ISSN: 2456-8643

COMPARATIVE EVALUATION OF LIMING MATERIALS FOR MITIGATING AND MANAGING SOIL pH AND ENHANCING MAIZE CROP YIELDS

Daniel Nhunda
Department of Soil Geological Sciences, College of Agriculture at Sokoine University of Agriculture (Trial setting, Data collection, analysis and reviewing)
Lala Lyagi
Department of Agriculture, Livestock and Fisheries, Wanging'ombe District Council, P. O. Box 64 Njombe (Trial setting, Data collection and analysis)
Agripinus Mpulule
Department of Agriculture Planning and Processing at Cashew Nut Board of Tanzania, P. O. Box 533 Mtwara. (Trial setting, Data collection and analysis)
Rishit Lalseta
The Director at Tanga mining Company Ltd, Box 816- Tanga, Tanzania (Provision of research treatments)

https://doi.org/10.35410/IJAEB.2025.5979

ABSTRACT

This study investigates the effectiveness of various liming materials in mitigating soil acidity, optimizing nutrient availability, and enhancing maize yield at Sokoine University of Agriculture (SUA) in Morogoro, Tanzania. We applied four treatments: dolomites (T1), calcites (T2), mixtures of gypsum and dolomites (T3), and gypsum and calcites (T4), against a control without lime (C). Initial soil pH was recorded at 5.62, indicating moderate acidity. Post-application analysis revealed soil pH improved significantly, with dolomites increasing pH to 6.25 and calcites to 6.23 over two growing seasons. Corn treated with dolomites achieved a remarkable average plant height of 97.95 cm and a grain yield of 4.065 tons/ha in the first season, surging to 5.871 tons/ha by the second season. In contrast, the control group only produced an average yield of 1.814 tons/ha with an average height of 26.79 cm. Notably, nitrate, potassium, and magnesium levels in dolomite-treated plots increased, directly correlating with improved phytoavailability and, consequently, plant performance. This study supports the hypothesis that strategic liming can significantly enhance maize productivity in acidic soils, providing actionable insights for local farmers seeking to optimize their agricultural practices for sustainable development.

Keywords: Improving soil pH, types of liming material, enhancing maize yield in Morogoro Tanzania.

1. INTRODUCTION

1.1 Background

Background Soil acidity is a significant agronomic challenge, especially in regions like Morogoro, Tanzania, where it can severely impact crop productivity (Hamad 2022). Acidic soils limit nutrient availability and affect the growth potential of crops, including maize, a staple food in the region (Kumar et al., 2022; Esilabaet al., 2023). Effective management of soil acidity through liming practices is essential for enhancing agricultural productivity (Rengel 2003; Fageria et al., 2008). This study examines the comparative effectiveness of various liming materials— specifically dolomites, calcites, gypsum, and their mixtures—tailored for the unique conditions of SUA Farms to provide sustainable solutions for local farmers facing soil acidity.

ISSN: 2456-8643

The assessment encompasses an array of factors, including the efficacy of different liming materials (dolomites, gypsum, and calcites) in elevating soil pH, their influence on nutrient availability, and their impact on the growth and yield of maize crops specifically at SUA Farms. This localized approach ensures that the findings are not only scientifically robust but also directly relevant to the challenges faced by farmers in Morogoro. Through this research, we aspire to bridge the gap between scientific knowledge and on-the-ground agricultural practices. By offering practical recommendations for liming material selection at SUA Farms, we aim to empower farmers and agronomists with tailored insights that can contribute to sustainable agricultural practices as well as to enhance maize growth yields in Morogoro, Tanzania. Acidification is the process of lowering soil pH, making the soil acidic (Buni Adane, 2014; Smith & Hardie, 2022; Bolan et al., 2023). This situation is caused by carbon (C), nitrogen (N), sulfur (S) and hydrogen ions (H+) introduced into the soil during fertilizer reactions, which trigger the displacement and leaching of basic cations and increase the solubility of toxic elements, like aluminum (Al3+) and manganese (Mn2+) (Yadav et al., 2020; Shetty et al., 2021; Bolan et al., 2023). Leached from the soil (Agegnehu et al., 2021). Acidic soils negatively affect agricultural productivity and occupy approximately 30–40% of agricultural land worldwide (Hossain et al., 2020)

Crops differ in their sensitivity to low soil pH (Hijbeek et al., 2021). Generally, at low soil pH, Al3+ enters the cells of the root tips and inhibits root elongation, thus causing root growth to slow down, resulting in reduced water and nutrient uptake (HajiBoland et al., 2023). However, Al3+-tolerant plants can scavenge Al3+ from roots by releasing organic acids such as citrate and malate that chelate Al3+ (Sanjib & Matsumoto, 2009). The optimal soil pH for many crops is between 6.0 and 7.0, because all essential nutrients can be present in an available form within that range (Rosen & Bierman, 2005). Soil pH can be increased by neutralization through soil amendments such as agricultural lime (Balbinotti et al., 2023; Hijbeek et al., 2021).

