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Research Article

Determination of Lime Requirement with Compost on Acidic Ultisols for Wheat Crop in the Gurage Zone of Ethiopia

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Acidic soil adversely affects the plant growth and production. Various ameliorating strategies are known, but the optimum rate of lime and compost rate determination for better nutrient management and production in acid Ultisols was not well studied, so the main objective of this study was to determine optimum lime and compost rate for wheat production. A pot experiment was performed on the soil collected from Yefereze (Cheha District). The incubation trail was conducted in factorial combination of four level lime (8.44, 6.33, 4.22, and 0 $t{\cdot}ha^{-1}$) and compost (15, 10, 5, and 0 $t{\cdot}ha^{-1}$). The sixteen treatments were arranged in completed randomized design (CRD) with triplicate replications in the greenhouse. After 75 days, each pot that was planted with wheat and crop performance had been monitored. The textural class of the soils of the experiment was clay with strongly acidic pH. The organic carbon (2.17%) and total nitrogen content (0.17%) status was medium. The available phosphorus (Av. P) contents were very low (1.63 ppm). The experimental study result revealed that all the three rates of lime and compost continuously improve the soil pH throughout the study periods and the maximum soil pH (6.53) was obtained in combination of 8.44 $t{\cdot}ha^{-1}$ and 10 $t{\cdot}ha^{-1}$ lime and compost, respectively. The compost amended treatment indicated slight improvement in soil reaction which assert that using compost alone did not reduce soil acidity within 75-day periods in strongly acidic soil condition for suitable wheat production. Liming alone or integrated application increases soil pH (4.69 to 6.53), cation exchangeable capacity (CEC) (27.18 to 31.58 $cmol_c kg^{-1}$), exchangeable calcium (3.56 to 8.43 $cmol_c kg^{-1}$), available phosphorus (Av.P) (1.63 to 5.27 ppm), total nitrogen (TN) (0.19 to 0.24 ppm), and exchangeable acidity reduced (0.73 $cmol_c kg^{-1}$ to trace). Integrated application of 8.44 and 5 $t{\cdot}ha^{-1}$ lime and compost rates improve the overall soil property and maximize the wheat yield by 24.26%. Generally, the limiting factor for wheat production of the study area was the acidity of the soil. The combined application of lime and compost raised the pH and improved the suitability of the soil for wheat production. However, the status of Av. P was low after the amendment, and it is advisable to integrate phosphorus containing fertilizer in addition to lime and compost for optimum and sustainable production of wheat in the study area. Since the incubation and greenhouse experiment were conducted in a controlled environment, there is a need for field verification. It is also advisable to assess the economic feasibility of the different rates of lime and compost for an appropriate soil management decision.

1. Introduction

Worldwide, 30% of arable land is under the influence of soil acidity [1]; according to [2], nearly 41% of the Ethiopian total land is affected by soil acidity, and moderately to weakly acidic soil (4.5–5.5) accounts for 27.8%, while the remaining 13.2% is strongly acidic (pH (soil reaction) <4.5). Soil acidity can be raised because of different factors such as rainfall, temperature, topographic, cultivation, and crop residue managements [1].

Nutrient availability in soil depends on the pH value of soils. Most of the essential plant nutrients are available in the pH range of 5.5 to 6.8; however, soil acidity is a major growth-proscribing issue for plants in many parts of the world [3]. Farmers can reduce the effects of soil acidic by liming to adjust pH to the levels required by the crop.

Benefits of liming include improvement of nutrient availability and improvement of soil structure and increase rates of infiltration. Understanding soil pH is essential for the proper management of soil and crop productivity.

Soil acidity reduces nutrient availability which could affect crop yields [4] and degrade the agroecosystem [5]. Soil acidity consists of three components: active, exchangeable, and residual acidity. Active acidity is the activity of H^+ ions in the soil solution. The concentration of hydrogen ions owing to active acidity is extremely small; however, it is important because this form of soil acidity directly affects the environment to which plants and microbes are exposed [6]. Strong soil acidity also has pronounced deficiency in phosphorus (P), Ca, Mg, molybdenum (Mo), and potassium (K) and toxic concentration of Fe, Al, hydrogen (H), copper (Cu), and manganese (Mn) [7]. Nutrient deficiency and toxicity in strongly acidic soil highly affect nutrient uptakes, severe injury to plant roots, plant susceptibility to pathogen, and stunted plant growths [8, 9]. High P fixation by Al and Fe reduces its availability [10]. Liming of soil can raise soil pH to the ideal level by reducing the concentrations of H^+ and Al^{3+} as the result chemical properties of the soil improved and the yields of a crop can increase by $0.5\,t{\cdot}ha^{-1}$ [11, 12]. In addition to lime, organic sources of amendments such as plant residue, organic waste compost, animal residue, and biochar reduce soil acidity and Al saturation and as a result improve suitable conditions for plant growth [5, 13].

Previous studies asserted that soil acidity affects large areas of the cultivated lands in different parts of Ethiopia [14, 15], and the wheat growing farmers of the areas have been forced to shift to tolerant crops [16]. Soil characterization and classification research conducted in the study area showed that the soils were strongly acidic (pH (H_2O) of 4.5 to 4.9) [17]. Therefore, there is an urgent need to ameliorate those acid soils for optimum and sustainable agricultural production. Addition of inputs such as lime, manure, and compost to acidic soils is potentially a feasible approach for increasing soil pH and decreasing concentrations of Al [18, 19] for optimum and sustainable crop production. However, there is a research need for the sole and combined application rates of those inputs for a specific crop and agroecological area.

Although organic and inorganic amendments have significant contribution to reduce soil acidity and improve soil fertility, the amount and the time of sole or combined applications of lime and organic fertilizer were not sufficiently investigated in various areas of Ethiopia. Lime rate determination methods used in Ethiopia were acid saturation and buffering methods, which are time-consuming [20]. Integrated application of lime and compost rates were not investigated as soil acidity reclamation alternative methods in the study area. Therefore, the objectives of this study were (1) to determine lime and compost application rates based on soil pH in incubation trials; (2) to examine the change in selected chemical properties; and (3) to evaluate crop performance as a result of the amendments.

