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Effect of Calcium Source from Golden Apple Snail's Shell on Soil Nutrient and pH

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ABSTRACT

This study explores a sustainable approach to utilize golden apple snail shells as a soil amendment. Calcination process at 600°C created calcium carbonate ($CaCO_3$), while further increasing the temperature to 900°C produced calcium oxide (CaO). Microscopic (SEM) and spectroscopic (FTIR) analyses proved structural changes during calcination process. Both calcined shells were then applied to soil at various concentrations (2.50%, 5.00% and 7.50%). Based on the findings, CaO when applied at 5.00% concentration helps in improving soil pH, and at the same time increased nutrients (nitrogen, phosphorus and potassium) availability. Mixing 5.00% CaO in soil led to the highest levels of nitrogen on day 14. The same result was obtained for phosphorus and potassium, where the highest levels were obtained in the soil treated with CaO, compared to $CaCO_3$, dolomite, and the control. These findings highlight the potential of calcined shells, especially CaO as a promising and eco-friendly alternatives of liming materials which not only manage golden apple snail's invasion but also contribute to enhanced soil fertility.

Keywords: Golden Apple Snail, Calcium Carbonate, Calcium Oxide, Soil Amendment.

1. INTRODUCTION

Soil pH significantly influences plant health and growth by affecting nutrient uptake and the functionality of beneficial soil microorganisms. Most plants thrive in a pH range from slightly acidic to neutral, specifically between 6.0 and 7.0 (Ab Manan & Ab Aziz, 2018). When the soil pH is above 5.5, some essential elements become less available to plants due to changes on their chemical forms, making them insoluble and difficult for plant roots to absorb. At the same time, other essential elements for plant growth such as manganese and aluminum become more soluble, which could stop root growth. In alkaline soils, characterized by a pH above 7.5, there is a deficiency of nutrients such as iron, manganese, and phosphorus, which subsequently limits normal plant growth. Microbial activity was influenced by pH, which is critical for nutrient cycling and organic matter decomposition. Maintaining optimal soil pH is essential for ensuring that plants receive the necessary nutrients for healthy growth (Barrow & Hartemink, 2023). As a soil amendment, liming either by addition of materials rich in calcium or magnesium, can become an alternative approach in controlling soil acidity, in return providing several benefits for soil health and plant growth. Increasing soil pH by the addition of lime will subsequently reduce the soil acidity and in turn improving nutrient availability and crop growth (Dejene et al., 2023; Amsalu & Beyene, 2020).

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Enesi et al. (2023) stated that the application of liming in acidic soils is an effective approach in increasing soil pH, boosting base cation concentrations and amend toxicity caused by aluminium and manganese.

Golden apple snails (GAS), or scientifically known as *Pomacea canaliculata* are a problematic pest in agriculture, particularly in rice fields. This snail's invasion causes reduction of crop productivity, which negatively impact the environment and health through heavy reliance on agrochemical. Although golden apple snails are a nuisance, their shells represent a vastly underutilized resource. Its shell is made up of several layers including periostracum, prismatic and pearl layers, with prismatic layer as the strongest and rich in calcium (Leelatawonchai & Laonapakul, 2014). Laonapakul et al. (2019) mentioned that GAS shell could be utilized in the production of calcium compound with 95 – 98% pure calcium. By undergoing calcination, these shells may be converted into calcium carbonate ($CaCO_3$) and calcium oxide (CaO), a high-value agricultural input that can enhance soil quality and promote sustainable farming. While the potential of GAS shells as a source of calcium for agricultural use is recognized, there is lack of study on their efficacy as a practical soil amendment. There is a need to evaluate whether calcium sources derived from GAS shells can perform comparably to commercially available liming materials. Thus, the aim of this study is to evaluate the calcium sources from GAS as soil amendment for crop cultivation specifically by assessing their impact on soil pH and nutrient availability.

2. MATERIALS AND METHODS

2.1 Samples Collection and Preparation

GAS was collected from a paddy field in Pauh, Perlis. The shells were cleaned properly to remove any organic materials, dust particles or any other impurities. Excess liquid was removed by allowing the shells to remain at ambient temperature or exposed to light. The shell was then put into a furnace for three hours at 600°C to produce calcium carbonate ($CaCO_3$), and two hours at 900°C for the production of calcium oxide (CaO). The shell was then cooled at ambient temperature followed by further grinding into fine powder using pestle and mortar (Laonapakul et al., 2019). Shells dried at 80°C for 24 hours was further ground into powder and used as a control sample for characterization purpose. The fine powder was placed in a zip-lock bag and labelled as calcined-600, calcined-900 and dried shell.

