International Journal of Plant & Soil Science

19(2): 1-16, 2017; Article no.IJPSS.35915
ISSN: 2320-7035

Effects of Lime, Mineral P, Farmyard Manure and Compost on Selected Chemical Properties of Acid Soils in Lay Gayint District, Northwestern Highlands of Ethiopia

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Authors' contributions

This work was carried out in collaboration between all authors. Author EF designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors KK and AM managed the analyses and interpretations of the study. Author BB managed the literature searches. Authors BY and BBM edited the manuscript. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/IJPSS/2017/35915
Editor(s):
(1) Nasima Junejo, Department of Forest Production, Faculty of Forestry, Universiti Putra Malaysia, Selangor, Malaysia.
Reviewers:
(1) Ade Onanuga, Dalhousie University, Canada.
(2) Benjamin A. Osei, University of Cape, Ghana.
Complete Peer review History: http://www.sciencedomain.org/review-history/21311

Original Research Article

Received 2nd August 2017
Accepted 5th October 2017
Published 10th October 2017

ABSTRACT

Aim: To evaluate the effects of sole and combined applications of lime, mineral P, Farmyard manure, and compost on selected chemical properties of acid soils of Lay Gayint District after 20, 40, and 60 days of incubation under greenhouse conditions.
Study Design: The treatment consisted of fifteen treatments (lime, mineral P, FYM, compost, and their combinations) arranged in a completely randomized design (CRD) in three replications.
Place and Duration of the Study: The study was conducted in Amhara Agricultural Research

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Institute greenhouse in 2015 cropping season.
Methodology: Treatments (lime, mineral P, FYM, and compost) were applied in sole and combination to acid soils collected from cultivated lands. After application, the soils were incubated for 20, 40, and 60 days to evaluate the effects of the applied treatments on selected soil chemical properties.
Results: The treatment combinations raised the soil pH significantly ($P < 0.001$) at the 40 days of incubation. All the treatments showed increased P availability with increasing time of incubation. Maximum available P was observed at the 60 days of incubation due to application of 8 t FYM ha^{-1} + 30 kg P ha^{-1} + 5 t lime ha^{-1} followed by 8 t compost ha^{-1} + 30 kg P ha^{-1} + 5 t lime ha^{-1}. Exchangeable acidity and Al^{3+} were reduced significantly ($P < 0.001$) at the 40 and 60 days of incubation with the application of 30 kg P ha^{-1} + 10 t lime ha^{-1} followed by 4 t FYM or compost ha^{-1} + 15 kg P ha^{-1} + 10 t lime ha^{-1}. The highest exchangeable Ca^{2+} was obtained at 20 days of incubation with the application of 30 kg P ha^{-1} + 10 t lime ha^{-1} followed by 4 t ha^{-1} FYM + 15 kg P ha^{-1} + 10 t lime ha^{-1}. Sole addition of 10 t lime ha^{-1} increased effective cation exchange capacity (ECEC) from 17.59 to 22.09 $cmol_c$ kg^{-1} at the 40 days of incubation. Likewise, combined applications of 30 kg P ha^{-1} + 10 t lime ha^{-1} followed by 4 t FYM ha^{-1} + 15 kg P ha^{-1} + 10 t lime ha^{-1} improved ECEC of the soil from 17.59 to 23.95 and 22.97 $cmol_c$ kg^{-1}, respectively at the 40 days of incubation.
Conclusion: Integrated applications of organic and inorganic amendments were found to be more effective in reducing soil acidity and Al^{3+} concentration while increasing the fertility of the soil.

Keywords: Soil pH; exchangeable acidity; cation ratio; organic amendment.

1. INTRODUCTION

Soil acidity covers a significant part of at least 48 developing countries located mainly in tropical areas, being more frequent in Oxisols and Ultisols in South America and in Oxisols in Africa [1]. Soil acidity is a critical issue requiring urgent attention in most highlands of Ethiopia due to its impact on crop production and productivity [2]. Recent studies have also indicated that soil acidity affects large areas of the cultivated lands in different parts of Ethiopia [3].

Most acid soils have been found to be low in fertility, with poor chemical and biological properties. Strongly acid soil is associated with Al, H, Fe, and Mn toxicities to plant roots in the soil solutions and deficiencies of the available P, Mo, Ca, Mg and K [4]. Aluminum toxicity primarily affects the root apex [5]. Exposure to Al causes stunting of the primary root and inhibition of lateral root formation [6]. The result of restricted root system impaired nutrient and water uptake, making the plant more susceptible to drought stress [7,8]. Among biological properties, activities of beneficial microorganisms are affected by adverse soil acidity, since in normal soils, these microbes might have profound effects on decomposition of organic matter (OM), nutrient mineralization, immobilization, uptake, and utilization by plants and consequently affect crop yields [9]. Where management strategies have not been put in place, crop yields are critically limited under such conditions.

Several practices have been recommended to reclaim acidity and upgrade the productivity of strongly acid soils. These include the cultivation of acid tolerant plants, covering the surface with non-acid soil, the use of organic fertilizers, and liming. Of these practices, liming and the application of organic fertilizers are generally considered to be the best measures, because their effects are more persistent [10]. However, the high cost of fertilizers and lime, and unsustainable crop production calls for the use of locally available low cost organic sources such as manures, green manures, and biofertilizers along with inorganics in a synergistic manner for sustainable production and to maintain soil health [11]. Lime in the form of calcium carbonate or dolomite is applied to acid soils to increase the pH, Ca concentration, CEC and base saturation, and to minimize Al and Mn toxicity and P fixation [12-15]. Another research indicated that liming can increase, decrease, or have no effect on P availability [16]. However, recent studies [3,17,18] indicated a significant increase in Olsen P due to liming of acid soils. To get maximum benefits from liming or for improving crop yields, liming materials should be applied before sowing of crops and thoroughly mixed into the soil to enhance its reaction with soil exchange acidity [9].

Addition of manure and compost to acid soils is potentially a feasible approach for increasing soil pH, decreasing concentrations of Al, and reducing lime requirements [17,19-22].

Enhancing P availability is possible through the combined use of animal manures, plant residues, and green manures with mineral P fertilizers in low-P acid soils [21,23]. Organic materials supplement P and increase the efficiency of applied fertilizer P by chelating soil Fe and Al by organic acids released upon decomposition [24]. Numerous studies reported that application of OM like compost and manures provide nutrients and improve the physical properties of soils [25]. The role of compost as a complimentary amendment for improving soil aggregation, increasing microbial biomass, improving moisture holding capacity, raising CEC and pH of soils has been recognized [26].

Although all these mentioned organic and inorganic amendments have significant contribution to reduce soil acidity and improve soil fertility and nutrient transfer, farming in the highlands of Ethiopia is characterized by low agricultural productivity as compared with developed countries due to progressive soil fertility decline over the years and inadequate applications of amendments. Some researchers have reported the effect of different rates of lime, FYM, wood ash, and P application on selected soil chemical properties [3,27,28]. However, the amount and the time of separate or combined applications of lime, manure, compost, and inorganic fertilizers applied to the soil and the chemical effects observed are not sufficiently investigated in different areas of Ethiopia.

Land productivity decline as a result of soil acidity and fertility depletion is a major problem facing smallholder farmers of Lay Gayint and other similar areas of the region. This decline primarily results from continuous cultivation and crop removal of nutrients, leaching of ions due to high amount of rainfall, and low OM use. Improved soil fertility and acidity management through the use of integrated organic and inorganic amendments enables efficient use of the inputs applied and increase agricultural productivity. However, manure or compost is used mostly on small plots that are located around the household's residence and the quantity of amendments and the time of application is not research based. Hence, this study was proposed with the objective of determining the effects of lime, mineral P, FYM and compost on selected soil chemical properties at different periods of incubation of cultivated acid soils at Lay Gayint district, in northwestern highlands of Ethiopia.