2. Materials and Methods

2.1. Description of the Soil Sampling Site. The trail was taken place in the Wolkite University compound in the temporary constructed shed. The soil sampling was located from the Cheha district of the Yefereze research site of Wolkite University, and the soil sampling area geographically lies between latitude 8°00′00″ and 8°20′00″N and longitude 37°40′00″ and 38°10′00″ E (Figure 1). The mean annual rainfall is 1216 mm, and the mean annual maximum and minimum temperatures are 26° C and 17° C, respectively (Figure 2). Based on the Ethiopian agroecological zonation, the sampling site is located in the “Woyenadega” agro-ecological zone.

2.2. Soil Sample Collection. Based on the preliminary assessment, characterization, and classification studies performed in Gurage zone soils, the soil sampling areas experienced the soil acidity problem so that the sampling site was purposefully selected and the soil sample has been collected at a depth of 0–20 cm for incubation and wheat performance study. Composite soil samples were collected at a depth of 0–20 cm. The soil samples were taken on April 21, 2021, and the experiment involving incubation trials began on May 1, 2021 and ended on July 9, 2021. Wheat seeds were planted and harvested in October 2021. The composite soil samples were brought to the Wolkite University for soil pH, color, bulk density, and measurement. Before conducting an incubation trail, soil texture, organic matter, CEC, exchangeable acidity, and exchangeable bases (Ca, Mg, K, and Na) were determined at the Ethiopia National Soil Testing Laboratory.

2.3. Incubation Trial. The incubation trail was performed to establish the relationship between soil pH with lime and the compost rate. Four levels of lime and compost were combined in factorial arrangement, and a total of sixteen treatments were arranged in completely randomized design (CRD) in the laboratory. In each pot, 2 kg of soil was weighed and placed and amendments were added based on the rates presented in Table 1. The moisture of the soil sample in pots was maintained at 65% of the field capacity, and each pot is intermittently weighted in sensitive balance to determine weight loss due to moisture drop, and based on the reduced amount, distilled water was added. Soil pH in water at a ratio of 1 : 2.5 was recorded periodically (15 days interval) for seventy-five days by taking 5 gm of soil from each treatment and dried at room temperature, and the dried soil samples were grinded using mortar and pestle. Finally, after the incubation trail was completed, the soil samples from each pot were collected and analyzed for CEC, TN, available phosphorous, exchangeable bases (Ca, Mg, K, and Na), and exchangeable acidity as presented in soil and compost physicochemical properties’ determination based on the standard laboratory procedure indicated in Section 2.6.

2.4. Experimental Design and Treatments for Wheat Performance Evaluation in Greenhouse. The pot experiment was conducted using 16 treatments (Table 2). Four rates of lime

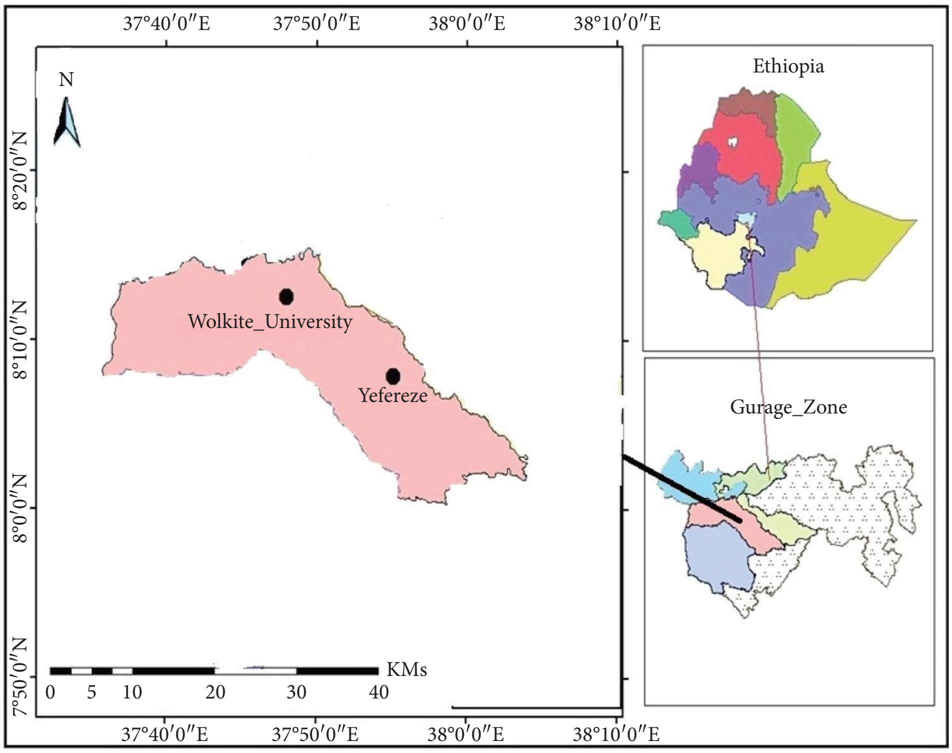

Figure 1: Location map of the soil sampling area.