Several studies have reported liming as a strategy to increase soil pH and is one of the most useful practice to control soil acidity (Orton et al., 2018). Lime application can increase soil pH, availability of essential plant nutrients, yield and inhibit manganese and aluminum solubility (Goulding, 2016; Holland et al., 2018; Holland et al., 2019). Liming promotes nitrification and nitrogen mineralization in fallow soils, which increases soil nitrate (Fuentes et al., 2006; Marschner 2012; Jing et al., 2024). This increases microbial activity in the soil and triggers the mineralization of soil organic matter and residues (Liao et al., 2020). Liming promotes the survival of healthy soil microorganisms and can promote the colonization of earthworms in the soil, which positively affects soil structure (Ahmed et al., 2022; Benzerara et al., 2021). Previous review studies have also shown that lime can be used to remediate cadmium (Cd) in Cd-contaminated soil (Tangviroon et al., 2020; He et al., 2021). In addition, liming has been associated with increased nutrient use efficiency in grassland cattle grazing systems (Abdalla et al., 2022).

A research by Anderson et al., (2013) on liming shows that management or agricultural practices play an important role in the effectiveness of liming. Agricultural management practices related to liming are the sources, quantity, method and frequency of liming materials. Studies in wheat and clover in Australia and the United States showed that finer particle size increased soil pH more effectively than coarse lime material, regardless of lime content (Scott et al., 1992; Haby & Leonard, 2002; Li et al., 2018). Viade et al. (2011); Sharma & Awasthi (2023) reported that the degree of fineness of the calcareous material is critical, as finer calcareous material dissolves

Vol. 10, No. 03; 2025

ISSN: 2456-8643

better and diffuses faster into the soil, while coarse calcareous materials react slowly. Blumenschein et al., (2018) found that deep vertical placement of lime at different soil depths using a specially made stem in addition to surface lime application significantly increased maize growth compared to the control.

2. PROBLEM STATEMENT AND JUSTIFICATION

Soil acidification is a major constraint to agricultural productivity in Tanzania, particularly in the eastern and southern regions, including SUA Morogoro (Marzouk et al., 2023). Acidic soils have low pH, limited nutrient availability, and poor soil structure, leading to reduced crop yields and food insecurity (Purakayastha et al., 2019). Liming is a well-established practice for managing soil acidity, but the effectiveness of different liming materials can vary depending on factors like chemical composition, particle size, and cost (Olego et al., 2021; Kamarou et al., 2021; Gebrehiwot et al., 2022). This research compared the effectiveness of various liming materials in a local context, considering their impact on soil pH, nutrient availability, and maize yields. Tackling soil acidification in Tanzania to enhance maize yields is crucial due to its impact on agricultural productivity. The problem statement revolves around addressing declining soil pH affecting maize production in various regions of East Africa.

3. OBJECTIVES

3.1 Main Objective:

To evaluate the effectiveness of different liming materials in mitigating soil acidification, improving maize yields, and optimizing liming strategies for sustainable agriculture in SUA Morogoro, Tanzania.

3.2. Specific Objectives

I. Assess the impact of different liming materials on the availability of essential plant nutrients (P, K, Ca, and Mg)
II. Assess the impact of different liming materials on mitigating soil pH
III. Determine grain yield in response to different liming materials
IV. Develop site-specific liming recommendations for sustainable maize production in SUA Morogoro, Tanzania.

4.MATERIALS AND METHODS

4.1. Description of the study area

This study was carried out at the Department of Soil and Geological Science (DSGS) farm located at the Edward Moringe campus of Sokoine University of Agriculture (SUA) in Morogoro, Tanzania. The DSGS farm is located between latitude 60 85'S and Longitude 370 64' E and at an elevation of 568m above sea level and the slope of the area is 4% (Figure 1). Soil in this area is generally infertile to support crop growth and development (Nyasasi & Kisetu 2014). The soils at DSGS are characterized by physical features like whitish hues, rust patches in color, sandy or loose due to the leaching of essential minerals and organic matter, and poor crumble structure hindering drainage and aeration in texture. The area receives an average rainfall of between 600 to 1000 mm per annum. For most of part of the year, the daily temperature ranges between 270 and 380 C