2.2 Morphological Characterization

The dried and calcined shells were characterized using a Scanning Electron Microscopy (SEM) (Hitachi TM3000, Japan) referring to the method by Laonapakul et al. (2019). Sample of calcined-600, calcined-900 and dried shell were analyzed on their surface morphology and structural changes due to heat treatment. Samples were prepared by coating with a conductive material to prevent charging and placed in a vacuum chamber for imaging. SEM images revealed detailed surface features such as particle size, shape, and texture. The images were taken at three magnifications of 300x, 500x and 1000x.

2.3 Functional Groups Analysis

Fourier Transform Infrared Spectroscopy, FTIR (Perkin Elmer, USA) was used to identify functional groups and analyzed molecular structures by detecting chemical changes during the calcination of GAS shells, particularly the transformation of $CaCO_3$ to CaO. For analysis, the powdered sample (dried shell, calcined-600 and calcined-900) were mixed with potassium bromide (KBr) and formed into a pellet. Infrared radiation was then passed through the sample, and the absorbance of specific wavelengths corresponding to molecular vibrations was measured.

The resulting data was transformed into an FTIR spectrum, displaying absorbance versus wavenumber, to reveal structural changes. Method was done as referred to Seesanong et al. (2024).

2.4 Soil Analysis

2.4.1 Soil Preparation and Amendment

Loam soil was mixed with dolomite as the positive control, calcined-600 and calcined-900 at various concentrations (2.5%, 5%, and 7.5% w/w), and untreated soil acted as the negative control. Each of these powders were thoroughly mixed into the soil to ensure uniform distribution. Seedlings of bok choy (*Brassica rapa* var *chinensis*) were transferred from the seedling pots into polybags and watered daily. Five g of fertilizer was poured into each polybag after 14-days of transplant.

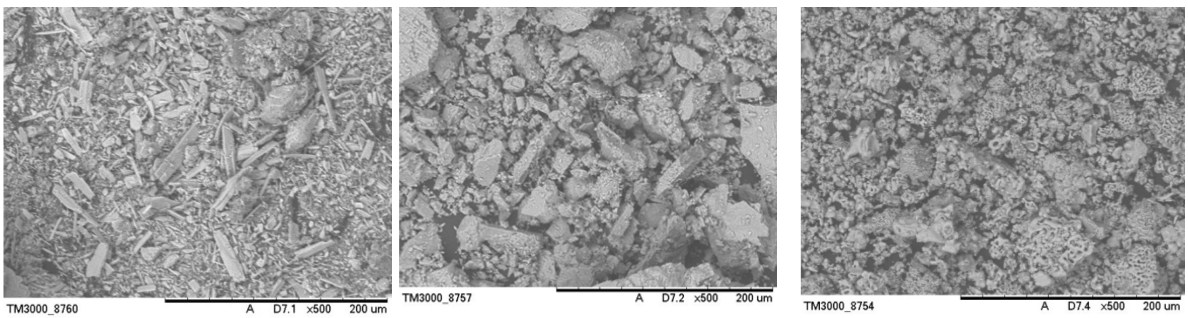
2.4.2 Soil pH and Nutrient Testing

The effectiveness of calcined snail shells compared to dolomite as soil amendments was evaluated by monitoring the soil pH and nutrient levels over time. Key nutrients such as nitrogen, phosphorus, potassium and calcium were also analyzed to assess their availability. The soil pH and nutrient were measured using the JXBS-3001-SCY-PT all-in-1 soil sensor.

3. RESULTS AND DISCUSSION

3.1 Microscopic Analysis

Figure 1(a), (b) and (c) presents the SEM images of ground dried GAS shells, GAS shell calcined at 600°C to produce calcium carbonate ($CaCO_3$), and GAS shell calcined at 900°C to produce calcium oxide (CaO) captured at 500X magnifications, respectively.