2. MATERIALS AND METHODS

2.1 Description of the Study Area

The study was conducted at Lay Gayint district of South Gondar Zone of the Amhara National Regional State (ANRS), Ethiopia. Lay Gayint district is located at about 175 km northeast of Bahir Dar, along the Woreta-Woldia highway. The district lies between the coordinates of 11°32'-12°16' N and 38°12'-38°19' E, and covers an estimated area of 1511 km^2. Altitude of Lay Gayint district varies between 1500 and 4235 meters above sea level (masl). Physiographically, the area is characterized by plain (10%), undulating (70%), mountainous (15%), and gorges and valleys (5%). The major land use patterns of the study area comprise of cultivated land (44%), grazing land (14%), forest/bush land (5%), water body (2%), infrastructure and settlement (6%), and unproductive land (29%). Agro-ecologically, the district is divided into four elevation and temperature zones, namely: lowland (*kolla*) (12.5%), midland (*woina-dega*) (39.42%), highland (*dega*) (45.39%), and *wurch* (very cold or alpine) (2.71%) [29]. Lay Gayint district receives a mean annual rainfall of 1020 mm. The main rainy season, which represents the long rainy season (*meher*), occurs between June and September, and the small rainy season (*belg*) occurs between March and May. The mean minimum and maximum air temperature of the district are 6.9 and 21.9°C, respectively [30]. Geologically, the study area is covered by loosely compacted tuff, boulders tuffs and normal light, fine grained tuff, and basalts of varying texture which changes laterally to pyroclasts erupted during Cenozoic Tertiary and mid to late Tertiary period in the Pliocene. The majority of the soils in Lay Gayint district include Luvisols, Leptosols, Regosols, and Cambisols. Most of the people in the district are engaged in mixed crop-livestock agriculture. The most commonly produced crops in the study area are annual crops such as, *Triticum aestivum* L., *Eragrostis tef* (Zuccagni), *Zea mays* L., *Sorghum bicolor* L., *Hordeum vulgare* L., *Cicer arietinum* L., *Vicia faba* L., *Phaseolus vulgaris* L., and *Solanum tuberosum* L. [29].

2.2 Soil Sampling and Preparation

Six cultivated lands from the high rainfall area in Lay Gayint district were selected. Eight surface soil sub-samples (0-20 cm depth) from each land were collected using auger and bulked to make one composite soil sample for soil pH determination in the field. Based on field soil pH test, strongly acid soils with pH < 5 were collected from 3 cultivated lands and bulked to make one composite sample for laboratory analysis. The surface soil samples collected from the study area were bagged, labeled, and transported to the laboratory for preparation and analysis of selected soil physicochemical properties. Similarly, bulk soil samples from these fields were collected using spade for greenhouse incubation experiment. Undisturbed soil samples were collected from the cultivated lands for determination of bulk density. A cylindrical metal core with volume of 100 cm^3 was pressed in to the soil until it is completely filled. The soil was trimmed at both ends with a knife and covered with a cap, labeled and packed in box.

The soil samples were air dried, crushed and made to pass through a 2 mm sieve size for analysis of soil pH, texture, available P, exchangeable bases, exchangeable acidity and Al^{3+}, and CEC whereas, for analysis of organic carbon (OC) and total N, samples were made to pass through 0.5 mm sieve size. The composite soil samples were analyzed based on standard laboratory procedures.

2.3 Laboratory Analysis of Soil Physical and Chemical Properties

Soil texture was determined using the Bouyoucos hydrometer method [31]. Bulk density (BD) was determined on the undisturbed soil sample using the core method, in which the samples were dried in an oven set at 105 °C to constant weight [32]. The oven dried weight was divided by the volume of the soil core to get the bulk density value. The pH of the soil was measured potentiometrically in the supernatant suspension of a 1:2.5 soil to water ratio using a pH meter as described by [33]. Organic carbon was determined using the wet oxidation method [34] where the carbon was oxidized under standard conditions with potassium dichromate ($K_2Cr_2O_7$) in sulfuric acid (H_2SO_4) solution. Total N was determined by the Kjeldahl method [35] while available P was extracted using the sodium bicarbonate solution [36]. The exchangeable cations (Ca^{2+}, Mg^{2+}, K^+ and Na^+) were extracted with 1 M ammonium acetate (NH_4OAc) solution at pH 7.0 [35]. Exchangeable Ca^{2+} and Mg^{2+} in the leachate were determined by atomic absorption spectrophotometer (AAS) while exchangeable K^+ and Na^+ were determined by flame photometry [37]. The potential cation exchange capacity (CEC) of the soil was determined from the NH_4^+ saturated samples that were subsequently replaced by K^+ using KCl solution. The excess salt was removed by washing with ethanol and the NH_4^+ that was displaced by K^+ was measured using the micro-Kjeldahl procedure and reported as CEC [38]. Total exchangeable acidity was determined by saturating the soil samples with 1 M KCl solution and was titrated with 0.02 M NaOH [37]. From the same extract, exchangeable Al^{3+} in the soil samples was determined by application of 1 M NaF, which forms a complex with Al and releases NaOH and then NaOH was back titrated with a standard solution of 0.02 M HCl as described by [39].

2.4 Manure, Compost, and Liming Material Analysis, and Lime Requirement Determination

The pH of manure and compost samples was measured in water (soil: solution ratio of 1:5) using a pH meter with a glass and reference calomel electrode after the suspension was shaken for 30 minutes and allowed to stand for 1 hour [40]. Total N content was determined by Kjedahl method as described by Jackson [35]. The organic carbon was determined by the wet oxidation method through chromic acid digestion [34]. Total P, K, Ca, Mg and Fe were determined following the wet digestion with H_2O_2/H_2SO_4 [41]. Total Ca, Mg, K and Na were determined by AAS and P was measured as described by [42]. The calcium carbonate equivalent (CCE) of the Dejen lime was determined by dissolving a graduated amount of lime with excess of standard 0.5 M HCl followed by boiling for 5 minutes. The excess acid was back titrated with standard 0.1 M NaOH solution using phenolphthalein as an indicator after filtration. From the amount of NaOH used to neutralize the excess acid of the blank and the filtrate, the CCE of the lime was calculated [43] as:

$$\% \, CaCO_3 = [(mlHCl * 1M) - (mlNaOH * 0.5\,M)] * \frac{Volume\ of\ HCl(100\ ml)}{Volume\ of filtratealiquote(10\ ml)} * \frac{100}{1000 * 2} * \frac{100\ g}{Weigt\ of\ soil\ g}$$

Lime requirement (LR) of the soil was determined by Shoemaker, McLean and Pratt (SMP) single buffer procedure [44], where triplicate dry soil samples each weighing one kg were thoroughly mixed with 0, 800, 1600, 2400, 3200, 4000 and 4800 mg of $CaCO_3$. Each soil sample weighing one kilogram was filled in polyethylene bags and mixed with the rate of lime to be tested. Then, the soil was mixed thoroughly and incubated under room temperature for a period of 30 days. The soil and the $CaCO_3$ were wetted with distilled water to maintain field capacity. Finally, soil samples were collected, dried and ground to pass through a 2 mm sieve and then the pH was measured. From the relationships between the amounts of $CaCO_3$ applied and the corresponding pH values, the level of $CaCO_3$ sufficient to raise the pH of the soils to 5.5 was selected as the lime requirement of the soils.

2.5 Incubation Study

Based on the pH and the LR, composite soil samples of the acid soils were selected for this experiment. The composite soil samples were air dried and passed through a 2 mm sieve and then placed separately in plastic containers and mixed with the different treatments in a laboratory. The treatments were lime, mineral P as triple super phosphate (TSP) fertilizer, FYM, and compost which were applied separately and in systematic combination at different rates (Table 1). Manure and compost, dried and allowed to pass through a 0.25 mm sieve, were added. Farmyard manure was collected from Abaregay dairy farm in Debretabor. Compost was prepared from wheat straw, manure, green leaves and thin layer of topsoil supplied with moisture and aeration conditions. The compost was turned once and kept in the pit for 3 months before the incubation experiment. The matured compost was observed to be dark, crumbly, and earthy-smelling substance with acceptable C: N ratio. Dejen lime was used as a liming material, which is calcitic with moisture content of 1.0562%, purity of 0.91 and fineness factor of 0.52 (27). Lime which passed through 50 and 100 mesh size was added based on the LR of the soil. The lime used for the experiments was found to have a CCE of 93.8%. A completely randomized design (CRD) was used and treatments were replicated three times. The study was conducted in plastic containers with 500 g of soil in each plastic container. Lime, mineral P fertilizer, manure and compost were incubated for two months in a greenhouse having a temperature 18°C and humidity of 51%. All pots were subjected to wetting and drying cycles every 3 days during the incubation period. Soil samples were drawn at 20, 40 and 60 days of the incubation period and then were air dried and sieved through a 2 mm sieve and used for analysis of soil pH, exchangeable acidity, exchangeable Al^{3+}, exchangeable bases, ECEC, and available P. The soil chemical analysis procedures outlined under Section 2.3 were employed for the analysis of these parameters. Effective cation exchange capacity was determined as the sum of exchangeable Ca^{2+}, Mg^{2+}, K+, and exchangeable acidity.