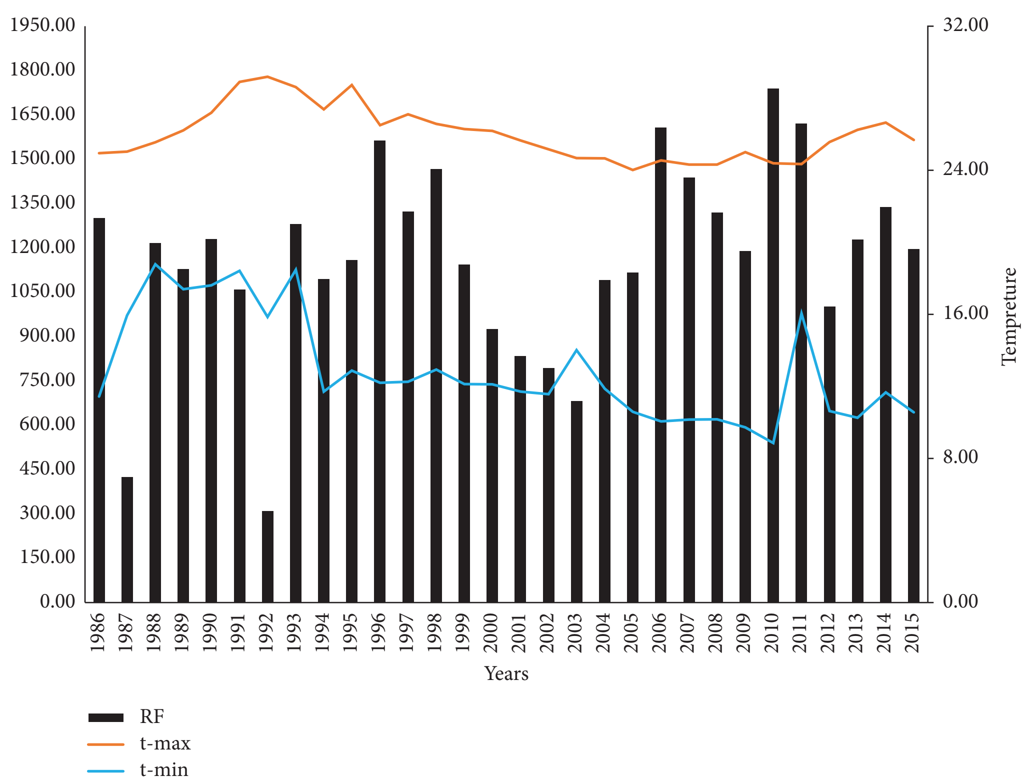

Figure 2: Mean annual rainfall (mm) and mean annual maximum and minimum temperatures (°C) of the study area from 1986 to 2015 (data source: Ethiopia Meteorological Agency).

Table 1: Factorial combination lime and compost used for the incubation study (the treatment selection was based on the recommendation suggested by the Ethiopian Ministry of Agriculture crop package extension guideline).

Treatment combination		Lime rate ($t \cdot ha^{-1}$)			
		8.44	6.33	4.22	0
Compost rate ($t \cdot ha^{-1}$)	15	T1 (8.44, 15)	T5 (6.33, 15)	T9 (4.22, 15)	T13 (0, 15)
	10	T2 (8.44, 10)	T6 (6.33, 10)	T10 (4.22, 10)	T4 (0, 10)
	5	T3 (8.44, 5)	T7 (6.33, 5)	T11 (4.22, 5)	T15 (0, 5)
	0	T4 (8.44, 0)	T8 (6.33, 0)	T12 (4.22, 0)	T16 (0, 0)

Table 2: Factorial combination of four levels of composts and lime rate.

Treatment	Lime rate ($t \cdot ha^{-1}$)	Compost ($t \cdot ha^{-1}$)
1	8.44	15
2	8.44	10
3	8.44	5
4	8.44	0
5	6.33	15
6	6.33	10
7	6.33	5
8	6.33	0
9	4.22	15
10	4.22	10
11	4.22	5
12	4.22	0
13	0	15
14	0	10
15	0	5
16	0	0

and four rates of compost were combined in factorial arrangement (Table 1), and the treatments were arranged in completely randomized design (CRD) with three replications. Lime ($CaCO_3$) with 56% of CaO taken from Buie Lime Mill Enterprise and compost from Hamburg consultancy service, Addis Ababa, were used. The compost and lime were thoroughly mixed with the soil.

The greenhouse experiment was tested to see the effects of lime and compost on the wheat performance. In the beginning, the incubation experiment was conducted in 48 pots. Its dimensions (22 cm diameter, 16 cm height, and 24 cm bottom width) were used for 75 days to get designed soil pH for wheat planting. After the first experiment was completed, each one of 48 pots was filled with three kg of air-dried and sieved acidic soils with predetermined lime and compost rates as presented in Table 1. The pots filled with acidic soil were stayed for 75 days immediately after indicating that 75 days planted with twelve (12) seed per pot wheat variety called "*Digalu*" was used as the test crop. The fertilizer was added to each treatment except for control at the rate of 46 $kg \cdot ha^{-1}$N and P_2O_5. Watering was conducted periodically based on weight loss. The crop was harvested after 105 days, and plant height, biomass, and grain yield data were collected.

2.5. Lime Application and Crop Management. Three kilograms' soil sample was placed in plastic pots, and each received treatment indicated amounts of lime as well as composts and were thoroughly mixed using a glass rod (Table 2). Treatments were periodically weighed and brought back to initial weight to maintain moisture contents at 65% during the incubation time as explained in Section 2.3 and wheat performance evaluation. After the incubation period was completed (after 75 days), 12 seeds of wheat were sown and agronomic management such as weeding was executed continuously until maturity and watering was carried out based on weight loss after weight determination of each pot. During wheat maturity, all the wheat plants in each pot were counted. Plant height was also determined using a measuring tape from the pot surface level to the tip of each wheat stand, biomass yield was estimated by weighing the whole biomass harvest above the roots, and grain yield was obtained after separating spike from wheat grain.

2.6. Soil and Compost Physicochemical Properties' Determination. Soil bulk density was determined by the procedure outlined by Black [21]. Soil colors in moist and dry condition have been identified using a Munsell color chart [22]. Soil pH was measured in 1 : 2.5 soils to water suspension [23]. The soil texture was determined using the hydrometer method [24]. The organic carbon (OC) was analyzed following the wet digestion method described by [25]. The Kjeldahl procedure has been followed for the determination of N that follows oxidation of the same concentrated sulfuric acid and converting the nitrogen in the organic compounds into ammonium sulphate during oxidation. Available phosphorus (P) has been determined according to the [26] method by shaking the soil samples with an extraction solution of 0.5M sodium bicarbonate (Na_2HCO_3) at a constant pH of 8.5, and phosphorus in the extract was determined calorimetrically using a spectrometer after developing blue colors.

