP + lime	35.69bc	52.96a	35.62a	43.35ab	41.91a
½ (FYM+NP) + Lime	39.18ab	32.02bc	29.54ab	44.56ab	36.33bac
½ (compost+ NP + lime)	33.73bcd	3613b	2632abc	45.38a	35.39bc
LSD0.05	13.33	16.39	11.68	8.15	6.41
CV (%)	23.19	29.73	28.89	12.48	13.84

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

In acid soils, where P fixation is a problem application of FYM releases a range of organic acids that can form stable complexes with Al and Fe thereby blocking the P retention sites, and as a result, the availability and use efficiency of P is improved [2].

3.4. Screening Acid Tolerant Genotypes

3.4.1. Screening Common Bean for Acid Soil Tolerance

This study was conducted to identify common bean varieties that tolerate acid soil or soil of low pH. The results revealed that variety by amendment by location by season interaction was significant ($p<0.01$) for both grain yield and plant height. Varietal difference among common bean varieties under both lime amended and un amended acid soil conditions was observed from this study. The highest grain yield (1.989 t/ha) was obtained from SER 119 variety under lime and phosphorus treated treatment, while, the highest grain yield (1.043 t/ha) under un-limed soil conditions. The highest yield under un-limed condition, yield levels are still below the national average (1.59 t/ha), but the yield of SER 119 variety under limed condition is higher than the national average. In this context, SER 119 variety *was recommended* for those farmers who have the capacity to apply lime with phosphorus based on the yield performance at both locations (Jimma and Mettu).

Results from several studies revealed genotypic variability in plant growth, physiology, and quality in response to aluminum application [9].

Table 12. *Over year and amendment combined mean value of grain yield (Kg/ha) of fifteen common bean varieties at individual location.*

Varieties	Mettu	Jimma	Combined
SER 119	1483.3^{a}	1392.6^{ab}	1438.0^{a}
SER 125	1276.9^{abc}	1358.4^{abc}	1317.7^{ab}
Naser	1421.3^{ab}	1158.7^{cd}	1290.0^{ab}
Ayenew	1194.0^{abcd}	1360.4^{abc}	1277.2^{ab}
Dimtu	1021^{cdef}	1350.9^{abc}	1185.9^{bc}
Gofat	1233.3^{abcd}	1089.6^{de}	1161.5^{bc}
Melka	1231.4^{abcd}	1062.6^{de}	1147.0^{bc}
Roba	1093.6^{bcdef}	1182.8^{bcd}	1138.2^{bc}
Bashbash	838.3^{efg}	1415.8^{a}	1127.1^{bc}
GLP 2	1155.1^{abcde}	1078.9^{de}	1117.0^{bcd}
Awash -1	1324.2^{abc}	743.2^{f}	1033.7^{cde}
Dame	905.6^{defg}	938.6^{ef}	922.1^{efg}
Iboda	928.1^{defg}	785.1^{f}	856.6^{efg}
Goberasha	810^{fg}	781.7^{f}	795.9^{fg}
Awash Melka	643.3^{g}	783.4^{f}	713.4^{g}
Mean	1103.956	1098.872	1101.414
Level significant	**	**	**
LSD	331.07	219.38	207.47
CV	17.93	11.94	11.26

Where, CV=coefficient of variation, LSD=list significant different, Note: Means with the same letters are statistically not significant ($p>0.05$) different from each other.

Table 13. *Over year combined mean value of grain yield (Kg/ha) of fifteen common bean varieties at individual location under different amendments.*