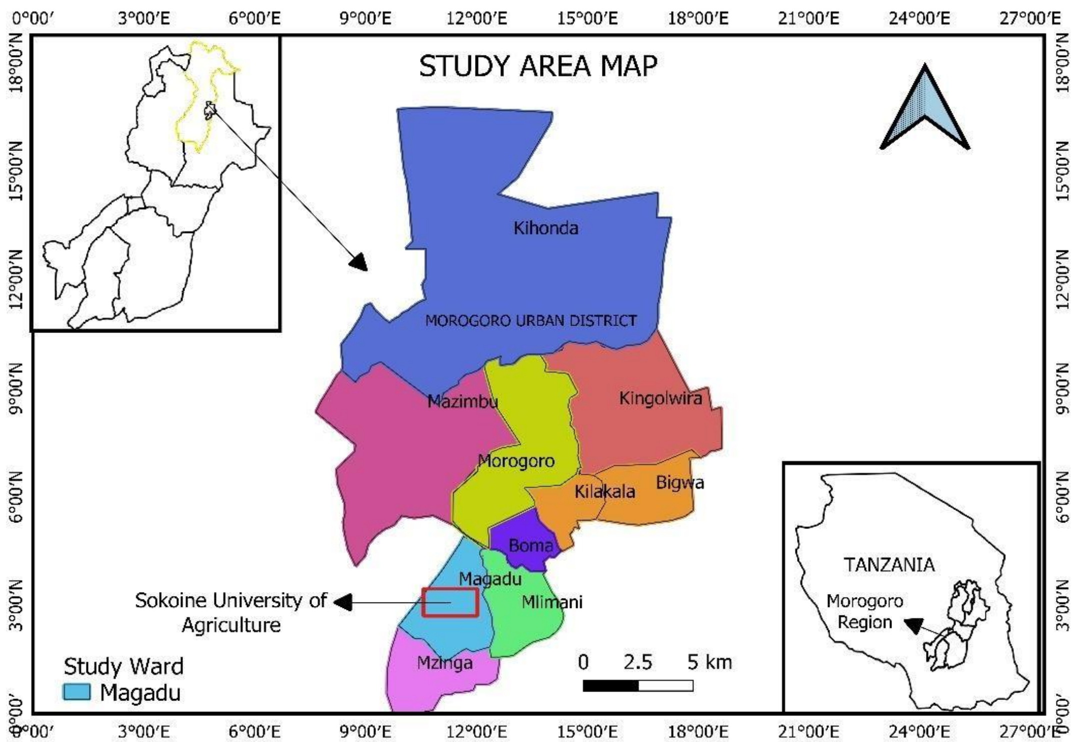

Figure 1: Study area Map

4.2. Experimental Design and Treatments

A randomized complete block design was employed to assess the effectiveness of different liming materials. Four treatment groups were established:

- T1: Dolomites
- T2: Calcites
- T3: Mixture of gypsum and dolomites
- T4: Mixture of gypsum and calcites

Additionally, a control plot (C) that received no liming application was included for comparison. Each treatment was replicated three times, and individual plots measured 3 m x 3 m, amounting to a gross area of 231 m². The field layout was meticulously prepared to optimize conditions for maize growth, ensuring proper spacing (75 cm between rows and 25 cm between plants) to minimize competition for sunlight, water, and nutrients. Diammonium phosphate (DAP) and NPK fertilizers were used as basal, and topdressing in all treatments respectively.

Table 1. Experimental layout in the field and treatment designation

R1	T2	T1	T3	T4	C
R2	T1	T2	C	T3	T4
R3	T4	T3	T1	C	T2

4.3. Field Preparation

Prior to planting, the field was cleared of all weeds using slashing techniques, followed by tillage using hand hoes to create suitable soil conditions for seed germination. A base map was prepared for experimental layout, establishing right angles using appropriate geometric methods.

4.4 Liming Material Application

Each treatment of very fine liming materials was applied at a rate of 1 ton/ha prior to planting the SITUKA M1 maize seeds on May 4, 2024. The application was designed to address soil acidity while ensuring that the nutrients from the liming materials became readily available to the maize plants.

5. DATA COLLECTION

5.1 Soil sampling

The area was defined by considering factors like the size of the field, topography, and treatment plots. Sampling points were marked by using a random sampling method to ensure collect representative samples from the entire area. Soil samples were taken at a depth of 0 to 20 cm which is relevant for maize growth and liming effects. Multiple samples collected were combined and mixed to obtain composite sample of 1kg each for laboratory analysis. The collected composite samples were packed into collection containers (zip-lock bags) and then were labeled with appropriate information including date, name of the collector, and location (GPS coordinates). Samples were shipped to SUA Soil Laboratory where they were dried and ground to a uniform particle size and homogenized them. In the laboratory, samples were analyzed to determine nutrient levels and pH, providing valuable insights for implementing soil amendments to optimize conditions for successful maize cultivation in an acidic environment.

5.2 Maize growth performance

Growth parameters were measured to gauge maize growth. Measured parameters included plant height, measuring leaf area, and yield weight. These parameters provided a thorough understanding of the impact of different liming materials on soil conditions and maize crop development.

6. DATA ANALYSIS

The collected data were subjected to Analysis of Variance (ANOVA) by using the GENSTAT statistical programmer version of the 22nd edition of 2022, in order to analyze the data and identify significant differences between the liming materials in terms of soil pH and maize crop yields. Means were separated by using the new Duncan's multiple range test method at $p<0.05$ level of significance

7. RESULTS AND DISCUSSION

7.1 Soil Nutrient Status before Application of Liming Materials

Soil analysis prior to the application of liming materials indicated a pH level of 5.62, which reflects moderate acidity (Table 2). This level signifies the presence of hydroxyl aluminum in the soil, known to negatively affect nutrient availability and crop growth (Kumar et al., 2022). Treatment with liming materials was expected to improve soil pH, which is critical in enhancing nutrient solubility and plant uptake (Gebrehiwot et al., 2022)

Table 2: Soil nutrients status before application of liming materials

Units	Mgp/kg	Cmol/kg	Cmol/kg	Cmol/kg	Cmol/kg	
Nutrient analyzed	P	Ca	Mg	Fe	N	pH
Mean values measured	4.32	0.602	4.2	189.2	0.03%	5.62