Exchangeable bases have been extracted by excess ammonium acetate (1M NH_4OAc at pH 7) solution and measured by an atomic absorption spectrophotometer (Ca^{2+} and Mg^{2+}) and flame photometer (Na^+ and K^+). The CEC was determined from ammonium saturated samples which were subsequently replaced by Na^+ from a percolating sodium chloride solution. The excess salt was removed by 96% ethanol, and the NH_4^+ ion that would be displaced by Na^+ ion was measured by the Kjeldahl procedure [27].

2.7. Statistical Analysis. The effects of different rates of lime and compost treatments on soil chemical properties and wheat performance were assessed by two-way analysis of variance using SAS statistical package software version 9.2. Significance differences among treatments were analyzed at the 0.05 probability level using least significant difference (LSD). Regression analysis was conducted using soil pH and lime and compost rate.

3. Results and Discussion

3.1. Soil Physicochemical Properties of the Experimental Soil and Compost. The summary of soil physicochemical properties is presented in Table 3. The soil in sampled area was classified as TypicHaplustults [27]. The soil reaction was very strongly acidic [28]. The CEC of an experimental soil was high (27.24 $cmol_c kg^{-1}$) as the rating set by [29]. According to [25], Av.P contents were very low (1.63 ppm), and very low availability was due to its fixation by Al and Fe ions in strongly acidic soils [30]. The organic carbon (2.17%) and total nitrogen content (0.17%) status was medium [31]. Exchangeable acidity of the soil under investigation was high (0.73 $cmol_c kg^{-1}$) because in acidic soil, hydrogen and aluminum ions occupy a larger proportion of the exchangeable site [32]. The compost properties were characterized by measuring pH, electrical conductivity, organic carbon, total nitrogen, available phosphorus, and exchangeable Ca, Mg, K, and sodium.

3.2. Soil Reaction and Amendment Rate Relationships. Previous studies asserted that application of lime and organic matter increased the soil pH and crop yield and improved soil physical and chemical properties [16, 33]. In this study, the application of lime and compost in different rates changes the soil pH. In this incubation trail, small pH changes nearly for one month were observed, but after one month, dramatic soil pH changes in treatments were observed (Figure 3). All the three rates of lime continuously improve the soil pH (4.90) throughout the study periods, and the maximum soil pH (6.53) was obtained in combination with 8.44 $t{\cdot}ha^{-1}$and 10 $t{\cdot}ha^{-1}$ lime and compost, respectively. The raise in soil pH by the combined application of lime and compost might be due to reduction in H^+ and Al^{3+} concentration in the soil solution by the neutralizing and buffering ability of lime and compost [34]. The sole compost amended treatment indicated slight improvement in soil reaction which asserts that using compost alone did not reduce soil acidity within 75-day periods (Figure 3) in strongly acidic soil condition for suitable wheat production. The minimum recommended soil pH for wheat production is 5.5 [35]. In general, as the lime and compost rates increased, the soil pH would also increase that indicates quantity of lime and compost integrated application had a linear relationship with soil pH; this has been mathematically represented in the following equations (1) and (2). These two equations are helpful to determine the lime rate alone and integrated application of lime and compost based on the initial soil pH.

Table 3: Soil and compost physicochemical properties used for the experiments.

Properties		The values obtained	
		Soil	Compost
Soil texture	Sand (%)	21.33	—
	Silt (%)	21.00	—
	Clay (%)	57.67	—
Bulk density ($g{\cdot}cm^{-3}$)		1.10	—
Soil color	Dry	10YR5/1	—
	Moist	10YR4/1	—
pH		4.90	4.5
Organic carbon (%)		2.17	9.07
Electrical conductivity (dSm^{-1})		—	9.08
N (%)		0.17	1.26
Av.P (ppm)		1.63	427.92
Cation exchange capacity ($cmol_c{\cdot}kg^{-1}$)		27.24	44.91
Exchangeable Ca ($cmol_c{\cdot}kg^{-1}$)		0.35	0.55
Exchangeable Mg ($cmol_c{\cdot}kg^{-1}$)		0.29	0.23
Exchangeable K ($cmol_c{\cdot}kg^{-1}$)		0.003	0.085
Exchangeable Na ($cmol_c{\cdot}kg^{-1}$)		—	0.022
Exchangeable acidity ($cmol_c{\cdot}kg^{-1}$)		0.73	0.22

$$pH = 4.861 + 0.171\,\text{lime}\left(t\,ha^{-1}\right) - 0.003\,\text{compost}\left(t\,ha^{-1}\right), \quad (1)$$

$$pH = 4.811 + 0.172\,\text{lime}\left(t\,ha^{-1}\right). \quad (2)$$

3.3. Effect of Liming on Selected Soil Chemical Properties. The chemical properties found in the soil have been changed after incubation trial with different levels of lime rates [36, 37]. According to [38], application of lime effectively increased the soil pH from extremely acidic to medium and neutral ranges. Cation exchange capacity (CEC) of the incubated soil has been significantly increased ($p < 0.05$) in lime and compost treated pots; the highest (31.58 $cmol_c kg^{-1}$) value was obtained in treatment two (8.44 $t{\cdot}ha^{-1}$and 10 $t{\cdot}ha^{-1}$ lime and compost, respectively) (Table 3). This highest value implies that lime and compost have a significant effect in increasing the CEC of soils through isomorphic substitutions. Similar to CEC, the exchangeable calcium contents were changed from 3.56 $cmol_c kg^{-1}$ in control to 8.43 $cmol_c kg^{-1}$ in 8.44 $t{\cdot}ha^{-1}$ lime. Appreciable amounts of Ca had occurred as a result of combined application of lime and composts that would neutralize the soil acidity (Table 4). Along with an increase of free Ca^{2+}, the Al^{3+}/Ca^{2+} ratio drops significantly and one may assume that the negative effects of acidification have been largely alleviated [39].