Varieties	Mettu		Jimma		Combined	
	C	LP	C	LP	C	LP
SER 119	535.1	2431.6^{a}	1238.1^{abc}	1547.2^{a}	886.6^{abc}	1989.4^{a}
SER 125	598.3^{bc}	1955.5^{bc}	1311.3^{ab}	1405.6^{abc}	954.8^{abc}	1680.6^{bc}
Naser	786.8^{abc}	2055.8^{ab}	965.2^{cdef}	1352.2^{abcd}	876.6^{abc}	1704^{b}
Ayenew	712.6^{bc}	1675.4^{cdef}	1211.3^{abcd}	1509.5^{ab}	962^{abc}	1592.5^{bcd}
Dimtu	714.7^{bc}	1327.2^{efg}	1371.9^{a}	1329.9^{abcd}	1043.3^{a}	1328.6^{efg}
Gofat	568.5^{c}	1898.0^{bcd}	947.2^{cdef}	1232.1^{bcd}	757.8^{cde}	1565.1^{bcde}
Melka	971.1^{ab}	1491.8^{defg}	1058.1^{bcde}	1067.2^{def}	1014.6^{ab}	1279.5^{fgh}

Varieties	Mettu		Jimma		Combined	
	C	LP	C	LP	C	LP
Roba	485^{c}	1702.3^{bcde}	1191.4^{abcd}	1174.3^{cde}	838.2^{abc}	1438.3^{cdef}
Bashbash	443.1^{c}	1233.5^{fgh}	1461.8^{a}	1369.8^{abc}	952.4^{abc}	1301.7^{fg}
GLP 2	689.8^{bc}	1620.3^{cdef}	918.9^{def}	1238.9^{bcd}	804.3^{bcd}	1429.6^{def}
Awash -1	1147.7^{a}	1500.8^{defg}	704.5^{f}	781.8^{f}	926.1^{abc}	1141.3^{ghi}
Dame	690.1^{bc}	1121^{gh}	992^{cdef}	885.3^{ef}	841.1^{abc}	1003.1^{ij}
Iboda	440.6^{c}	1415.6^{efg}	712.5^{f}	857.6^{f}	576.6^{de}	1136.6^{ghi}
Goberasha	391.8^{c}	1228.3^{fgh}	690.6^{f}	872.9^{f}	541.2^{e}	1050.6^{hij}
Awash Melka	397.6^{c}	889^{h}	779.3^{ef}	787.6^{f}	588.4^{de}	838.3^{j}
Mean	638.25	1569.74	1036.94	1160.799	837.566	1365.38
Level of significant	*	**	*	**	**	**
LSD	397.55	427.07	304.85	291.75	233.9	249.41
CV	37.246	16.266	17.577	15.027	16.77	10.9223

Where, C=control, LP=Lime with phosphorus treated, CV=coefficient of variation, LSD=list significant different, Note: Means with the same letters are statistically not significant (p>0.05) different from each other.

3.4.2. Screening of Soybean for Acid Soil Tolerance

Similar to common bean, screening of soybean for its acid soil tolerance was conducted to assess the response of soybean genotypes to lime and phosphorus for yield and to identify soybean genotypes that tolerate low pH soil. The result revealed that genotype by amendment interaction was significant ($p<0.01$) for plant height and yields. The maximum grain yields (2620, 2083 and 1415 and 2047.2 kg ha^{-1}) were obtained under un-limed soil conditions at Jimma, Haru and Mettu respectively from HAWASSA-04, and 2000 Kg/ha from combined analysis under control soil condition from HAWASSA-04 variety. The tolerance index value indicated that variety HAWASSA-04 performed well for grain yield and selected as tolerant. The result also verified that application of lime and phosphorus improved grain yield of soybean genotypes. In conclusion, observation of large variation indicates that selection would be effective to improve soybean genotypes performance on acid soils and identify low phosphorus tolerant genotype that helps smallholder farmers optimize soybean productivity on acid soils in the study area. HAWASSA-04 variety is the most tolerant among the tested materials. Therefore for resource-poor farmers who have no capacity to afford high rates of lime and phosphorus fertilizers, HAWASSA-04 variety is recommended to be used alternatively with clarck-63. However, further screening of large mass of genotypes is important as few genotypes were included the present study.

Studying responses of selected genotypes with contrasting tolerance to aluminum toxicity may help in generating information that could be utilized by breeding programs aimed at developing aluminum-tolerant cultivars for areas where aluminum-induced soil acidity remains a key environmental constraint to crop production [8].