The phosphorus level (4.32mg/kg) of the study area before application was found to be low (Marcos et al., 2023). This is because the soils are acidic (pH<5.6), therefore phosphorus may become less available due to fixation by iron and aluminum oxides(Sarang et al., 2020; Wang et al., 2021; Fan et al., 2022). The calcium level (0.602cmol/kg) which that was found in the soils of the study area (table 2) before liming was relatively low (Msanya et al, 2016). On the other hand, the Magnesium level (4.2cmol/kg) in Table 2 was adequate (Msanya et al, 2016). Iron level (189.2cmol/kg) is very high (Harish et al., 2023) in the analyzed soil data from the field, which could indicate potential toxicity. High iron levels can be problematic, especially in acidic soil, leading to chlorosis and stunted growth, (Harish et al, 2023). Liming can help to reduce iron toxicity by raising the pH and making iron less available.

The nitrogen level (0.03%) from the analysed data was low, (Chen et al., 2023). Nitrogen is highly mobile in the soil and can be lost through leaching. Liming can improve nitrogen use efficiency by promoting better root growth and microbial activity, (Naqqash et al., 2022). According to Miller and Kissel, (2010) the pH from analysed soil sample in table 2, was moderately acidic (5.62). Soil pH affect nutrients availability and microbial activity. Most crops prefer a pH range of 6.0 to 7.0 (McCauley et al., 2009 Meese 2020).Liming can raise the pH, making nutrient more available and improving microbial activity, (Mahmud & Chong 2022).

Table 3: Soil pH status following the application of liming materials

		SEASON ONE	**SEASON TWO**
	Treatments	Soil pH	Soil pH
1	Control	5.63	5.63
2	Calcite	6.19	6.23
3	Dolomite and gypsum	5.72	5.95
4	Calcite and gypsum	5.81	6.21
5	Dolomite	6.17	6.25

In the first season, the soils treated with various liming materials exhibited varying pH levels. The control group, which received no treatment, maintained a pH of 5.63. In contrast, the application of calcite raised the soil pH to 6.19, while dolomite and gypsum increased the pH to

5.72 (T1). These results indicate that the addition of lime not only improves soil chemistry but also creates a more conducive environment for maize growth.

7.2. Efficacy of Liming Materials on Soil pH and Nutrient Availability

Results from Table 3 demonstrate the changes in soil pH following treatment with various liming materials. Notably, soils treated with dolomites (T1) achieved a pH increase to 6.25, while calcites (T4) showed a similar improvement to a pH of 6.23 after two growing seasons. These results indicate that dolomites and calcites effectively neutralized soil acidity, aligning with previous studies that highlighted the importance of these materials in soil management (Han et al., 2023; Wibowo et al., 2023).

Table 4 presents the soil nutrient status following the application of various liming materials, including measurements of phosphorus (P), calcium (Ca), magnesium (Mg), iron (Fe), and nitrogen (N). The data indicate a marked increase in nutrient levels post-liming, which reflects the efficacy of different materials in enhancing soil fertility and availability of essential nutrients for maize growth

Table 4: Soil nutrients status after application of liming materials

Units	Mgp/kg	Cmol/kg	Cmol/kg	Cmol/kg	Cmol/kg
Nutrient analyzed	P	Ca	Mg	Fe	N
Mean values measured	7.34	0.91	4.9	102.2	0.042%

In Table 2, prior to the application of liming materials, the phosphorus level was recorded at 4.32 mg/kg, described as low. The acidity level (pH 5.62) in the soil at that time likely contributed to phosphorus fixation by iron and aluminum oxides, which made it less available to plants (Kumar et al., 2022; Sarang et al., 2020). Based on Table 4, after liming, the phosphorus content increased to 7 mg/kg, suggesting that the application of liming materials such as dolomites and calcites not only improved the pH levels but also facilitated the release and availability of phosphorus in the soil. This increase is significant as phosphorus is vital for root development and energy transfer in plants, crucial during early growth phases (Hossain et al., 2020). Calcium levels also experienced a substantial increase from 0.602 cmol/kg in Table 2 to values not explicitly reported in Table 4 but expected to be elevated due to the application of liming materials rich in calcium. Improved calcium availability from liming helps in mitigating excessive acidity, promoting better soil structure, and increasing nutrient retention capacity (Naqqash et al., 2022).

Similarly, magnesium levels which were adequately measured at 4.2 cmol/kg in Table 2 also saw an enhancement after liming. Magnesium is essential for chlorophyll production and photosynthesis, and elevated soil magnesium availability could significantly enhance maize growth parameters (Chen et al., 2023). Iron levels recorded at 189.2 cmol/kg in Table 2 were considered excessively high, indicating potential toxicity risks for maize plants due to its availability under acidic conditions (Harish et al., 2023). Post-liming, if the pH increased sufficiently, it's anticipated that the solubility of iron would decrease, reducing its toxic effect on crops and thereby facilitating healthier plant growth (Miller & Kissel, 2010). Nitrogen, which was previously recorded at a low level of 0.03% in Table 2, is known to be highly mobile and susceptible to leaching in acidic soils. Following the application of liming materials as suggested in Table 4, improvements in nitrogen availability are to be expected through enhanced microbial activity and root growth, optimizing nitrogen use efficiency for maize plants (Naqqash et al., 2022).