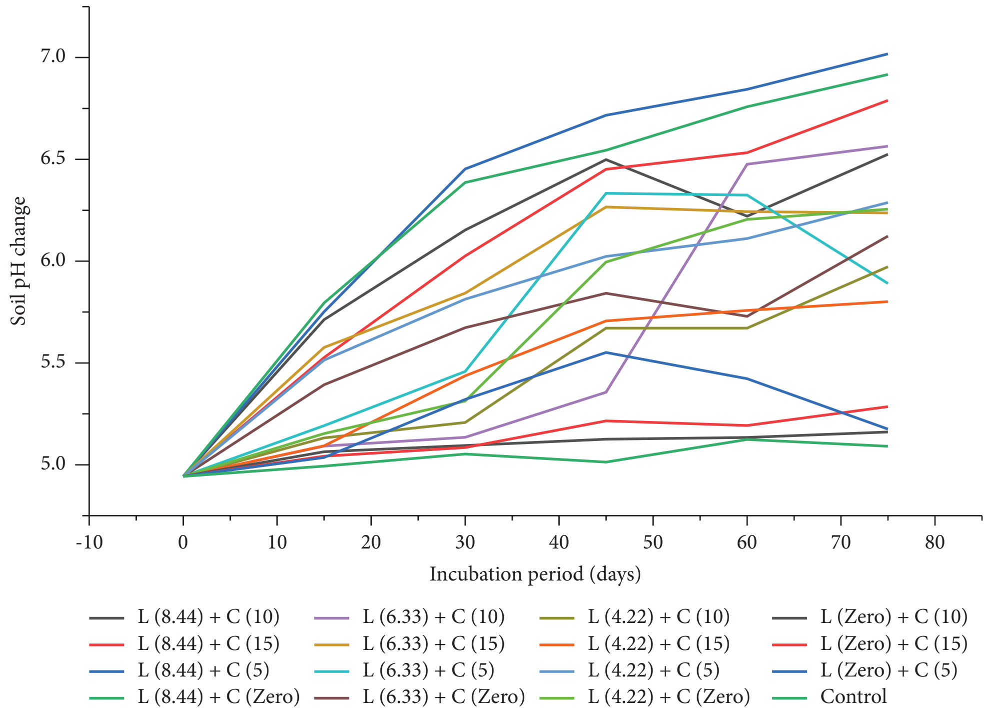

Figure 3: Lime and compost rate relationships with soil pH change within 75 days.

Table 4: Mean values of exchangeable bases and CEC treated with different rates of lime and compost.

Treatment	pH water (1 : 2.5)	Exchangeable Ca ($cmol_c \cdot kg^{-1}$)	Exchangeable Mg ($cmol_c \cdot kg^{-1}$)	Exchangeable K ($cmol_c \cdot kg^{-1}$)	CEC ($cmol_c \cdot kg^{-1}$)
1	6.48^{ba}	8.43^{a}	2.99^{ba}	1.20^{bdc}	30.20^{ba}
2	6.53^{a}	7.66^{ba}	2.72^{ebda}	1.11^{e}	31.58^{a}
3	6.34^{ba}	7.54^{ba}	2.50^{ed}	1.28^{a}	29.13^{bac}
4	6.19^{bc}	6.33^{dce}	2.33^{e}	1.17^{edc}	29.06^{bac}
5	5.69^{dgef}	6.17^{de}	2.56^{edc}	1.20^{bdc}	29.32^{bac}
6	5.92^{dc}	7.27^{bc}	2.89^{bdac}	1.23^{bac}	27.74^{bdc}
7	5.81^{def}	5.82^{dfe}	2.64^{ebdc}	1.24^{ba}	28.10^{bdc}
8	5.82^{def}	5.37^{fe}	2.51^{ed}	1.11^{e}	28.29^{bdc}
9	5.38^{gh}	6.34^{dc}	3.13^{a}	1.20^{bdc}	26.16^{d}
10	5.50^{gf}	5.45^{dfe}	2.97^{bac}	1.23^{bac}	29.01^{bdac}
11	5.53^{gef}	5.10^{f}	2.80^{bdac}	1.20^{bdc}	27.40^{bdc}
12	5.83^{de}	6.22^{de}	3.12^{a}	1.23^{bac}	26.66^{dc}
13	4.8^{1i}	3.35^{g}	2.69^{ebdc}	1.25^{ba}	28.07^{bdc}
14	4.8^{1i}	1.79^{h}	2.47^{ed}	1.20^{bdc}	27.29^{dc}
15	5.15^{h}	3.07^{g}	2.57^{ebdc}	1.17^{edc}	27.24^{dc}
16	4.69^{i}	3.56^{g}	2.86^{bdac}	1.16^{ed}	27.18^{dc}
CV (%)	3.41	10.35	9.64	3.19	6.09
LSD	0.32	0.96	0.44	0.06	2.86
Mean	5.65	5.59	2.73	1.20	28.28

Means within column followed by the same letter are not statistically different from each other at $p > 0.05$; LSD = least significant difference; CV = coefficient of variation.

Generally, lime and compost have the potential to increase the status of pH, CEC, and exchangeable bases which in turn improve the suitability of soils for crop production.

3.4. Nutrient Availability after Incubation. The available phosphorus (Av.P) concentration of the incubated soil was significantly ($p < 0.05$) increased than the control (Table 5). Based on the research conducted in acid soils of Ebantu District, Western Highlands of Ethiopia, the status of Av. P increased by 45% over the control due to the application of lime and organic matter [40]. This might be due to the conversion of unavailable P into available form because of the raise in pH and reduction of exchangeable acidity [41]. However, in the study area, the status of Av. P was not high, which indicates that the soils inherently have a deficiency in Av. P. Therefore, there is a need to consider

Table 5: Mean value of soil chemical properties treated with different rates of lime and compost.