Table 14. *Tolerance and susceptibility index of common bean varieties for yield at individual locations and combined on acid soil.*

Locations	Jimma		Mettu	Combined	
Varieties	TI	SI	TI	TI	SI
Bashbash	1.853^{a}	-0.070^{ab}	1.353	1.77^{a-d}	0.270^{cd}
SER 119	1.777^{ab}	0.1970^{ab}	3.23^{a-d}	2.513^{a}	0.150^{d}
Ayenew	1.74^{ab}	0.210^{ab}	3.17^{a-d}	2.270^{abc}	0.41^{abc}
SER 125	1.693^{ab}	0.020^{ab}	2.97^{a-d}	2.29^{ab}	0.43^{abc}
Dimtu	1.67^{abc}	-0.063^{ab}	2.42^{a-e}	1.990^{a-d}	0.203^{d}
Roba	1.31^{bcd}	-0.010^{ab}	2.103^{b-e}	1.750^{bcd}	0.42^{abc}
Naser	1.217^{cde}	0.280^{a}	4.017^{ab}	2.123^{abc}	0.483^{ab}
Gofat	1.08^{de}	0.270^{ab}	2.81^{a-e}	1.703^{bcd}	0.527^{a}
Melka	1.06^{de}	0.013^{ab}	3.527^{abc}	1.85^{a-d}	0.203^{d}
GLP 2	1.057^{def}	0.243^{ab}	2.77a-e	1.647^{b-e}	0.447^{abc}
Dame	0.82^{efg}	-0.137b	2.00^{b-e}	1.230^{d-g}	0.170^{d}
Iboda	0.58^{fg}	0.183^{ab}	1.67^{cde}	0.933^{efg}	0.487^{a}
Awash Melka	0.560^{g}	-0.030^{ab}	0.84^{e}	0.703^{g}	0.293^{bcd}
Goberasha	0.557^{g}	0.1830^{ab}	1.23^{de}	0.81^{fg}	0.473^{ab}
Awash -1	0.520^{g}	0.070^{ab}	4.24^{a}	1.517^{c-f}	0.550^{a}
Mean	1.165	0.085	2.53	1.673	0.366
Level significant	**	NS	*	*	**
LSD	0.47	0.3819	2.0184	0.7656	0.1911
CV	24.51	26.9	47.88	27.44	31.29

Where, TI=tolerance index, SI=Susceptibility index, CV=coefficient of variation, LSD=list significant different, Note: Means with the same letters are statistically not significant (p>0.05) different from each other.

Table 15. *Mean values of grain yields as affected by interaction of amendments, genotypes, year and locations.*