(a) (b) (c)

Figure 1: Microscopic analysis for (a) dried GAS shell (b) calcined-600 ($CaCO_3$) (c) calcined-900 (CaO)

Figure 1(a) shows fibrous layers and irregular particle sizes reflecting the biogenic origin of the material, with no signs of thermal decomposition. However, in Figure 1(b), it can be observed that flaky and angular particles with visible voids and micro-cracks likely from CO_2 release during calcination were observed with enhanced surface area that could improve ion exchange and nutrient retention in soil amendments. Calcination at 900°C gives a porous and granular surface morphology as in Figure 1(c). The particles can be seen much smaller, in which the original shell materials was greatly destroyed during the calcination process, in turning decomposing $CaCO_3$ into CaO. The results are in agreement with Seesanong et al. (2024), Laonapakul et al. (2019) and Leelatawonchai and Laonapakul (2014). Seesanong et al. (2024) in their reports mentioned that the morphological analysis of calcined shells might differ in shape and size depending on different calcination temperatures and types of gases produced due to thermal decomposition in each step.

3.2 Spectroscopic Analysis

Figure 2 presents the FTIR spectra of (a) dried shell, (b) GAS shell calcined at 600°C and (c) GAS shell calcined at 900°C.

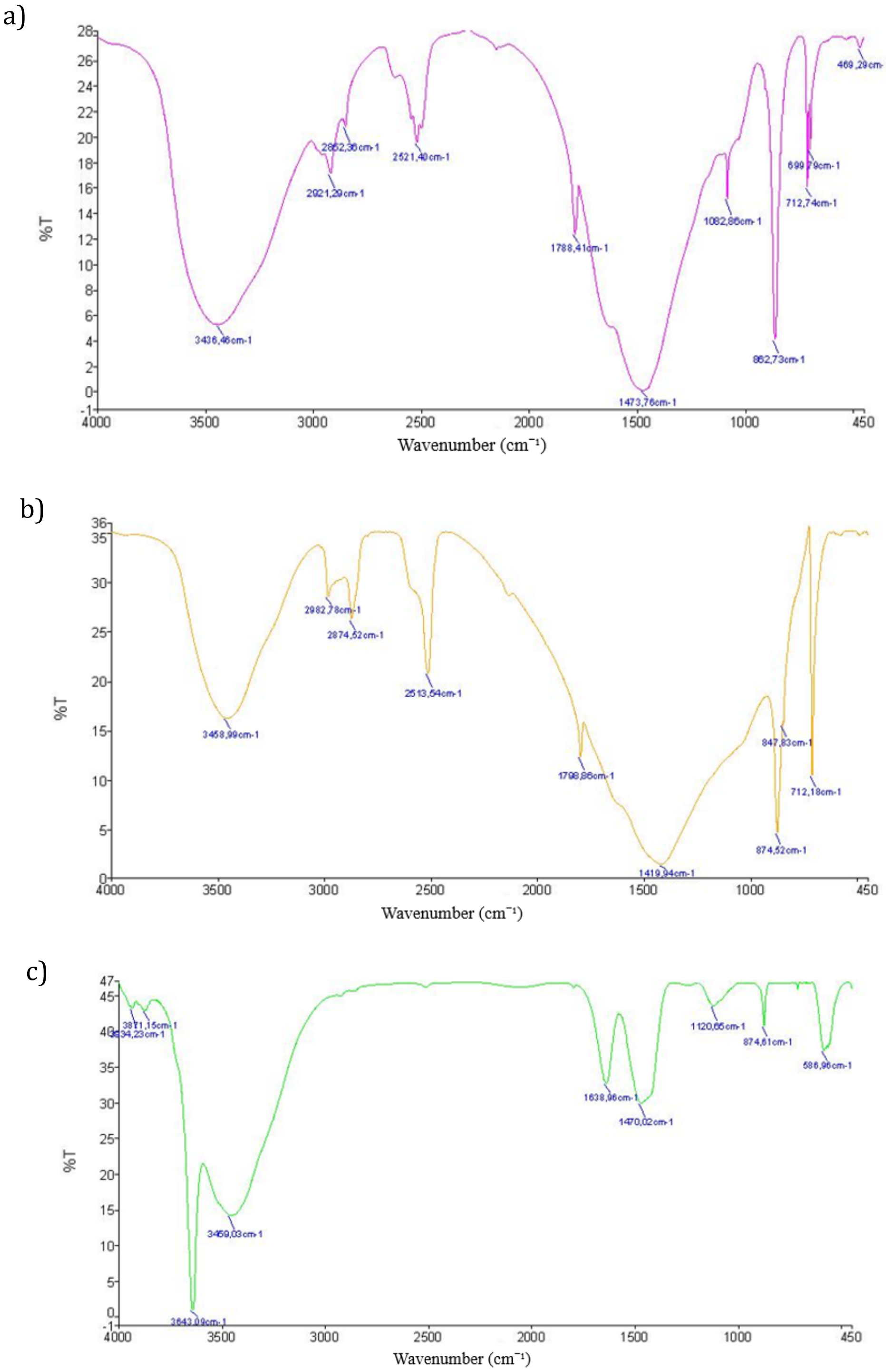


Figure 2: Fourier-Transform Infrared (FTIR) spectra of (a) dried GAS shell (b) calcined-600 ($CaCO_3$) (c) calcined-900 (CaO)