Treatment	OC (%)	TN (%)	Av. P (ppm)	Ex. acidity ($cmol_c \cdot kg^{-1}$)
1	2.57^{bc}	0.21^{bc}	3.26^{ed}	Trace
2	2.38^{d}	0.19^{c}	3.80^{dc}	Trace
3	2.56^{bc}	0.19^{c}	3.25^{ed}	Trace
4	2.49^{c}	0.21^{bc}	2.90^{edf}	Trace
5	2.54^{c}	0.21^{bc}	4.35^{bac}	Trace
6	2.54^{c}	0.24^{a}	2.18^{gf}	Trace
7	2.51^{c}	0.21^{bc}	3.25^{ed}	Trace
8	2.50^{c}	0.20^{bc}	3.86^{bdc}	Trace
9	2.58^{bc}	0.19^{c}	4.84^{ba}	0.003^{e}
10	2.65^{ba}	0.22^{bac}	4.58^{bac}	0.001^{b}
11	2.49^{c}	0.22^{ba}	3.05^{edf}	0.001^{b}
12	2.74^{a}	0.20^{bc}	2.38^{egf}	0.001^{b}
13	2.57^{bc}	0.21^{bc}	4.61^{bac}	0.001^{b}
14	2.51^{c}	0.21^{bc}	5.27^{a}	1.03^{a}
15	2.49^{c}	0.21^{bc}	4.72^{bac}	1.05^{a}
16	2.50^{c}	0.19^{c}	1.63^{g}	0.73^{b}
CV (%)	2.49	8.23	16.34	18.60
LSD	0.11	0.03	0.98	0.10
Mean	2.45	0.21	3.62	0.33

Means within column followed by the same letter are not statistically different from each other at $p > 0.05$; LSD = least significant difference; CV = coefficient of variation.

Table 6: Mean value plant height, stand count, biomass, and grain yields treated with different rates of lime and compost.

Treatments	Plant height (cm)	Stand count (number pot^{-1})	Biomass yield (g pot^{-1})	Grain yield (g pot^{-1})
1	35.33^{ced}	9.33^{bdc}	15.75^{ba}	1.90^{b}
2	33.83^{ed}	8.33^{ed}	14.91^{bdac}	1.67^{ghf}
3	40.00^{b}	11.00^{a}	16.46^{a}	2.10^{a}
4	45.56^{a}	9.33^{bdc}	15.80^{ba}	1.87^{b}
5	34.33^{ced}	8.67^{edc}	14.94^{bdac}	1.83^{cb}
6	31.24^{e}	8.67^{edc}	13.87^{dec}	1.90^{b}
7	34.06^{ed}	10.00^{bac}	12.51^{fe}	1.62^{hi}
8	40.22^{b}	9.00^{dc}	12.71^{fe}	1.48^{j}
9	33.00^{e}	8.00^{edf}	12.66^{fe}	1.52^{ji}
10	38.33^{cbd}	10.00^{bac}	14.65^{bdc}	1.72^{ghef}
11	40.11^{b}	10.67^{ba}	14.07^{dec}	1.77^{cefd}
12	40.39^{b}	9.33^{bdc}	14.94^{bac}	1.75^{gcefd}
13	38.74^{cb}	6.67^{f}	14.85^{bdac}	1.79^{cebd}
14	38.78^{cb}	7.33^{ef}	13.27^{fde}	1.64^{gh}
15	40.92^{b}	8.33^{ed}	9.53^{g}	1.28^{k}
16	32.96^{e}	10.00^{bac}	11.95^{f}	1.69^{ghef}
CV (%)	7.37	9.71	7.22	4.08
LSD	4.58	1.46	1.67	0.12
Mean	37.36	9.04	13.93	1.72

Means within column followed by the same letter are not statistically different from each other at $p > 0.05$; LSD = least significant difference; CV = coefficient of variation.

phosphorus containing fertilizer in addition to lime and compost to optimize crop production in sustainable manner.

Incubation caused an increase in N from 0.19% (control) to 0.24% (the treatment that received 6.33 and 10 $t \cdot ha^{-1}$ lime and compost, respectively). As the soil acidity level decreased through liming, mineralization would take place as a result of favored microbial activities because liming minimizes the soil acidity level and improves mineralization of nitrogen. According to Uchida [42] study report, decomposition of residues and return of larger amount of nitrogen are rapid in the soil pH range of 6.0–6.5. Similarly, application of lime increases nitrate-N concentration in soil after incubation [43]. The exchangeable acidity also significantly ($p < 0.05$) reduced in lime-treated plots, but as the lime rate gets reduced to 4.22 $t \cdot ha^{-1}$, the exchangeable acidity has been increased. The mechanisms that reduced soil acidity in the experimental soil were displacement of Al^{3+} and H^{+} ions from the soil sorption sites by Ca^{2+} from lime [44]. Additions of organic amendments reduce exchangeable acidity by precipitating excess soluble Al [45].

3.5. Crop Performance and Liming. Integrated application of lime and compost in the rates of 8.44 and $5\,t{\cdot}ha^{-1}$, respectively, significantly ($p < 0.05$) increases wheat grain and biomass yields, but the plant height was higher in lime treatments without compost (Table 5). The study asserted that the combined application of lime and compost at the rate of 8.44 and $5\,t{\cdot}ha^{-1}$ showed optimum crop performance because several chemical properties of the soil were improved, which were helpful in improving plant growth in acid soil [30, 42]. The study conducted in the acidic soils of northwestern Ethiopia showed that application of $2\,t{\cdot}ha^{-1}$ lime, $6\,t{\cdot}ha^{-1}$ compost alone and their combination increased wheat grain yield by 24.6%, 42%, and 97.5%, respectively, as compared to the control [45]. Wheat yield improvement could explain by reduction of exchangeable acidity from its toxic concentration to trace. As the same time, availability of nutrients could be improved to optimize plant growth and yields. The lowest plant height and biomass were obtained from the control plot. The study revealed that soil acidity limits plant growth and consequently crop yield.

As it is presented in Tables 5 and 6, lime, compost, and integrated application increase soil pH and nutrient availability which increased wheat yields and associated plant growth parameters. Sole and combined application of lime and compost increased wheat grain yields, but the maximum yield (24.26%) was obtained in integrated application of lime and compost. The compost has the potential to reduce the Al^{3+} toxicity through the formation of organo Al complexes [35] and increase the quality of wheat flour due to the increase in the amount of gluten protein [46].