Genotypes	Loc	Year 1 (2017)				Year 2 (2018)			
		L	Control	P	LP	L	Control	P	LP
	Jimma	21.33	20.33	21.00	22.00	33.33	29.30	30.30	30.30
JM-ALM/H3-15-SC-1	Haru					16.33	16.33	18.67	18.67
	Metu	6.33	6.330	11.33	12.00	6.670	9.670	14.33	11.00
	Jimma	15.0	15.67	20.33	20.33	30.30	27.00	33.00	31.30
JMALM/PR142-15-SC	Haru					18.67	16.33	18.67	21.00
	Metu	12.0	11.00	16.33	18.33	9.330	9.670	19.67	16.67
	Jimma	21.0	20.33	27.67	25.70	31.00	29.00	33.00	31.30
JM-H3/SCS-15-SG	Haru					21.00	16.33	18.67	21.00
	Metu	9.670	11.00	13.33	14.33	8.000	9.000	15.00	13.33
	Jimma	21.67	23.3	30.0	26.00	30.00	29.00	32.70	31.00
HAWASSA-04	Haru					23.30	21.00	23.30	25.70
	Metu	16.0	15.67	21.33	20.67	11.33	13.00	21.00	17.67
	Jimma	24.0	23.70	30.30	28.30	27.70	29.00	32.00	30.70
PI423958	Haru					16.33	9.330	9.330	18.67
	Metu	7.00	5.33	15.33	19.67	14.00	16.67	23.00	19.33
	Jimma	20.0	18.67	23.00	23.00	29.30	28.30	31.30	28.70
BRS268	Haru					21.00	18.67	23.30	23.30
	Metu	11.33	13.33	14.33	13.00	10.67	12.33	15.67	13.33
	Jimma	22.70	26.30	21.00	26.30	29.70	29.70	28.70	31.30
JM-HAR/DAV-15-SA	Haru					21.00	18.67	25.70	23.30
	Metu	7.00	6.670	12.67	18.33	7.000	12.33	16.00	12.30
	Jimma	20.33	19.67	23.70	21.67	29.70	29.70	31.00	31.00
SCS-1	Haru					18.67	18.67	16.33	21.00
	Metu	6.33	5.33	9.33	12.00	5.330	7.000	14.67	10.67
	Jimma	19.0	19.0	20.00	21.67	30.30	29.70	30.30	30.00
JM-CLK/CRFD-15-SA	Haru					21.00	16.33	21.00	23.30
	Metu	9.33	6.33	9.00	13.67	6.000	11.00	13.67	11.33
	Jimma	22.0	21.33	24.7	23.00	25.70	28.00	28.70	30.00
JM-DAV/PR142-15-SA	Haru					11.67	11.67	18.67	21.00
	Metu	9.33	9.330	8.670	10.67	4.000	7.670	14.00	6.00
	Jimma	15.00	16.00	20.67	18.33	29.00	23.30	25.30	21.67
H-7	Haru					14.00	11.67	16.33	23.30
	Metu	8.00	8.33	12.00	15.00	7.330	11.00	15.33	15.00
	Jimma	23.3	20.33	28.00	25.70	25.00	24.70	23.30	21.67
JM-PR142/H3-15-SB	Haru					23.30	16.33	23.30	28.00
	Metu	13.33	10.33	15.00	16.67	7.000	10.00	18.33	15.00
	Jimma	21.33	21.67	25.00	21.33	22.7	23.3	26.30	24.00
JM-CLK/G99-15-SB	Haru					21.00	11.67	14.00	25.70
	Metu	10.67	7.67	9.00	11.33	4.67	8.33	10.33	10.67
	Jimma	20.67	22.00	24.7	22.3	24.3	23.7	24.00	24.30
JM-CLK/G99-15-SC	Haru					16.33	9.33	14.00	18.67
	Metu	7.670	8.33	11.67	11.33	4.33	8.00	10.67	7.67
	Jimma	17.67	16.00	19.67	16.33	13.67	15.33	14.67	15.33
PI567046A	Haru					9.33	9.33	11.67	16.33
	Metu	19.33	10.67	15.33	20.67	13.67	10.67	16.00	15.33
Mean		18.25							
CV		17.67							

Where, L=recommended lime alone, p=recommended phosphorus alone, LP=both recommended lime and phosphorus treated, LSD=list significant different, Loc=location, CV=coefficient of variation.

Table 16. *Combined mean grain yield of genotypes over locations and years with their corresponding ranks under control soil conditions.*

Nº.	Genotypes, varieties and lines	Yield (quintal/ha)	Rank
1	HAWASSA-04	20.24	1st
2	JM-HAR/DAV-15-SA	18.36	2nd
3	BRS-268	17.88	3rd
4.	JM-H3/SCS-15-SG	16.89	4th
5.	JM-PR142/H3-15-SB	16.17	5th

Table 17. *Tolerance index of soybean genotypes for yield and plant height at individual locations on acid soil.*