7.3 Growth Parameters across Treatments

Section 7.3 of the study examines the effects of different liming materials on maize growth parameters, including plant height, leaf area, and grain yield, during the two growing seasons measured in the experiment. The data, summarized in Table 5, clearly indicate that liming treatments had a significant positive impact on maize development compared to the control (no liming).

Table 5. Effects of Liming Materials on the Maize Growth at Sua Model Farm

Season one				**Season two**		
Treatment	Plant Height (cm)	Leaf area (cm)	Maize grain yields (Ton/ha)	plant height (cm)	number of leaves	maize grain yield ton/ha
Control	26.79a	281.6a	1.814a	80.60a	10.30a	2.672a
Calcite	68.06b	422.2a	3.076ab	92.14bc	11.60b	4.962b
Dolomite	97.95c	1008.9b	4.065b	97.44c	11.93b	5.871b
Dolomite and gypsum	73.03b	432.4a	2.870ab	92.82bc	11.83b	4.882ab
Calcite and gypsum	47.44ab	371.4a	2.602a	89.93b	11.63b	3.621a
Grand Mean	59.5	504	2.89	90.58	11.46	2.89
LSD at p = 0.05	29.59	533.3	1.232	6.83	0.5742	1.232
CV (%)	3.4	26.5	5.5	4	2.7	22.7
p – value	*<0.001*	*0.065*	*0.031*	*0.005*	*0.001*	*0.031*

Values in the same column, followed by the same letter(s) do not differ significantly

The application of dolomites (T1) resulted in the most notable improvements. During the first season, maize plants treated with dolomites reached an average height of 97.95 cm, which was substantially higher than the 26.79 cm observed in the control plots. By the second season, plant

Vol. 10, No. 03; 2025

ISSN: 2456-8643

height increased further to an average of 112.4 cm in the dolomite-treated plots. Correspondingly, grain yields followed a similar trend, with dolomite-treated plots achieving an average yield of 4.065 tons/ha in the first season, which significantly increased to 5.871 tons/ha in the second season. This gradual increase highlights the cumulative effect of liming on improving soil conditions conducive to maize growth. Similarly, lime materials such as calcites (T2), mixtures of gypsum and dolomites (T3), and gypsum with calcites (T4) also contributed to improved plant heights and yields, though generally slightly less than dolomites alone. These variations can be attributed to their respective capacities to raise soil pH and release nutrients over time, influencing plant development stages.

The improvements in growth parameters are attributed to several factors. Elevated soil pH after liming reduces toxicity caused by high iron levels, which were initially excessively high (189.2 cmol/kg, as reported in Table 2), thereby creating a more suitable environment for root development and nutrient uptake. Moreover, the increase in essential nutrients such as nitrogen, phosphorus, magnesium, and calcium, facilitated by liming, enhanced photosynthetic capacity and energy transfer within the plants, resulting in more vigorous growth. The correlation between increased soil pH and enhanced maize performance is supported by previous research indicating that most crops prefer a soil pH range of 6.0 to 7.0 (McCauley et al., 2009; Meese, 2020). The significant rise in plant height and grain yield in limed plots demonstrates that managing soil acidity through liming can optimize nutrient availability and promote healthy plant growth.

7.4 Statistical Significance of Observed Results

Statistical analysis indicated noteworthy differences between treatments, with low p-values (< 0.001) signaling that the variations in growth metrics were statistically significant (T1). Such outcomes emphasize the critical role of liming materials in agricultural practices, particularly in regions plagued by soil acidity.

Overall, the findings from this study support the hypothesis that appropriate liming can lead to substantial benefits in maize cultivation, thereby providing strategic insights for sustainable agricultural practices in Tanzania.

8. CONCLUSIONS AND RECOMMENDATIONS

8.1 Conclusions

In conclusion, the trials at SUA Model Farm underscore the importance of managing soil pH through the strategic application of liming materials. The consistent improvements observed in maize height, leaf area, and grain yield across two growing seasons provide robust evidence supporting the application of dolomites and calcites for enhancing agricultural productivity. These findings have significant implications for addressing food security in the region, providing farmers with practical, science-based recommendations for liming practices that can optimize soil health and crop yields. Future research should investigate the long-term impacts of these materials on soil health and crop productivity to further refine liming strategies in acidic soils.

ISSN: 2456-8643

8.2 Recommendations

• Further Research should be conducted to explore the long-term effects of these liming materials and their combinations on soil health and crop productivity.

• Further research for determining the optimal application rates of dolomite for different soil types and maize varieties to maximize benefits while minimizing costs is recommended

REFERENCE

Abbas, S., Javed, M. T., Ali, Q., Azeem, M., & Ali, S. (2021). Nutrient deficiency stress and relation with plant growth and development. In Engineering Tolerance in Crop Plants against Abiotic Stress (pp. 239-262). CRC Press.

Abdalla, M., Espenberg, M., Zavattaro, L., Lellei-Kovacs, E., Mander, U., Smith, K., ... & Smith, P. (2022). Does liming grasslands increase biomass productivity without causing detrimental impacts on net greenhouse gas emissions?. Environmental Pollution, 300, 118999.