4. Conclusions

The experimental soil had strongly acidic pH that adversely affects plant nutrient availability which in turn affects crop yield. The sole and integrated application of lime and compost had increased the pH status of the soil. Acid soil amelioration using integrated approaches was improved due to soil reaction, CEC, exchangeable Ca, Av. P, and reduced exchangeable acidity. The overall soil chemical properties' improvement results in better nutrient availability that would favor wheat growth and yields. As the incubation experiment indicated, the minimum time required to achieve the desired soil pH was seventy-five days. Compost application alone does not reduce soil acidity within the seventy-five day period. Within this time frame, the treatment received 8.44 limes combined with $5\,t{\cdot}ha^{-1}$ and the compost attained desired soil pH and better wheat yields. Since the incubation and greenhouse experiment were conducted in a controlled environment, there is a need for field verification. It is also advisable to assess the economic feasibility of the different rates of lime and compost for an appropriate soil management decision.

Data Availability

All the data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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References

[1] B. Gurmessa, "Soil acidity challenges and the significance of liming and organic amendments in tropical agricultural lands with reference to Ethiopia," *Environment, Development and Sustainability*, vol. 23, pp. 77–99, 2020.
[2] H. Schlede, *Distribution of Acid Soils and Liming Materials in Ethiopia*, Ethiopian Institute of Geological Survey, Addis Ababa, Ethiopia, 1989.
[3] F. Adams, "Nutritional imbalances and constraints to plant growth on acid soils," *Journal of Plant Nutrition*, vol. 4, no. 2, pp. 81–87, 1981.
[4] R. Y. Shi, J. Y. Li, N. Ni, and R. K. Xu, "Understanding the biochar's role in ameliorating soil acidity," *Journal of Integrative Agriculture*, vol. 18, no. 7, pp. 1508–1517, 2019.
[5] W. Zhao, J. Li, J. Jiang et al., "The mechanisms underlying the reduction in aluminum toxicity and improvements in the yield of sweet potato (Ipomoea batatas L.) after organic and inorganic amendment of an acidic Ultisol," *Agriculture, Ecosystems & Environment*, vol. 288, Article ID 106716, 2020.
[6] N. C. Brady and R. R. Weil, *The Nature and Properties of Soils*, Prentice Hall, Saddle River, NJ, USA, 2002.
[7] L. Keino, B. Fredrick, W. Ngetich et al., "Nutrients limiting soybean (Glycine max L.) growth in acrisols and ferralsols of western Kenya," *PLoS One*, vol. 10, no. 12, Article ID 145202, 2015.
[8] B. Rukia, M. Nancy, T. Moses, and M. Cargele, "Impact of soil acidity and liming on soybean (Glycine max L.) nodulation and nitrogen fixation in Kenyan soil," *Acta Agriculturae Scandinavica Section B Soil and Plant Science*, vol. 70, no. 8, pp. 667–678, 2020.
[9] S. Y. Durgesh, J. Bhavna, G. Meenu, and A. Madhoolika, *Soil Acidification and its Impact on Plants*, Springer Nature, Singapore, 2020.
[10] N. C. Brady and R. R. Weil, *Nature and Properties of Soils*, Prentice Hall, Saddle River, NJ, USA, 2014.
[11] Y. He, F. Gu, C. Xu, and Y. Wang, "Assessing of the influence of organic and inorganic amendments on the physical-chemical properties of a red soil (Ultisol) quality," *Catena*, vol. 183, Article ID 104231, 2019.
[12] M. M. Masud, M. Abdulaha-Al Baquyb, S. R. Akhtera, A. Sen, A. Barmana, and M. R. Khatuna, "Ecotoxicology and environmental safety liming effects of poultry litter derived biochar on soil acidity amelioration and maize growth," *Ecotoxicology and Environmental Safety*, vol. 202, Article ID 110865, 2020.
[13] A. Abewa, B. Yitaferu, Y. Gselassie, and T. Tadele Amare, "The role of biochar on acid soil reclamation and yield of Teff (Eragrostistef[Zucc] Trotter) in Northwestern Ethiopia," *Journal of Agricultural Science*, vol. 6, no. 1, pp. 1–12, 2013.
[14] H. Wassie, *Proceedings Of The National Conference On Sustainable Land Management And Poverty Alleviation,*

Organized By Environmental Economics Policy Forum For Ethiopia At Ethiopian Development Research Institute, Sustainable Land Use Forum, Addis Ababa, Ethiopia, 2009.

[15] M. Asmare and Y. Markku, "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*, vol. 11, no. 2, pp. 87–99, 2016.

[16] A. B. Asresach, "Role of lime and compost on soil properties and yield of bread wheat (*Triticum aestivum* L.) in acidic soil of Ethiopia: a Review," *International Journal of Advanced Research in Biological Sciences*, vol. 9, no. 10, pp. 24–37, 2022.

[17] T. Yitbarek, A. Jembere, and H. Kerebeh, "Characterization and classification of soils of Wolkite University research sites, Ethiopia," *Eurasian Journal of Soil Science*, vol. 7, no. 4, pp. 292–299, 2018.

[18] M. S. Mokolobate and R. J. Haynes, "Comparative liming effect of four organic residues applied to an acid soil. Biology and Fertility of Soils," *Biology and Fertility of Soils*, vol. 35, pp. 79–85, 2002.

[19] P. A. Opala, J. R. Okalebo, and C. O. Othieno, "Effects of organic and inorganic materials on soil acidity and phosphorus availability in a soil incubation study," *ISRN Agronomy*, vol. 2012, Article ID 597216, 10 pages, 2012.

[20] A. Getu, S. Adissie, T. Taye, and T. Hailu, "Evaluation of lime requirement estimation methods for acid soil management and yield of bread wheat (Triticumaestivum L.) in Wadla District of North Wollo Zone of Amhara Region," *Academic Research Journal of Agricultural Science and Research*, vol. 8, no. 3, pp. 164–173, 2020.

[21] C. A. Black, *Methods of Soil Analysis Part II'*, Amer. Soc. Agron, Madison, WI, USA, 1965.

[22] M. C. Color, *Munsell Soil Color Charts*, Munsell Color Company Inc, Boston, Massachusetts, 1975.