Locations	**Jimma**		**Mettu**		**Haru**	
Genotypes	Yield	Plant height	Yield	Plant height	Yield	Plant height
JM-HAR/DAV-15-SA	1.460^{a}	1.217^{bc}	1.55^{ef}	1.047^{de}	2.02^{abc}	0.997^{ef}
PI423958	1.437^{a}	1.210^{bc}	2.25^{b}	0.933^{e}	0.7467^{d}	0.513^{g}
HAWASSA-04	1.40^{ab}	1.247^{bc}	2.83^{a}	1.48^{b}	2.477^{a}	1.170^{de}
JM-H3/SCS-15-SG	1.290^{abc}	1.287^{b}	1.47^{f}	1.413^{b}	1.573^{abcd}	1.337^{d}
JM-ALM/H3-15-SC-1	1.18^{bcd}	0.950^{d}	1.0^{gh}	1.10^{cd}	1.423^{bcd}	1.14^{def}
JM-DAV/PR142-15-SA	1.177^{bcd}	0.580^{e}	0.757^{h}	0.783^{f}	1.123^{cd}	0.633^{g}
SCS-1	1.177^{bcd}	1.017^{cd}	0.747^{h}	1.09^{cd}	1.797^{abc}	1.277^{d}
JM-CLK/CRFD-15-SA	1.133^{bcde}	0.967^{d}	1.183^{g}	1.163^{c}	1.873^{abc}	1.280^{d}
BRS268	1.133^{cde}	1.420^{ab}	1.81^{cde}	1.45^{b}	2.02^{abc}	1.870^{b}
JMALM/PR142-15-SC	1.010^{cde}	0.830^{d}	1.947^{cd}	1.153^{c}	1.573^{abcd}	1.293^{d}
JM-CLK/G99-15-SC	0.990^{de}	0.950^{d}	0.790^{h}	1.093^{cd}	0.823^{d}	0.920^{f}
JM-PR142/H3-15-SB	0.990^{cd}	1.40^{ab}	1.687^{def}	1.38^{b}	2.097^{ab}	1.633^{c}
JM-CLK/G99-15-SB	0.937^{ef}	0.92^{d}	0.913^{gh}	1.07^{cd}	1.35^{bcd}	1.0167^{ef}
H-7	0.720f	0.56^{e}	1.48^{f}	0.68^{f}	1.273^{bcd}	0.610^{g}
PI567046A	0.453g	1.62^{a}	2.0367^{bc}	3.15^{a}	0.673^{d}	2.610^{a}
Mean	1.0944	1.076	1.149	1.265	1.522	1.219
LSD	0.2367	0.2239	0.285	0.1141	0.95	0.2298
CV	12.99	12.44	11.41	5.393	37.39	11.27

Where, CV=coefficient of variation, LSD=list significant different, Note: Means with the same letters are statistically not significant ($p>0.05$) different from each other.

4. Conclusion

More than ten-twenty years of efforts in soil acid soil management practices for annual crops production is reviewed. In this document, the annual crops refer to maize, soybean and common bean. I highlighted a wide range of soil acidity management practices such as using liming, organic amendment, using acid tolerant variety, integrated lime with organic, lime with inorganic and integrated soil fertility management. Infertile soils and acid soils are similar in most cases and hence their managements also similar. They are major constraint in crop production. The 33: 33: 33 combinations of lime: vermi-compost and chemical P fertilizer resulted in similar grain and biomass yield of maize with recommended chemical fertilizer. Strong acid soils (>5.5 in pH) should be amended with lime before fertilizer use. The practice of liming acid soils to mitigate soil acidity has been recognized for optimal crop production in acid soils of Jimma area. Liming should be coupled with the applications of optimum rates of inorganic and organic fertilizers, particularly P fertilizers. Using organic fertilizer can also be considered as an option for reclaiming acid soil. Overall, liming should be considered as a soil amendment to raise soil pH to the level that is suitable for maximum nutrient availability, plant growth, and crop yield. For a long term solution, identifying acid soil tolerant genotypes is an important practices and Hawassa 04 genotype is an example in that it is acid soil tolerant genotype.

Crops differ widely in their ability to tolerate acid soil conditions. These differences provide a good possibility for selection and breeding plants for improved tolerance to soil acidity, a low cost and effective alternative to the high cost of amending acid soil using lime. In general, the integrated use of all the available resources including acid tolerant crops and crop species, which improve and sustain soil and agricultural productivity, is of great practical significance. Overall, acid soil management needs to emphasize strategic research, integrating soil and water management with improved crop varieties and environmentally benign technologies for sustained food production within a framework of appropriate socio-economic and policy considerations.

Competing Interests

The authors declare that they have no competing interests.

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