2.6 Statistical Analysis

The data obtained was subjected to analysis of variance (ANOVA) by using statistical analysis system (SAS) software package version 9.1 [45]. The Duncan's Multiple Range Test (DMRT) was employed to test the significant difference between means of treatments at 1 % probability level.

Table 1. List of treatments for incubation study

Treatments	Descriptions
Control	No lime, FYM, P and compost
Compost only	8 t ha^{-1}
FYM only	8 t ha^{-1}
P only	30 kg ha^{-1}
Lime only	10 t ha^{-1}
P + lime R	30 kg ha^{-1} + 10 t ha^{-1}
P + ½ lime	30 kg ha^{-1} + 5 t ha^{-1}
Compost + ½ lime	8 t ha^{-1} + 5 t ha^{-1}
FYM + ½ lime	8 t ha^{-1} + 5 t ha^{-1}
Compost + P + ½ lime	8 t ha^{-1} + 30 kg ha^{-1} + 5 t ha^{-1}
FYM + P + ½ lime	8 t ha^{-1} + 30 kg ha^{-1} + 5 t ha^{-1}
½ compost + ½ P + lime R	4 t ha^{-1} + 15 kg ha^{-1} + 10 t ha^{-1}
½ FYM + ½ P + lime R	4 t ha^{-1} + 15 kg ha^{-1} + 10 t ha^{-1}
½ compost + ½ P + ½ lime	4 t ha^{-1} + 15 kg ha^{-1} + 5 t ha^{-1}
½ FYM + ½ P + ½ lime	4 t ha^{-1} + 15 kg ha^{-1} + 5 t ha^{-1}

3. RESULTS AND DISCUSSION

3.1 Soil Fertility Status Prior to Experiment and Quality of Organic Amendments

Following the USDA [46] soil textural class triangle, the soil is clay in texture and the clay separate is the dominant one (Table 2). The soil bulk density value was below the critical value of 1.4 g cm^{-3} for a clay texture to restrict root growth [47]. The soil was very strongly acidic in reaction [47]. The exchangeable soil acidity (Al^{3+} + H^{+}) was 4.04 $cmol_c$ kg^{-1} soil. Under such soil acidity environment, crop growth is adversely affected due to the toxicity of Al on plant roots, reduced availability of P, and microbial activity such as atmospheric N_2 fixation, and OM decomposition [4, 9]. The available P falls within the low range (6-10 mg kg^{-1}) for clay soils [48] and, therefore, indicates the need for applying supplemental P in these soils.

Table 2. Selected physical and chemical properties of the experimental soil

Parameter	Value
Sand (%)	19
Silt (%)	36
Clay (%)	45
Textural class	clay
Bulk density (g cm^{-3})	1.3
pH (H_2O)	4.93
Exchangeable Ca^{2+} ($cmol_c$ kg^{-1})	9.98
Exchangeable Mg^{2+} ($cmol_c$ kg^{-1})	4.26
Exchangeable K^{+} ($cmol_c$ kg^{-1})	0.45
Exchangeable Na^{+} ($cmol_c$ kg^{-1})	0.38
Cation exchange capacity ($cmol_c$ kg^{-1})	33.7
Exchangeable acidity ($cmol_c$ kg^{-1})	4.04
Exchangeable Al^{3+} ($cmol_c$ kg^{-1})	1.77
Organic carbon (%)	1.27
Total nitrogen (%)	0.19
Olsen P (mg kg^{-1})	5.87

Exchangeable Ca^{2+} and K^{+} were in the range of moderate, while exchangeable Mg^{2+} and Na^{+} were in the range of high and low, respectively in the soil [47]. The high amount of exchangeable Mg^{2+} could be attributed to the presence of Mg bearing minerals in the area, that gradually release from the mineral structure. The moderate range of exchangeable K^{+} indicates that supplemental K fertilization is required based on the types and varieties of crops grown in the area. The CEC of the soil was 33.70 $cmol_c$ kg^{-1} soil. The soils at the experimental site had moderate organic C (1.27%) and total N (0.19%) [49]. The result of LR determination indicated that the amount of lime required to raise the pH of the soils to the target pH value, which was 5.5, was 10 t $CaCO_3$ ha^{-1}. Since the soil has high clay content and CEC and thus high buffering capacity, high amount of lime was required to alleviate acidity and increase the productivity of acid sensitive crops.

The result of analysis of FYM and compost are indicated in Table 3. The composting materials used such as grass clippings, leaves and wheat straw were rich in C and thus had lower N added to the soil. The total C contents were 13.87 and 18.41% with a corresponding C: N ratio of 12.5 and 20.2 for FYM and compost, respectively. The ideal range of C: N in compost is 15:1-35:1 [50].

3.2 Effects of Organic and Inorganic Amendments on Soil pH and Available P

Soil pH was significantly ($P < 0.001$) increased with single or combined applications of the treatments except sole P (Table 4). Soil pH improvement was observed between the 20 and 40 days of incubation after which it declined for some of the treatments (Table 4). Application of 30 kg P ha^{-1} + 10 t lime ha^{-1} followed by 4 t FYM ha^{-1} + 15 kg P ha^{-1} + 10 t lime ha^{-1} showed a marked increase in pH at the 20 and 40 days of incubation and a decrease at 60 days of incubation. The results of the sole application of the treatments indicate that the effect of lime in reducing the level of soil acidity was more immediate and considerable as compared with the other treatments (Table 4). Although increasing the lime rate from 5 to 10 t ha^{-1} in the combination showed a linear increase in soil pH, combined application of half FYM or compost with half lime and P could be sufficient to improve soil pH to a level where soil acidity is reduced and nutrient availability is increased. Unlike the gradual change in pH due to FYM or compost application observed in this study, an immediate increase in the pH of acid soils after application of fresh cattle manure, and persistent increase during 60 days of incubation of soil manure mixtures was reported by [51]. The high initial pH, exchangeable bases, and proton consumption capacity might have contributed to the rise in pH of FYM or compost amended soils [52]. Similar effect on soil pH after manure or compost applications was reported [53]. It has been also suggested that changes in the pH of soils amended with cattle manure could be explained by the release of NH_3 from organic N mineralization [52]. Another justification could be due to the buffering of carbonates and bicarbonates and other compounds, such as organic compounds with carboxyl and phenolic hydroxyl functional groups, which consume proton and control the variation of pH in soils and their ability of buffering to neutralize soil acidity [19,54].

In the case of lime, the increase in soil moisture causes the dissociation of the carbonates of Ca at the end of the reaction and, the release of OH^- ions in the solution, which increases soil pH [55, 56]. The pH decline after 40 days of incubation could be attributed to the H^+ produced during the conversion of organic N and S to NO_3^- and SO_4^{2-}, respectively [57]. However, under field conditions much nitrate produced would be absorbed by growing plants leading to the release of OH^- ions that can neutralize soil acidity [58].

Application of organic and inorganic amendments significantly (P < 0.001) improved available P at various periods of incubation over the control (Table 4). All treatments showed increased P availability consistently with increasing time of incubation. Maximum available P was observed at the 60 days of incubation due to application of 8 t FYM ha^{-1} + 30 kg P ha^{-1} + 5 t lime ha^{-1}, with an increase of 70%, over the control. On the other hand, sole addition of 30 kg P ha^{-1} increased available P by 52%, over the control at the 60 days of incubation. The increased availability of P with time due to application of FYM or compost separately or in combination could be the result of gradual mineralization of OM [59] and the release of organic acids that bound with Al and decrease P fixation [60].