[23] S. H. Chopra and J. S. Kanwar, *Analytical Agricultural Chemistry*, Kalyani Publisher, Ludhiana, India, 1976.

[24] G. J. Bouyoucos, "Hydrometer method improvement for making particle size analysis of soils," *Agronomy Journal*, vol. 54, no. 5, pp. 179–186, 1962.

[25] A. Walkley and I. A. Black, "An examination of different methods for determining soil organic matter and the proposed modifications by the chromic acid titration method," *Soil Science*, vol. 37, no. 1, pp. 29–38, 1934.

[26] S. R. Olsen, "Estimation of available phosphorus in soil by extraction with sodium bicarbonate," *USDA Circular*, vol. 939, pp. 1–19, 1954.

[27] H. D. Chapman, "Cation exchange capacity," in *Methods of Soil Analysis*, C. A. Black, Ed., Agronomy 9, American Society of Agronomy Inc, Madison, Wisconsinpp. 891–901, 1965.

[28] J. Jones, *Agronomic Handbook: Management of Crops, Soils, and Their Fertility*, CRC press LLC, Boca Raton, FL, USA, 2003.

[29] P. Hazelton and B. Murphy, *Interpreting soil test results: what do all the numbers mean?*, Chemin de Baillarguet: CSIRO Publishing, clayton, Australia, 2016.

[30] N. K. Fageria and V. C. Baligar, "Ameliorating soil acidity of tropical Oxisols by liming for sustainable crop production," *Advances in Agronomy*, vol. 99, pp. 345–431, 2008.

[31] T. Tekalign, "Soil, plant, water, fertilizer, animal manure and compost analysis," *Working Document No. 13*, International Livestock Research Center for Africa, Addis Ababa, Ethiopia, 1991.

[32] R. H. Miller and D. R. Keeney, "Methods of soil analysis 2: chemical and microbiological properties," *American Soc. of Agronomy*, vol. 148, no. 3, pp. 363-364, 1982.

[33] B. S. Sultana, M. H. Mian, M. Jahiruddin, M. M. Rahman, M. N. E. Alam Siddique, and J. Sultana, "Amendment of acidic soil with lime and manure for enhancing fertility, nutrient uptake and yield of wheat-mungbean-Monsoon rice in the old himalayan piedmont plain," *Asian Journal of Soil Science and Plant Nutrition*, vol. 4, no. 2, pp. 1–26, 2019.

[34] N. Wegene, "Review on the extent of acid soil in Ethiopia, its mmpact and management methods," *Journal of Biology, Agriculture and Healthcare*, vol. 9, no. 15, pp. 29–36, 2019.

[35] J. R. Johnson, B. F. Carver, and V. C. Baligar, "Productivity in Great Plains acid soils of wheat genotypes selected for aluminum tolerance," *Plant and Soil*, vol. 188, pp. 101–110, 2007.

[36] J. E. Holland, P. White, M. J. Glendining, K. W. T. Goulding, and S. P. McGrath, "Yield responses of arable crops to liming–an evaluation of relationships between yields and soil pH from a long-term liming experiment," *European Journal of Agronomy*, vol. 105, pp. 176–188, 2019.

[37] S. M. Vieira Fontoura, O. H. de Castro Pias, T. Tiecher, M. Cherubin, R. P. de Moraes, and C. Bayer, "Effect of gypsum rates and lime with different reactivity on soil acidity and crop grain yields in a subtropical Oxisol under no-tillage," *Soil and Tillage Research*, vol. 193, pp. 27–41, 2019.

[38] D. Woubshet, K. Selamyihun, and C. Raghavaiah, "Effect of integrated use of lime, blended fertilizer and compost on productivity, nutrient removal and economics of barley (Hordeum vulgare L.) on acid soils of high lands in West Showa Zone of Ethiopia," *International Journal of Life Sciences*, vol. 5, no. 3, pp. 311–322, 2017.

[39] H. Siepel, R. Bobbink, B. P. van de Riet, A. B. van den Burg, and E. Jongejans, "Long-term effects of liming on soil physico-chemical properties and micro-arthropod communities in Scotch pine forest," *Biology and Fertility of Soils*, vol. 55, no. 7, pp. 675–683, 2019.

[40] B. Abdissa, K. Kibebew, B. Bobe, M. Yli-Halla, and B. Tesfaye, "Effects of lime, vermicompost, and chemical P fertilizer on selected properties of acid soils of Ebantu district, western Highlands of Ethiopia," *Applied and Environmental Soil Science*, vol. 2018, Article ID 8178305, 13 pages, 2018.

[41] N. Bolan, M. Hedley, and Z. Rengel, "Role of carbon, nitrogen and sulfur cycles in soil acidification," in *Handbook of Soil Acidity*, D. Marcel, Ed., Crc Press, Boca Raton, FL, USA,pp. 29–56, 2003.

[42] R. Uchida and N. V. Hue, *Soil Acidity and Liming. Plant Nutrient Management in Hawaiis Soils, Approaches for Tropical and Subtropical Agriculture*, University of Hawaii at Manoa, Honolulu, HI, USA, 2000.

[43] N. P. Mkhonza, N. N. Buthelezi-Dube, and P. Muchaonyerwa, "Effects of lime application on nitrogen and phosphorus availability in humic soils," *Scientific Reports*, vol. 10, no. 1, p. 8634, 2020.

[44] C. Tang, Z. Rengel, E. Diatloff, and C. Gazey, "Responses of wheat and barley to liming on a sandy soil with subsoil acidity," *Field Crops Research*, vol. 80, no. 3, pp. 235–244, 2003.

[45] K. A. Gopinath, S. Saha, B. L. Mina, H. Pande, S. Kundu, and H. S. Gupta, "Influence of organic amendments on growth, yield and quality of wheat and on soil properties during transition to organic production," *Nutrient Cycling in Agroecosystems*, vol. 82, no. 1, pp. 51–60, 2008.

[46] A. D. Noble, I. Zenneck, and P. Randall, "Leaf litter ash alkalinity and neutralisation of soil acidity," *Plant and Soil*, vol. 179, no. 2, pp. 293–302, 1996.