The result highlights chemical and structural changes during the calcination process where the decomposition of calcium carbonate ($CaCO_3$) to calcium oxide (CaO) can be detected. Based on Figure 2(a), strong C-H absorption bands (2800–3300 cm^{-1}) indicated the presence of organic matter, which progressively disappears at higher temperatures, signifying thermal decomposition. Prominent carbonate peaks (1430–1470 cm^{-1}) were visible in ground and 600°C samples (Figure 2(b)), confirming the presence of $CaCO_3$, but these peaks appear weakened or vanished at 900°C, indicating decomposition of $CaCO_3$ into CaO and CO_2. Margaretha et al. (2012) mentioned in their study that the intensity of the characteristic peak of $CaCO_3$ decreases after the calcination process. However, it can be seen that there is a sharp OH absorption peak near 3643 cm^{-1} that appears only in Figure 2(c), confirming the formation of CaO. These changes align with Seesanong et al. (2019) and Margaretha et al. (2012).

3.3 Nutrient Analysis and pH

3.3.1 Nitrogen

Figure 3 illustrates the nitrogen (N) levels over a 21-day period in soils amended with calcined GAS shell (CaO, $CaCO_3$), and dolomite at concentrations of 2.5%, 5.0%, and 7.5%, compared to the control. On day 14, soil treated with 5.0% CaO showed the highest nitrogen level, suggesting optimal conditions for microbial activity and organic matter breakdown. Other soil amendments also showed improved nitrogen levels, particularly at 2.5% and 5.0%, though lesser than CaO. By day 21, the nitrogen levels declined across all treatments, likely due to plant uptake, leaching, or microbial immobilization. However, the nitrogen levels in soil treated with CaO, $CaCO_3$, and dolomite remained higher compared to untreated soil. This finding is in line with Dejene et al. (2023) mentioning that lime application showed a significant effect on the total nitrogen (TN) soil chemical properties when compared to the untreated plot.

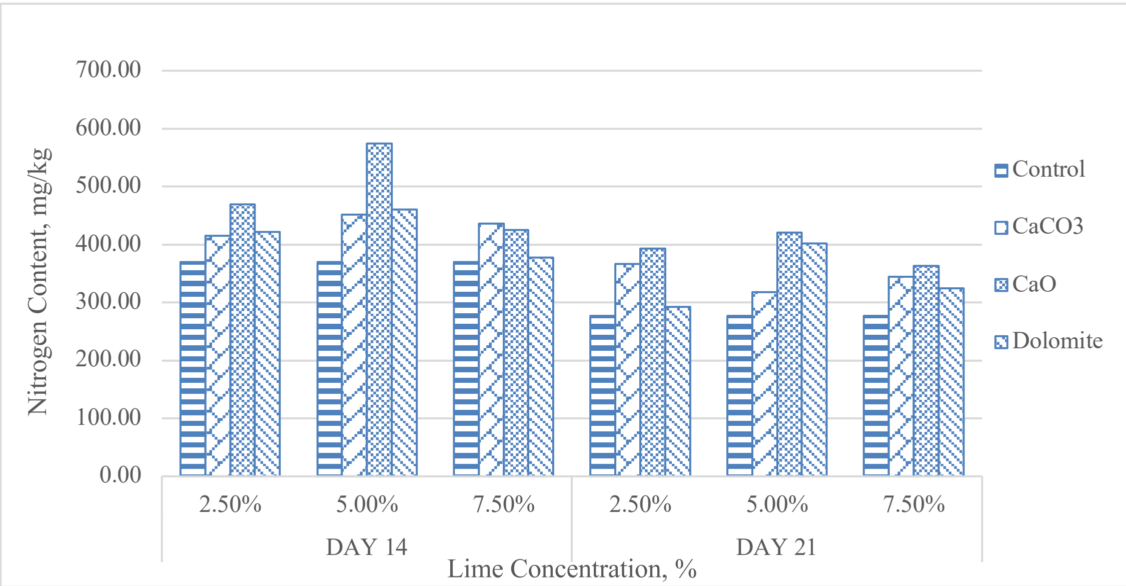


Figure 3: Nitrogen content in soil treated with calcined GAS shell ($CaCO_3$ and CaO) and dolomite