Table 3. Chemical characteristics of FYM and compost

Amendment	pH-H_2O (1:5)	N	C	P	Ca	K	Mg	Na
		---------------------------(%)---------------------------						
Farmyard manure	7.6	1.11	13.87	0.31	1.52	1.51	0.72	0.14
Compost	7.2	0.91	18.40	0.29	1.43	1.63	0.59	0.15

Table 4. Effects of organic and inorganic amendments on soil pH and available P

Treatments	20 days	40 days	60 days	20 days	40 days	60 days
	Soil pH			Available P (mg kg^{-1})		
Control	4.85m	4.87lm	4.95lm	5.87l	6.27kl	6.76f-l
8 t compost ha^{-1}	5.21lm	5.21lm	5.36kl	6.60 jkl	6.79i-l	9.27b-h
8 t FYM ha^{-1}	5.19lm	5.29klm	5.35klm	6.22 kl	6.54jkl	10.01a-e
30 kg P ha^{-1}	4.99lm	4.89lm	4.89klm	8.33 d-k	9.19b-h	10.28a-d
10 t lime ha^{-1}	5.99d-h	6.22b-e	6.11c-g	6.19 kl	7.61g-l	9.27b-h
30 kg P ha^{-1} + 10 t lime ha^{-1}	6.26bcd	6.59a	6.10c-g	10.33 a-d	9.40b-k	10.87a-d
30 kg P ha^{-1} + 5 t lime ha^{-1}	5.76hij	6.12c-g	5.93e-i	6.82 i-l	7.92e-l	10.12a-e
8 t compost ha^{-1} + 5 t lime ha^{-1}	5.87g-j	5.91f-i	5.56jk	7.46 h-l	7.69f-l	9.35a-h
8 t FYM ha^{-1} + 5 t lime ha^{-1}	5.91e-i	6.11c-g	5.89f-i	6.82 i-l	7.29h-l	9.21b-h
8 t compost ha^{-1} + 30 kg P ha^{-1} + 5 t lime ha^{-1}	5.94e-i	5.95d-i	5.87g-j	7.91 e-l	8.05e-l	11.10ab
8 t FYM ha^{-1} + 30 kg P ha^{-1} + 5 t lime ha^{-1}	5.91e-i	5.94e-i	5.79hij	9.45 a-h	10.05a-e	11.52a
4 t compost ha^{-1} + 15 kg P ha^{-1} + 10 t lime ha^{-1}	6.03c-h	6.32abc	6.03c-h	9.69 a-g	9.84a-f	10.43a-d
4 t FYM ha^{-1} + 15 kg P ha^{-1} + 10 t lime ha^{-1}	6.43ab	6.48ab	6.19b-f	8.81 c-i	8.91b-i	10.93abc
4 t compost ha^{-1} + 15 kg P ha^{-1} + 5 t lime ha^{-1}	5.56jk	5.91f-i	5.86g-j	6.72g-l	7.82f-l	8.80c-i
4 t FYM ha^{-1} + 15 kg P ha^{-1} + 5 t lime ha^{-1}	5.67ij	5.97d-i	5.75hij	6.23kl	8.66d-j	9.99a-e
CV (%)	3.32			11.75		

Means within a column followed by the same letter are not significantly different at P ≥ 0.001; CV = coefficient of variation

Net P mineralization would also be expected to occur because FYM had a higher P concentration (0.31%) than the critical level of 0.25% required for net P mineralization [61]. The presence of humic acid and fulvic acid on soil and oxide surfaces restrict subsequent P adsorption [19]. The observed earlier availability of the highest P with lime and P application might be due to the rapid neutralization of soil acidity and increased solubility of the applied TSP fertilizer. An increase in the available P content in strongly acid soils after liming was also recorded in other experiments [62]. Generally, incubation of all various combinations for 60 days, and incubation of 30 kg P ha^{-1} plus 10 t lime ha^{-1} for 20 days could improve the soil available P to the moderate range.

3.3 Effects of Organic and Inorganic Amendments on Exchangeable Acidity and Al^{3+}

Exchangeable acidity and Al^{3+} were affected significantly ($P < 0.001$) due to application of treatments and over incubation period (Table 5). Exchangeable acidity and Al^{3+} were reduced to the lowest level with the application of 30 kg P ha^{-1} + 10 t lime ha^{-1} followed by 4 t FYM or compost ha^{-1} + 15 kg P ha^{-1} + 10 t lime ha^{-1}. Statistically, application of 4 t FYM ha^{-1} + 15 kg P ha^{-1} + 5 t lime ha^{-1} was as effective as the above two treatments in reducing exchangeable acidity and Al^{3+}. Among the sole treatments, application of 10 t lime ha^{-1} reduced exchangeable acidity and Al^{3+} significantly over the control (Table 5). Considering the incubation period, application of all treatments consistently reduced exchangeable acidity and Al^{3+} with increasing time. The changes were significantly rapid at the 20 days of incubation with sole or the combined application of FYM, P and lime. When full or half rate of FYM, or compost was combined with half or full rate of lime in the treatment combinations, exchangeable Al^{3+} was reduced to the level of non toxicity at the 60 days of incubation, indicating that including organic amendments could reduce soil acidity but at a relatively slower rate. This might be ascribed to the time taken for complete decomposition of the applied OM.

Although both lime and FYM contributed in reducing exchangeable acidity and Al^{3+}, the changes observed were largely attributed to the applied lime. Because it was shown that, from the separate treatment applications, lime was found to be superior in reducing soil acidity. Application of lime tends to raise the soil pH and reduce acidity by displacement of H^{+}, Fe^{2+}, Al^{3+}, and Mn^{4+} ions from soil adsorption site [18]. Similarly, the presence of CO_3^{2-} and OH^{-} anions in lime neutralize the H^{+} released from the exchange sites and hydrolyzing Al species to the soil solution [9]. Increase in soil pH and exchangeable bases due to liming of acid soils, and the consequent reduction in the magnitude of exchangeable acidity and Al^{3+} saturation was reported by [18].

A significant change in soil pH from 4.6 to values above 5.6, and exchangeable acidity from 3.00 $cmol_c$ kg^{-1} to below 0.35 $cmol_c$ kg^{-1} due to application of manure was reported [15]. Another study conducted in acid soil in Kenya reported that application of FYM increased the soil pH and reduced the exchangeable acidity and Al^{3+} in the short term, but the inorganic P sources did not significantly affect these parameters [21]. Many studies have indicated that addition of OM to acid soils can reduce Al toxicity [63]. Organic matter reduces Al toxicity and its acidulating effect either by chelating or encapsulating the Al^{3+} [64]. An increase in soil pH due to manure application apparently results in precipitation of exchangeable and soluble Al^{3+} as insoluble Al hydroxides thus reducing the concentration of Al^{3+} in soil solution [15].

3.4 Effects of Organic and Inorganic Amendments on Exchangeable Bases

Exchangeable Ca^{2+} was significantly ($P < 0.001$) affected by organic and inorganic treatments and incubation period (Table 6). However, the effect of treatments on the other exchangeable bases was not significant ($P > 0.001$) (Table 6 and 7). The highest exchangeable Ca^{2+} was obtained at 20 days of incubation with the application of 30 kg P ha^{-1} + 10 t lime ha^{-1} followed by 4 t ha^{-1} FYM + 15 kg P ha^{-1} + 10 t lime ha^{-1}. Among the sole treatments, lime at the 20 days and FYM at the 60 days gave the highest exchangeable Ca^{2+}. Period of incubation did not show consistency for exchangeable Ca^{2+} and Mg^{2+}. In most of the treatments that have only lime or combinations having lime, exchangeable Ca^{2+} and Mg^{2+} showed antagonistic relationships. For example, applications of 10 t lime ha^{-1}, 30 kg P ha^{-1} + 10 t lime ha^{-1}, 8 t compost ha^{-1} + 5 t lime ha^{-1}, 8 t FYM ha^{-1} + 30 kg P ha^{-1} + 5 t ha^{-1} lime ha^{-1} brought about a decrease in exchangeable Ca^{2+} and an increase in exchangeable Mg^{2+} with increasing incubation period.