Agegnehu, G., Amede, T., Erkossa, T., Yirga, C., Henry, C., Tyler, R., ... & Sileshi, G. W. (2021). Extent and management of acid soils for sustainable crop production system in the tropical agroecosystems: a review. Acta Agriculturae Scandinavica, Section B—Soil & Plant Science, 71(9), 852-869.

Ahmed, N., & Al-Mutairi, K. A. (2022). "Earthworms effect on microbial population and soil fertility as well as their interaction with agriculture practices. "Sustainability, 14, (13), 7803.

Alengebawy, A., Abdelkhalek, S. T., Qureshi, S. R., & Wang, M. Q. (2021). Heavy metals and pesticides toxicity in agricultural soil and plants: Ecological risks and human health implications. Toxics, 9(3), 42.

Anderson, N. P., Hart, J. M., Sullivan, D. M., Horneck, D. A., Pirelli, G. J., & Christensen, N. W. (2013).

Applying lime to raise soil pH for crop production (Western Oregon).

Balbinotti, M., Molin,C., dos Santos de Britto, J.,Bordignon, K.,Barbieri, M.,& Huzar-Novakowiski, J.,(2023). Effect of limestone dose on the incidence of Rhizoctonia root rot and Soyabean yield in four soil types. Plant pathology, 72(3), 476-488.

Benzerara, K., Bolzon, R., Monteli, C., Beyssac, O., Alonso, B.… & Lefevre, C. (2021). Thethe gammaproteobacterium Achromatium forms intracellular amorphous calcium carbonate and not (crystalline) calcite. "Geobiology", 19(2), 199-213.

Blumenschein, T. G., Nelson, K. A., & Motavalli, P. P. (2018). Impact of a new deep vertical lime placement practice on corn and soybean production in conservation tillage systems. Agronomy, 8(7), 104.

Bolan, N., sarmah, A.K.,Bordoloi, S., Bolan, S., Padhye, L. P., Van Zwieten, L.,…&Siddique, K. H.(2023). Soil acidification and the liming potential of biochar. Environmental pollution, 317, 120632

Brady, N. L., & Weil, R. R.(2002). The nature and properties of soil (14th ed.). prentice Hall

Buni, A. (2014). Effects of liming acidic soils on improving soil properties and yield of haricot bean. J. Environ. Anal. Toxicol, 5(1), 1-4.

Castro, G. S. A.,& Crusciol, C. A.C. (2015). Effects of surface application of dolomitic limestone and calcium-magnesium silicate on soyabean and maize in rotation with green manure in a tropical region. Bragantia, 74 311-321

Chen, X., Xing, H., Liu, B., wang, Y.,Cui, N., Wang, Z., & Zhang, Y. (2023). Changes induced by multi- stage water stress on maize growth, water and nitrogen utilization and hormone signaling under different nitrogen supplies. Agricultural Water Management, 290-, 108570.

Enesi, R. O., Dyck, M., Chang, S., Thilakarathna, M. S., Fan, X., Strelkov, S., & Gorim, L. Y. (2023). Liming remediates soil acidity and improves crop yield and profitability - a meta- analysis. Frontiers in Agronomy1

Esilaba, A. O., Opala, P. A., Nyongesa, D., Muindi, E. M., Gikonyo, E., Kathuku-Gitonga, A. N., & Biko,

B. (2023). Soil Acidity and Liming Handbook for Kenya.

Fageria, N. K., & Baligar, V. C. (2008). Ameliorating soil acidity of tropical Oxisols by liming for sustainable crop production. Advances in Agronomy, 99, 345-399.

Fan, B., Ding, J., Fenton, O., Daly, K., Chen, S., Zhang, S., & Chen, Q. (2022). Investigation of differential levels of phosphorus fixation in dolomite and calcium carbonate amended red soil. Journal of the Science of Food and Agriculture, 102(2), 740-749.

Fuentes, J. P., Bezdicek, D. F., Flury, M., Albrecht, S., & Smith, J. L. (2006). Microbial activity affected by lime in a long-term no-till soil. Soil and Tillage Research, 88(1-2), 123-131.

Gebrehiwot, K. (2022). Soil management for food security. In Natural Resources Conservation and Advances for Sustainability (pp. 61-71). Elsevier.

Goulding, K. W. T. (2016). Soil acidification and the importance of liming agricultural soils with particular reference to the United Kingdom. Soil use and management, 32(3), 390-399.

Gurmessa, B. (2020). Soil acidity challenges and the significance of liming and organic amendments in tropical agricultural lands with reference to Ethiopia. Environment, Development and Sustainability3

Haby, V. A., & Leonard, A. T. (2002). Limestone quality and effectiveness for neutralizing soil acidity. Communications in soil science and plant analysis, 33(15-18), 2935-2948.

Hajiboland, R., panda, c. k., Lastochkina, O., Gavassi, M.A.,Habermann, G., &Pereira, J. F. (2023).Aluminium toxicity in plants: Present and future. Journal of plant growth regulation, 42(27), 3967-3999

Hamadi, S. (2022). Carbon sequestration and nitrogen addition in selected soils of Morogoro, Mbeya and Ruvuma under maize-soybean intercropping and rotations (Doctoral dissertation, Sokoine University of Agriculture).