Table 5. Effects of organic and inorganic amendments on exchangeable acidity and Al^{3+}

Treatments	20 days	40 days	60 days	20 days	40 days	60 days
	Ex acidity ($cmol_c\ kg^{-1}$)			Ex Al^{3+} ($cmol_c\ kg^{-1}$)		
Control	4.16a	4.07a	3.95ab	1.78a	1.77a	1.74a
8 t compost ha^{-1}	3.72b	2.78de	1.31hi	1.57b	1.23c	0.64f
8 t FYM ha^{-1}	3.27c	2.53e	1.26hi	1.26c	0.82e	0.58fg
30 kg P ha^{-1}	4.12a	4.04a	3.95ab	1.76a	1.74a	1.73a
10 t lime ha^{-1}	0.66kl	0.26m-p	0.07op	0.16lm	0.03mn	0.00n
30 kg P ha^{-1} + 10 t lime ha^{-1}	0.63kl	0.38l-o	0.04p	0.17klm	0.05mn	0.00n
30 kg P ha^{-1} + 5 t lime ha^{-1}	2.95d	1.86g	0.53klm	0.99d	0.65f	0.39hi
8 t compost ha^{-1} + 5 t lime ha^{-1}	2.76de	1.52h	1.20hi	1.15c	0.35hij	0.15lmn
8 t FYM ha^{-1} + 5 t lime ha^{-1}	2.15f	1.29hi	0.55klm	0.81e	0.35hij	0.00n
8 t compost ha^{-1} + 30 kg P ha^{-1} + 5 t lime ha^{-1}	1.81g	1.19i	0.80jk	0.63f	0.31ijk	0.16lm
8 t FYM ha^{-1} + 30 kg P ha^{-1} + 5 t lime ha^{-1}	1.08ij	0.65kl	0.21nop	0.43hi	0.11lmn	0.00n
4 t compost ha^{-1} + 15 kg P ha^{-1} + 10 t lime ha^{-1}	0.75k	0.15op	0.09op	0.23jkl	0.03mn	0.00n
4 t FYM ha^{-1} + 15 kg P ha^{-1} + 10 t lime ha^{-1}	0.50k-n	0.11op	0.08op	0.14lmn	0.00n	0.00n
4 t compost ha^{-1} + 15 kg P ha^{-1} + 5 t lime ha^{-1}	1.31ij	0.88jk	0.26m-p	0.22jkl	0.05mn	0.00n
4 t FYM ha^{-1} + 15 kg P ha^{-1} + 5 t lime ha^{-1}	1.24ij	0.76k	0.13op	0.16lm	0.03mn	0.00n
CV (%)	11.15			14.12		

Means within a column followed by the same letter are not significantly different at P ≥ 0.001; CV = coefficient of variation

Table 6. Effects of organic and inorganic amendments on exchangeable Ca^{2+} and Mg^{2+}

Treatments	20 days	40 days	60 days	20 days	40 days	60 days
	Ex Ca^{2+} ($cmol_c\ kg^{-1}$)			Ex Mg^{2+} ($cmol_c\ kg^{-1}$)		
Control	9.98lm	10.43klm	11.11h-m	4.26	4.11	3.82
8 t compost ha^{-1}	10.82i-m	11.22g-m	13.16e-l	4.26	4.18	2.97
8 t FYM ha^{-1}	10.64j-m	10.48klm	13.29d-l	4.87	5.29	3.21
30 kg P ha^{-1}	9.32m	11.11h-m	11.50f-m	4.81	3.53	3.26
10 t lime ha^{-1}	17.48abc	17.06a-e	15.40b-e	2.15	3.97	4.05
30 kg P ha^{-1} + 10 t lime ha^{-1}	19.54a	18.69ab	14.11c-k	2.68	4.24	4.58
30 kg P ha^{-1} + 5 t lime ha^{-1}	14.61c-i	13.50d-l	14.56c-i	2.66	4.87	3.81
8 t compost ha^{-1} + 5 t lime ha^{-1}	15.83a-e	15.22b-f	14.32c-j	2.73	3.84	4.00
8 t FYM ha^{-1} + 5 t lime ha^{-1}	16.06a-e	15.01b-g	15.35b-f	2.50	4.13	3.18
8 t compost ha^{-1} + 30 kg P ha^{-1} + 5 t lime ha^{-1}	15.06b-f	14.03c-k	14.85b-h	3.29	3.55	3.55
8 t FYM ha^{-1} + 30 kg P ha^{-1} + 5 t lime ha^{-1}	15.90a-e	14.48c-i	14.22c-k	2.39	5.23	6.50
4 t compost ha^{-1} + 15 kg P ha^{-1} + 10 t lime ha^{-1}	17.53abc	16.64a-e	16.22a-e	3.24	5.23	5.55
4 t FYM ha^{-1} + 15 kg P ha^{-1} + 10 t lime ha^{-1}	19.35a	17.85abc	17.14a-d	2.37	4.23	4.92
4 t compost ha^{-1} + 15 kg P ha^{-1} + 5 t lime ha^{-1}	15.85a-e	14.10c-k	13.23e-l	2.21	3.25	3.55
4 t FYM ha^{-1} + 15 kg P ha^{-1} + 5 t lime ha^{-1}	16.15a-e	15.30b-f	14.40c-j	2.50	3.55	3.67
CV (%)	13.10			42.37		

Means within a column followed by the same letter are not significantly different at P ≥ 0.001; CV = coefficient of variation

Table 7. Effects of organic and inorganic amendments on exchangeable K^+ and Na^+

Treatments	20 days	40 days	60 days	20 days	40 days	60 days
	Ex K^+ ($cmol_c\ kg^{-1}$)			Ex Na^+ ($cmol_c\ kg^{-1}$)		
Control	0.50	0.48	0.55	0.38	0.44	0.37
8 t compost ha^{-1}	0.55	0.50	0.49	0.34	0.49	0.33
8 t FYM ha^{-1}	0.45	0.53	0.55	0.29	0.42	0.39
30 kg P ha^{-1}	0.47	0.53	0.54	0.29	0.37	0.39
10 t lime ha^{-1}	0.47	0.54	0.49	0.30	0.45	0.36
30 kg P ha^{-1} + 10 t lime ha^{-1}	0.49	0.52	0.51	0.30	0.44	0.37
30 kg P ha^{-1} + 5 t lime ha^{-1}	0.47	0.51	0.57	0.37	0.36	0.43
8 t compost ha^{-1} + 5 t lime ha^{-1}	0.48	0.51	0.51	0.31	0.35	0.36
8 t FYM ha^{-1} + 5 t lime ha^{-1}	0.44	0.56	0.54	0.35	0.47	0.36
8 t compost ha^{-1} + 30 kg P ha^{-1} + 5 t lime ha^{-1}	0.49	0.53	0.56	0.39	0.53	0.42
8 t FYM ha^{-1} + 30 kg P ha^{-1} + 5 t lime ha^{-1}	0.55	0.47	0.54	0.32	0.34	0.39
4 t compost ha^{-1} + 15 kg P ha^{-1} + 10 t lime ha^{-1}	0.53	0.53	0.54	0.32	0.39	0.38
4 t FYM ha^{-1} + 15 kg P ha^{-1} + 10 t lime ha^{-1}	0.49	0.50	0.53	0.30	0.41	0.36
4 t compost ha^{-1} + 15 kg P ha^{-1} + 5 t lime ha^{-1}	0.41	0.45	0.51	0.41	0.32	0.38
4 t FYM ha^{-1} + 15 kg P ha^{-1} + 5 t lime ha^{-1}	0.55	0.52	0.54	0.35	0.33	0.36
CV (%)	11.05			18.32		

CV = coefficient of variation

Several researchers [12,55,65] reported increased Ca^{2+} and Mg^{2+} as a result of lime and FYM applications on acid soils. The increased exchangeable Ca^{2+} could be due to the dissociation of lime and the decomposition of OM [66]. In agreement with this result, [67] also found increase in exchangeable Ca^{2+} in the soil as a result of applied manure either alone or combined with lime and attributed this increase to improvement of soil pH, as was observed in this study. The observed antagonistic relation between exchangeable Ca^{2+} and Mg^{2+} could be due to the rapid dissolution of $CaCO_3$ to increase the exchangeable Ca^{2+} that compete with Mg^{2+} to take the exchange site whereas the effect of decomposition of FYM or compost gradually improved the exchangeable Mg^{2+} with increasing period of incubation from 20 to 60 days. In the same way, exchangeable Ca^{2+} can compete with Mg^{2+} for binding sites on soil colloids, increasing the likelihood that exchangeable Mg^{2+} will be leached from soils after it has been released from exchange sites [68].