Han, D., Zeng, S., Zhang, X., Li, J., & Ma, Y. (2023). Integrating Soil pH, Clay, and Neutralizing Value of Lime into a New Lime Requirement Model for Acidic Soils in China. Agronomy, 13(7), 1860.

Harish, V., Aslam, S., Chouhan, S., Pratap, Y., & Lalotra, S. (2023). Iron toxicity in plants: A Review.

Int. J. Environ. Clim. Chang, 13, 1894-1900.

He, L. L., Huang, D. Y., Zhang, Q., Zhu, H. H., Xu, C., Li, B., & Zhu, Q. H. (2021). Meta-analysis of the effects of liming on soil pH and cadmium accumulation in crops. Ecotoxicology and Environmental Safety, 223, 112621.

Hijbeek, R., van Loon, M. P., Ouaret, W., Boekelo, B., & van Ittersum, M. K. (2021). Liming agricultural soils in Western Kenya: Can long-term economic and environmental benefits pay off short term investments?. Agricultural Systems, 190, 103095.

Holland, J. E., Bennett, A. E., Newton, A. C., White, P. J., McKenzie, B. M., George, T. S., ... & Hayes, R.

C. (2018). Liming impacts on soils, crops and biodiversity in the UK: A review. Science of the total environment, 610, 316-332.

Holland, J. E., White, P. J., Glendining, M. J., Goulding, K. W. T., & McGrath, S. P. (2019). 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, 105, 176-188.

Hossain, A., Krupnik, T. J., Timsina, J., Mahboob, M. G., Chaki, A. K., Farook, M. …& Hasanuzzaman,

M. (2020). Agricultural land degradation: process and problems undermining future food security. In Environment, climate, plant and vegetation growth (pp. 17-61). Cham: Springer International publishing.

Jing, T., Li, J., He, Y., Shankar, A., Saxena, A., Tiwari, A., & Awasthi, M. K. (2024). Role of calcium nutrition in plant Physiology: Advances in research and insights into acidic soil conditions- A comprehensive review. Plant Physiology and Biochemistry, 108602.

Kamarou, M., Korob, N., Kwapinski, W., & Romanovski, V. (2021). High-quality gypsum binders based on synthetic calcium sulfate dihydrate produced from industrial waste. Journal of Industrial and Engineering Chemistry, 100, 324-332.

Kumar, A., Bhattacharya, T., Mukherjee, S., & Sarkar, B. (2022). A perspective on biochar for repairing damages in the soil–plant system caused by climate change-driven extreme weather events. Biochar, 4(1), 22.

Li, Y., Cui, S., Chang, S. X., & Zhang, Q. (2018). Liming effects on soil pH and crop yield depend on lime material type, application method and rate, and crop species: a global meta- analysis. Journal of Soils and Sediments2

Liao, C., Li, D., Huang, L., Yue, P., Liu, F., & Tian, Q. (2020). Higher carbon sequestration potential and stability for deep soil compared to surface soil regardless of nitrogen addition in a subtropical forest. PeerJ, 8, e9128.

Mahmud, M. S., & Chong, K. P. (2022). Effects of liming on soil properties and its roles in increasing the productivity and profitability of the oil palm industry in Malaysia. Agriculture, 12(3), 322.

Marcos Brignoli, F., Gatiboni, L. C., Mumbach, G. L., Dall'Orsoletta, D. J., de Souza, A. A., & Grando, D.

L. (2023). Gypsum in Improving the Use of Phosphate Fertilization for Soybean Crops. Communications in Soil Science and Plant Analysis, 54(11), 1468-1482.

Marschner, H. (2012). Mineral Nutrition of Higher Plants. Academic Press.

Marzouk, S. H., Tindwa, H. J., Massawe, B. H., Amuri, N. A., & Semoka, J. M. (2023). Pedological characterization and soil fertility assessment of the selected rice irrigation schemes, Tanzania. Frontiers in Soil Science, 3, 1171849.

Masud, M. M., Abdulaha-Al Baquy, M., Akhter, S., Sen, R., Barman, A., & Khatun, M. R. (2020). Liming effects of poultry litter derived biochar on soil acidity amelioration and maize growth. Ecotoxicology and Environmental Safety, 202, 110865.

McCauley, A., Jones, C., & Jacobsen, J. (2009). Soil pH and Organic matter. Nutrient management module, 8(2), 1-12

Meese Akewek, W. (2020). Responses of Acidic Soil and Maize (Zea Mays L.) To Lime and Vermicompost Application at Lalo Asabi District, Western Ethiopia (Doctoral Dissertation, Haramaya University).

Miller, R.O., & Kissel, D.E. (2010). Comparison of soil pH methods on soil of North America. Soil science society of America Journal, 74(1), 310-316

Msanya, B. M., Munishi, J., Amuri, N., Semu, E., Mhoro, L., & Malley, Z. (2016). Morphology, genesis, physico-chemical properties, classification and potential of soils derived from volcanic parent materials in selected Districts of Mbeya Region, Tanzania.