3.5 Effects of Organic and Inorganic Amendments on ECEC and Cation Ratios

Effective cation exchange capacity was affected significantly ($P < 0.001$) due to organic and inorganic treatment applications (Table 8). Sole or combined applications of lime, compost, and FYM improved the ECEC of the soil. Considering sole treatment applications compared with the control, addition of 10 t lime ha^{-1} increased ECEC from the respective control to 20.82 and 22.09 $cmol_c\ kg^{-1}$ at the 20 and 40 days of incubation, respectively. Likewise, combined applications of 30 kg P ha^{-1} + 10 t lime ha^{-1}, 4 t FYM ha^{-1} + 15 kg P ha^{-1} + 10 t lime ha^{-1}, and 8 t FYM ha^{-1} + 5 t lime ha^{-1} improved ECEC of the soil from 17.59 to 23.95, 22.97, and 20.27 $cmol_c\ kg^{-1}$, respectively at the 40 days of incubation. At low pH values, Al^{3+} is the predominant exchangeable cation on clay minerals. As the pH is raised due to lime application, the Al^{3+} hydrolyzes, freeing the exchange sites for Ca^{2+}, and results in an increase in the ECEC [69]. Moreover, the improvement could also be attributed to the integrated effect of the amendments by improving soil pH, microbial activity, and exchangeable bases from FYM and compost decomposition. Increased ECEC and nutrient concentrations in acid soils amended with compost or manure were observed in Senegal's peanut basin [70]. Significant increases in exchangeable Ca^{2+}, Mg^{2+} and ECEC were obtained following the application of organic materials [54]. Similarly, liming acid soil significantly increased base saturation and ECEC [71]. The effects of separate or combined application of organic and inorganic amendments on the ratio of exchangeable Ca/K was significant ($P < 0.001$), but it was found to be non-significant on the ratio of Ca/Mg and Mg/K (Table 8). However, it was observed that numerical variations exist among the treatments and the incubation periods. Application of

Table 8. Effects of organic and inorganic amendments on exchangeable cation ratios and ECEC

Treatments	20 days	40 days	60 days	20 days	40 days	60 days	20 days	40 days	60 days	20 days	40 days	60 days
	Ex Ca/Mg			Ex Ca/K			Ex Mg/K			ECEC ($cmol_c\ kg^{-1}$)		
Control	2.38	3.32	3.37	19.98i	21.69ghi	20.47hi	8.48	8.52	7.01	17.36j	17.59ij	18.30ghi
8 t compost ha^{-1}	2.55	2.81	4.51	19.67i	22.15f-i	26.51c-i	7.76	8.26	6.09	17.84ghi	18.23ghi	18.38g-j
8 t FYM ha^{-1}	2.24	1.99	3.41	24.97d-i	19.96i	24.31e-i	11.89	9.99	7.53	18.07ghi	18.51g-j	19.75c-j
30 kg P ha^{-1}	2.11	3.51	4.15	19.84i	21.09ghi	21.15ghi	10.32	6.71	6.18	17.62ij	18.02ghi	18.04ghi
10 t lime ha^{-1}	11.19	4.31	3.84	38.83ab	31.11a-h	31.54a-g	4.48	7.31	8.37	20.82a-i	22.09a-f	20.42b-j
30 kg P ha^{-1} + 10 t lime ha^{-1}	10.40	4.55	3.08	40.54a	36.45abc	27.46c-i	5.18	8.41	15.19	23.06ab	23.95a	22.64a-d
30 kg P ha^{-1} + 5 t lime ha^{-1}	10.29	4.55	3.85	31.18a-h	26.65c-i	25.57c-i	5.67	9.64	6.69	18.24ghi	19.31d-j	19.59d-j
8 t compost ha^{-1} + 5 t lime ha^{-1}	6.46	3.98	4.23	33.28a-e	29.57b-h	28.41b-i	5.63	7.46	7.90	22.12a-f	19.98b-j	19.54d-j
8 t FYM ha^{-1} + 5 t lime ha^{-1}	6.48	3.76	6.26	36.27abc	27.08c-i	28.35b-i	5.69	7.40	5.76	19.45d-j	20.27b-j	19.61d-j
8 t compost ha^{-1} + 30 kg P ha^{-1} + 5 t lime ha^{-1}	4.85	4.40	4.41	30.22a-h	26.54c-i	26.53c-i	6.69	6.83	6.31	19.33d-j	18.72g-j	19.62d-j
8 t FYM ha^{-1} + 30 kg P ha^{-1} + 5 t lime ha^{-1}	9.08	7.21	4.60	29.18b-h	32.79a-f	26.58c-i	4.24	7.90	6.45	20.25b-h	18.55g-j	18.86f-j
4 t compost ha^{-1} + 15 kg P ha^{-1} + 10 t lime ha^{-1}	5.61	7.96	3.54	32.92a-f	31.61a-g	30.13a-h	6.07	7.15	9.50	21.69a-g	21.24a-h	22.28a-e
4 t FYM ha^{-1} + 15 kg P ha^{-1} + 10 t lime ha^{-1}	11.30	4.54	7.44	40.75a	35.90a-d	33.21a-e	4.80	8.29	4.52	22.54a-e	22.97abc	20.42b-j
4 t compost ha^{-1} + 15 kg P ha^{-1} + 5 t lime ha^{-1}	7.17	4.34	3.73	38.66ab	31.33a-g	25.94c-i	5.41	6.59	7.02	18.88f-j	18.12ghi	17.67ij
4 t FYM ha^{-1} 15 kg P ha^{-1} + 5 t lime ha^{-1}	6.46	4.31	3.92	29.36b-h	29.42b-h	26.67c-i	4.60	6.91	6.81	19.55d-j	19.70c-j	18.97f-j
CV (%)	68.15			19.00			46.13				8.19	

Means within a column followed by the same letter are not significantly different at P ≥ 0.001; CV = coefficient of variation

4 t FYM ha^{-1} + 15 kg P ha^{-1} + 10 t lime ha^{-1}, and 10 t lime ha^{-1} + 30 kg P ha^{-1} increased the ratio of Ca/K from 19.98 to 40.75 and 40.54, respectively at the 20 days of incubation. The observed increased ratio might be due to the availability of Ca from the applied lime. Although statistically, non-significant values were obtained for Ca/Mg and Mg/K ratios, the nutrient balance is more affected by the magnitude of the ratio. The influence of liming on cation ratio has been reported by different researchers [71,72]. The basic cation ratio philosophy promotes that maximum yields can be achieved by creating an ideal ratio of Ca, Mg, and K in the soil [73]. Graham [74] proposed that for production of annual crops, ratio ranges of 7.1 to 10.8 for Ca/Mg, 17.0 to 32.5 for Ca/K, and 2.4 to 3.0 for Mg/K in soils are needed. Accordingly, calculated values of Ca/Mg ratio for the applied 30 kg P ha^{-1} + 5 or 10 t lime ha^{-1} at the 20 days incubation, and 8 t FYM ha^{-1} + 15 kg P ha^{-1} + 5 t lime ha^{-1}at the 40 days incubation were within the proposed range. The ratio of Ca/K in most of the separate or combined treatments across the incubation periods could be considered as favorable ratio for most crops whereas the Mg/K ratio obtained was higher than the proposed values.

Lierop et al. [75] suggested that onion appears to be able to absorb sufficient Ca and Mg to meet its requirement for these nutrients within at least a soil-extracted Ca/Mg range of about 0.5 to 16, as yield did not seem to be affected by unfavorable Ca/Mg ratios within that range. Common bean produced maximum grain yield at pH (water) 6.3, Ca/Mg ratio 3.1, Ca/K ratio 22.6, and Mg/K ratio of 6.7 in acid soils treated with dolomitic lime and Fe [76]. In contrast to the proposed ranges discussed above, [77] reviewed that examination of data from numerous studies would suggest that, within the ranges commonly found in soils, the chemical, physical, and biological fertility of a soil is generally not influenced by the ratios of Ca, Mg, and K.