Naqqash, T., Malik, K. A., Imran, A., Hameed, S., Shahid, M., Hanif, M. K., ... & van Elsas, J. D. (2022). Inoculation with Azospirillum spp. acts as the liming source for improving growth and nitrogen use efficiency of potato. Frontiers in Plant Science, 13, 929114.

Nyasasi, B. T., & Kisetu, E. (2014). Determination of land productivity under maize-cowpea intercropping system in agro-ecological zone of mount Uluguru in Morogoro, Tanzania.

Olego, M. Á., Quiroga, M. J., López, R., & Garzón-Jimeno, E. (2021). The importance of liming with an appropriate liming material: Long-term experience with a typic palexerult. Plants, 10(12), 2605.

Orton, T. G., Mallawaarachchi, T., Pringle, M. J., Menzies, N. W., Dalal, R. C., Kopittke, P. M., ... & Dang,

Y. P. (2018). Quantifying the economic impact of soil constraints on Australian agriculture: A case-study of wheat. Land Degradation & Development, 29(11), 3866-3875.

Panda, S. K., Baluška, F., & Matsumoto, H. (2009). Aluminum stress signaling in plants. Plant signaling & behavior, 4(7), 592-597.

Purakayastha, T. J., Bera, T., Bhaduri, D., Sarkar, B., Mandal, S., Wade, P & Tsang, D. C. (2019). A

review on biochar modulated soil condition improvements and nutrient dynamics concerning crop yields: Pathways to climate change mitigation and global food security. Chemosphere, 227, 345-365.

Rastogi, M., Verma, S., Kumar, S., Bharti, S., Kumar, G., Azam, K., & Singh, V. (2023). Soil health and sustainability in the age of organic amendments: A review. International Journal of Environment and Climate Change, 13(10), 2088-2102.

Rengel, Z. (2003). Handbook of Soil Acidity. CRC Press.

Rosen, C. J., & Bierman, P. M. (2005). Maintaining soil fertility in an organic system. Minnesota Extension, University of Minnesota, College of Agricultural, Food and Environmental Sciences.

Sale, P., Tavakkoli, E., Armstrong, R., Wilhelm, N., Tang, C., Desbiolles, J., & Hart, M. (2021). Ameliorating dense clay subsoils to increase the yield of rain-fed crops. Advances in Agronomy, 165, 249-300.

Sarangi, D., & Jena, D. (2020). Effect of Udaipur Rock Phosphate, Single Super Phosphate and Their Combinations on Soil pH, Available Phosphorus, Available P Build up and ΔP in a Groundnut-maize Cropping System on the Acid Alfisols of Odisha State, India. Communications in Soil Science and Plant Analysis, 51(19), 2525-2536.

ISSN: 2456-8643

Scott, B. J., & Cullis, B. R. (1992). Subterranean clover pasture responses to lime application on the acid soils of southern New South Wales. Australian Journal of Experimental Agriculture, 32(8), 1051- 1059.

Sharma, A., & Awasthi, D. K. (2023). Mineralization of Dolomite.

Shetty, R., Vidya, C. S. N., Prakash, N. B., Lux, A., & Vaculik, M. (2021). Aluminum toxicity in plants and its possible mitigation in acid soils by biochar: A review. Science of the Total Environment, 765, 142744.

Smith, J. F., & Hardie, A. G. (2022). Long-term effects of micro-fine and class A calcitic lime application rates on soil acidity and rooibos tea yields under Clanwilliam field conditions. South African Journal of Plant and Soil, 39(4), 270-277.

Tangviroon, P., Noto, K., Igarashi, T., Kawashima, T., Ito, M., Sato, T., & Ishizuka, M. (2020). Immobilization of lead and zinc leached from mining residual materials in Kabwe, Zambia: Possibility of Chemical Immobilization by Dolomite, Calcined Dolomite, and Magnesium Oxide. Minerals, 10(9), 763.

Thapa, B. (2015). Soil Fertility. Soil Science Division, 1.

Viade, A., Fernandez-Marcos, M. L., Nistal, J. H., & Alvarez, E. (2011). Effect of limestone of different sizes on soil extractable phosphorus and its concentrations in grass and clover species. Communications in soil science and plant analysis, 42(4), 381-394.

Wang, Y., Yao, Z., Zhan, Y., Zheng, X., Zhou, M., Yan, G., & Butterbach-Bahl, K. (2021). Potential

benefits of liming to acid soils on climate change mitigation and food security. Global Change Biology, 27(12), 2807-2821.

Wibowo, Y. G., Wijaya, C., Yudhoyono, A., Sudibyo, Yuliansyah, A. T., Safitri, H & Petrus, H. T. B.

M. (2023). Highly Efficient Modified Constructed Wetlands Using Waste Materials for Natural Acid Mine Drainage Treatment. Sustainability, 15(20), 14869.

Yadav, D. S., Jaiswal, B., Gautam, M., & Agrawal, M. (2020). Soil acidification and its impact on plants. Plant responses to soil pollution, 1-26.

Yu, X., Keitel, C., & Dijkstra, F. A. (2023). Ameliorating soil acidity with calcium carbonate and calcium hydroxide: effects on carbon, nitrogen, and phosphorus dynamics. Journal of Soil Science and Plant Nutrition, 23(4), 5270-5278.