4. CONCLUSION

Soil acidity is a critical issue requiring urgent attention in most highlands of Ethiopia due to its impact on crop production and productivity. Thus, organic and inorganic amendments were tested to evaluate the effects on selected soil chemical properties. Accordingly, all the treatments, when applied as a sole or in combination, improved the selected soil properties significantly with the exception of few parameters. The treatments, for most of the parameters, were more effective when applied in combination than sole. The changes in soil properties across treatments varied with incubation period. The gradual mineralization of FYM and compost, and the resultant release of carbonates, bicarbonates, and other compounds in general, and the rapid dissociation of lime in the combination affect the rate of change of soil chemical properties. For the sole treatments, lime was found to change the selected soil properties more quickly than the FYM and compost.

Therefore, combined application of 4 t FYM ha^{-1} + 15 kg P ha^{-1} + 10 t lime ha^{-1} or 8 t FYM ha^{-1} + 30 kg P ha^{-1} + 5 t lime ha^{-1} could be taken as a provisional recommendation for managing soil acidity and improving soil fertility in Lay Gayint district. Generally, 40 to 60 days of incubation earlier to planting would allow decomposition and chemical reaction of lime, FYM, and compost combinations with the soil and improve soil properties.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Narro L, Pandey S, Leon CD, Salazar F, Arias MP. Implication of soil acidity tolerant maize cultivars to increase production in developing countries. In: Arihara, N.J. Okada, K. and A. Srinivasan, (ed), Plant Nutrient Acquisition: New Perspectives, Springer, Tokyo. 2001;447-463.
2. Tessema Genanew, Mekuria Argaw, Enyew Adgo. Farmers soil management practices and their perceptions to soil acidity at Ankesha District of Awi Zone, Northwestern Ethiopia. Libyan Agriculture Research Center Journal International. 2012;3:64-72.
3. Asmare Melese, Yli-Halla M. Effects of applications of lime, wood ash, manure and mineral P fertilizer on the inorganic P fractions and other selected soil chemical properties on acid soil of Farta District, northwestern highland of Ethiopia. African Journal of Agricultural Research. 2016;11: 87-99.
4. Kisinyo PO, Opala PA, Gudu SO, Othieno CO, Okalebo JR, Palapala V, Otinga AN. Recent advances towards understanding Kenyan acid soils for improved crop

production. African Journal of Agricultural Research. 2014;9:2397-2408.
5. Mossor-Pietraszewska T. Effect of aluminium on plant growth and metabolism. Acta Bichemica Polonica. 2001;48:673-686.
6. Samac DA, Mesfin Tesfaye. Plant improvement for tolerance to aluminium in acid soils. Plant Cell, Tissue and Organ Culture. 2003;75:189-207.
7. Wang JP, Harsh R, Ping ZG, Neville M, Xue ZM. Aluminium tolerance in barley (*Hordeum vulgare* L.): Physiological mechanisms, genetics and screening methods. Journal of Zhejiang University Science B. 2006;7:769-787.
8. Miyasaka SC, Hue NV, Dunn MA. Aluminum. In: Barker, A.V and Pilbeam, D.J. (Ed.), Handbook of Plant Nutrition. Tayler and Francis Group, Boca Raton; 2007.
9. Fageria NK, Baligar VC. Ameliorating soil acidity of tropical Oxisols by liming for sustainable crop production. Advances in Agronomy. 2008;99:345-399.
10. Chen JH, Wu JT, Huang WT. Effects of compost on the availability of nitrogen and phosphorus in strongly acidic soils. Food and Fertilizer Technology Center Bulletin 155. Dec., 2001.
11. Acharya CL. Integrated input management for sustainable crop production in rainfed agroecosystem. Journal of the Indian Society of Soil Science. 2002;50:398-413.
12. Fageria NK, Baligar VC. Fertility management of tropical acid soils for sustainable crop production. In: Rengel, Z. (Ed.), Handbook of Soil Acidity. Marcel Dekker, Inc., New York, Basel; 2003.
13. Fageria NK, Stone LF. Yield of common bean in no-tillage system with application of lime and zinc. Pesquisa Agropecuária Brasileira. 2004;39:73-78.
14. Caires EF, Churka S, Garbuio FJ, Ferrari RA, Morgano MA. Soybean yield and quality as function of lime and gypsum application. Scientia Agricola (Piracicaba, Brazil). 2006;63:370-379.
15. Ano AO, Ubochi CI. Neutralization of soil acidity by animal manures: Mechanism of reaction. African Journal of Biotechnology. 2007;6:364-368.
16. Anjos JT, Rowell DL. The effect of lime on phosphorus adsorption and barley growth in three acid soils. Plant Soil. 1987;103: 75-82.
17. Crawford TW, Singh JU, Breman H. Solving agricultural problems related to soil acidity in Central Africa’s Great Lake Region. Catalyst project report. Muscle shoals, Alabama, USA; 2008.
18. Osundwa MA, Okalebo JR, Ngetich WK, Ochuodho JO, Othieno CO, Langat B, Omenyo VS. Influence of agricultural lime on soil properties and wheat yield on acidic soils of Uasin Gishu County, Kenya. American Journal of Experimental Agriculture. 2013;3:806-823.
19. Mokolobate MS, Haynes RJ. Comparative liming effect of four organic residues applied to an acid soil. Biology and Fertility of Soil. 2002;35:79-85.
20. Wong MTF, Swift RS. Role of organic matter in alleviating soil acidity. In: Rengel, Z. (ed), Handbook of Soil Acidity, NewYork. Marcel Dekker. 2003;337-358.
21. Opala PA, Okalebo JR, Othieno CO. Effects of organic and inorganic materials on soil acidity and phosphorus availability in a soil incubation study. International Scholarly Research Network. 2012;1-10.
22. Ermias Abate, Shimelis Hussien, Laing M, Fentahun Mengistu. Aluminium toxicity tolerance in cereals: Mechanisms, genetic control and breeding methods. African Journal of Agricultural Research. 2013;8: 711-722.
23. Toor GS. Enhancing phosphorus availability in low-phosphorus soils by using poultry manure and commercial fertilizer. Soil Science. 2009;174:358-364.
24. von Wandruszka R. Phosphorus retention in calcareous soils and the effect of organic matter on its mobility. Geochemical. Transactions. 2006;7:1-8.
25. Chiu KK, Ye ZH, Wong MH. Growth of *Vetiveria zizanioides* and *Phragmities australis* on Pb/Zn and Cu mine tailings amended with manure compost and sewage sludge: A greenhouse study. Bioresource Technology. 2006;97:158-170.
26. Martínez-Blanco J, Cristina L, Christensen TH, Muñoz P, Rieradevall J, Møller J, Antón A, Boldrin A. Compost benefits for agriculture evaluated by life cycle assessment. A review. Agronomy for Sustainable Development. 2013;33:721-732.
27. Mekonnen Asrat, Heluf Gebrekidan, Markku Yli-Halla, Bobe Bedadi, Wakene Negassa. Effect of integrated use of lime, manure and mineral P fertilizer on bread

wheat (*Triticum aestivum*) yield, uptake and status of residual soil P on acidic soils of Gozamin District, North-Western Ethiopia. Agriculture, Forestry and Fisheries. 2014;3:76-85.
28. Achalu Chimdi, Heluf Gebrekidan, Kibebew Kibret, Abi Tadesse. Effects of liming on acidity-related chemical properties of soils of different land use systems in western Oromia, Ethiopia. World Journal of Agricultural Sciences. 2012;8:560-567.
29. Addisu Baye, Menberu Teshome. Crop sensitivity to inter-annual climate variability in Lay Gayint woreda, Northwest Ethiopia. Ethiopian Renaissance Journal of Social Sciences and the Humanities. 2015;2:27-42.
30. Ethiopian National Meteorological Service Agency (ENMSA). Lay Gayint weather station rain fall and temperature data. Bahir Dar, Ethiopia; 2017.
31. Day PR. Hydrometer method of particle size analysis. In: C.A. Black (ed.). Methods of soil analysis. Agronomy Part I, No. 9. American Society of Agronomy. Madison, Wisconsin, USA; 1965.
32. Baruah TC, Barthakur HP. A textbook of soil analyses. Vikas Publishing House Pvt. Ltd. New Delhi; 1997.
33. Chopra SH, Kanwar JS. Analytical agricultural chemistry. Kalyani Publisher Ludhiana, New Delhi, India; 1976.
34. Walkley A, Black CA. An examination of digestion method for determining soil organic matter and proposed modification of the chromic acid titration method. Soil Science. 1934;37:29-38.
35. Jackson ML. Soil chemical analysis. Prentice Hall Pvt. Ltd., New Delhi; 1967.
36. Olsen SR, Watenabe VC, Dean LA. Estimate of available phosphorous in soil by extraction with sodium bicarbonate. USDA Circular. 1954;939.
37. Rowell DL. Soil science: Method and applications. Addison Wesley Longman Limited, England; 1994.
38. Chapman HD. Cation exchange capacity by ammonium saturation. In: C.A. Black (ed.). Methods of Soil Analysis. Agronomy Part II, No. 9. American Society of Agronomy, Madison, Wisconsin, USA; 1965.
39. Sahlemedhin Sertsu, Taye Bekele. Procedures for soil and plant analysis. National Soil Research Center, Addis Ababa, Ethiopia; 2000.
40. John BP. Recommended method of manure analysis. University of Wisconsin, Cooperative Extension Publishing. USA; 2003.
41. Okalebo JR, Gathua KW, Woomer PL. Laboratory methods of soil and plant analysis, 2nd Edition. A working manual, Nairobi, Kenya; 2002.
42. Murphy J, Riley JP. A modified single solution method for the determination of phosphate in natural waters. Analytica Chemica Acta. 1962;27:31-36.
43. Issam IB, Antoine HS. Methods of analysis for soils of arid and semi-arid regions. Food and Agriculture Organization of the United Nations, Rome; 2007.
44. Shoemaker HE, McLean EO, Pratt PF. Buffer methods of determining lime requirements of soils with appreciable amounts of extractable aluminium. Soil Science Society of America Journal. 1961; 25:274-277.
45. SAS (Statistical Analysis System) Institute). SAS/STAT user's guide. Proprietary software version 9.1. SAS Institute, Inc., Cary, NC; 2004.
46. USDA (United States Department of Agriculture). Textural soil classification. Study guide, Soil mechanics level I, Module 3. USA; 1987.
47. Hazelton P, Murphy B. Interpreting soil test results: What do all the numbers mean? 2nd Edition. CSIRO Publishing, Australia; 2007.
48. Jones JB. Agronomic handbook: Management of crops, soils, and their fertility. CRC Press LLC, Boca Raton, FL, USA; 2003.
49. Tekalign Tadese. Soil, plant, water, fertilizer, animal manure and compost analysis. Working Document NO 13. International Livestock Research Center for Africa (ILCA), Addis Ababa; 1991.
50. Food and Agriculture Organization of the United Nations (FAO). Farmer´s compost handbook experiences in Latin America Regional Office for Latin America and the Caribbean, Santiago; 2015.
51. Whalen JK, Chang C, Carefoot JP. Cattle manure amendments can increase the pH of acid soils. Soil Science Society of American Journal. 2000;64:962-966.
52. Escobar OME, Hue NV. Temporal changes of selected chemical properties in three manure-Amended soils of Hawaii. Bioresource Technology. 2008;99:8649-8654.

53. Liu J, Hue NV. Amending subsoil acidity by surface applications of gypsum, lime and composts. Communication in Soil Science and Plant Analysis. 2001; 32:2117–2132.
54. Naramabuye FX, Haynes RJ. The liming effect of five organic manures when incubated with an acid soil. Journal of Plant Nutrition and Soil Science. 2007; 170:615-622.
55. Verde BS, Danga BO, Mugwe JN. Effects of manure, lime and mineral P fertilizer on soybean yields and soil fertility in a humic Nitisols in the Central Highlands of Kenya. International Journal of Agricultural Science Research. 2013;2:283-291.
56. Moreira A, Sfredo GJ, Moraes LAC, Fageria NK. Lime and cattle manure in soil fertility and soybean grain yield cultivated in Tropical soils. Communications in Soil Science and Plant Analysis. 2015;46: 1157-1169.
57. Samake A. Use of locally available amendments to improve acid soil properties and maize yield in the savanna zone of Mali. PHD Thesis, Kwame Nkrumah University of Science and Technology, Kumasi; 2014.
58. Helyar KR, Porter WM. Soil acidification, its measurement and the processes involved. In: Robson, A.D. (ed), Soil Acidity and Plant Growth. Academic Press, Sydney; 1989.
59. Opala P, Okalebo JR, Othieno CO, Kisinyo P. Effect of organic and inorganic phosphorus sources on maize yields in an acid soil in western Kenya. Nutrient Cycling Agroecosystems. 2010;86:317-329.
60. von Wandruszka R. Phosphorus retention in calcareous soils and the effect of organic matter on its mobility. Geochemical. Transactions. 2006;7:1-8.
61. Nziguheba G, Cheryl AP, Buresh RJ, Paul CS. Soil phosphorus fractions and adsorption as affected by organic and inorganic sources. Plant and Soil. 1998; 198:159-168.
62. Jaskulska I, Jaskulski D, Kobierski M. Effect of liming on the change of some agrochemical soil properties in a long-term fertilization experiment. Plant Soil Environment. 2014;60:146-150.
63. Liasu MO, Ogundare AO, Ologunde MO. Effect of soil supplementation with fortified tithonia mulch and directly applied inorganic fertilizer on growth and development of potted okra plants. American-Eurasian Journal of Sustainable Agriculture. 2008;2:264-270.
64. Nyarko FO. Ameliorating soil acidity in Ghana: A concise review of approaches. Journal of Science and Technology. 2012; 2:143-153.
65. Kheyrodin H, Antoun H. Tillage and manure effect on soil physical and chemical properties and on carbon and nitrogen mineralization potentials. African Journal of Biotechnology. 2011;10:9824-9830.
66. Adeleye EO, Ayeni LS, Ojeniyi SO. Effect of poultry manure on soil physico-chemical properties, leaf nutrient contents and yield of yam (*Dioscorea rotundata*) on Alfisols in Southwestern Nigeria. Journal of American Science. 2010;6:871-878.
67. Rahman MA, Meisner CA, Duxbury JM, Lauren J, Hossain ABS. Yield response and change in soil nutrient availability by application of lime, fertilizer and micronutrients in an acidic soil in a rice-wheat cropping system. Paper presented in 17th WCSS, 14th-21st August, Thailand; 2002.
68. Barker AV, Pilbeam DJ. Handbook of plant nutrition. CRC Press. Boca Raton, London; 2007.
69. Fageria NK, Baligar VC. Growth and nutrient concentrations of common bean, lowland rice, corn, soybean, and wheat at different soil pH on an Inceptisols. Journal of Plant Nutrition. 1999;22:1495-1507.
70. Nathan CMC, Amadou MD. Soil fertility management and compost use in Senegal's peanut basin. International Journal of Agricultural Sustainability. 2005; 3:79-91.
71. Fageria NK, Moreira A, Moraes LAC, Moraes MF. Influence of lime and gypsum on yield and yield components of soybean and changes in soil chemical properties. Communications in Soil Science and Plant Analysis. 2014;45:271-283.
72. Moreira A, Fageria NK, Garcia AYG. Effect of liming on the nutritional conditions and yield of alfalfa grown in tropical conditions. Journal of Plant Nutrition. 2011;34:1107-1119.
73. Eckert DJ. Soil test interpretation: Basic cation saturation ratios and sufficiency levels. In; Brown, J.R (ed), Soil testing: Sampling, correlation, calibration, and

interpretation. WI: Soil Science Society of America. Madison. 1987;53-64.
74. Graham ER. An explanation of theory and methods of soil testing. Missouri Agricultural Experiment Station Bulletin 734, University of Missouri: Columbia, Missouri; 1959.
75. Lierop WV, Martel YA, Cescas MP. Onion response to lime on acid Histosols as affected by Ca/Mg ratios. Soil Science Society of America Journal. 1979;43: 1172-1177.
76. Fageria NK, dos Santos AB, Moreira A. Yield, nutrient uptake, and changes in soil chemical properties as influenced by liming and iron application in common bean in a no-tillage system. Communications in Soil Science and Plant Analysis. 2010;41: 1740-1749.
77. Kopittke PM, Menzies NW. A review of the use of the basic cation saturation ratio and the "Ideal" Soil. Soil Science Society of America Journal. 2007;71:259-265.

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