3.3.2 Phosphorus

Figure 4 illustrates the changes in phosphorus (P) levels for 14 and 21-days after transplant for soil treated with different concentrations of calcined GAS shell and dolomite (2.5%, 5% and 7.5%). Based on Figure 4, it can be seen that phosphorus level is higher in all treated soil ($CaCO_3$, CaO and dolomite) compared to control sample for all three concentration used. On day 21, when compared to day 14, slight decrease in phosphorus level was observed which most likely due to plant uptake, leaching or fixation. Phosphorus level in CaO-treated soil (even at different concentration) maintain the highest compared to control, $CaCO_3$-treated soil and dolomite-treated soil. However, all three liming agent showed higher phosphate values when compared to untreated soil, indicating that liming contributes to the release of available phosphate in soil. This study is in agreement with Ameyu (2019) and Buni (2014), describing increased trend in available phosphorus with lime applications. Use of lime can help to enhance phosphate availability by stimulating mineralization of organic phosphorus in the soil. Ameyu (2019) mentioned that application of liming contributes to the release of fixed phosphorus, making it available for plant uptake. The addition of lime and biochar will increase the soil's pH, subsequently causing elevation of rate at which phosphate ions are released (Adekiya et al., 2024). Thus, utilizing lime as soil amendments promotes hydrolization of aluminium and iron ions that have precipitated with phosphorus.

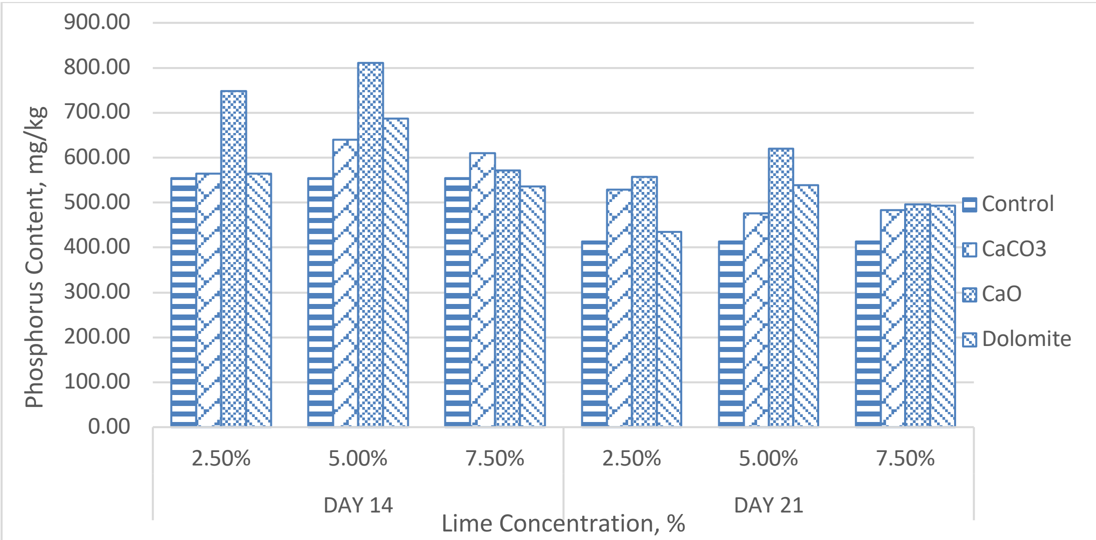


Figure 4: Phosphorus content in soil treated with calcined GAS shell ($CaCO_3$ and CaO) and dolomite

3.3.3 Potassium

Figure 5 illustrates the changes in the soil's potassium (K) levels, where at day 14, highest level of potassium can be observed in soil treated with 5% CaO, followed by dolomite and $CaCO_3$, while the control remained low. On day 21, potassium levels slightly declined compared to day 14, across all treatments, likely due to plant uptake or leaching. This finding is in agreement with Li et al. (2019) where their study reported that liming significantly improved total potassium (TK) concentration in field condition. However, based on Han et al. (2023), the influence on soil's K dynamics remains inconsistent under diverse acidic environment. Addition of lime on acidic soil may increase available exchange site which caused higher capacity to hold and retain potassium, resulting in higher soil's K availability and also enhanced uptake of K by crops (Han et al., 2019).

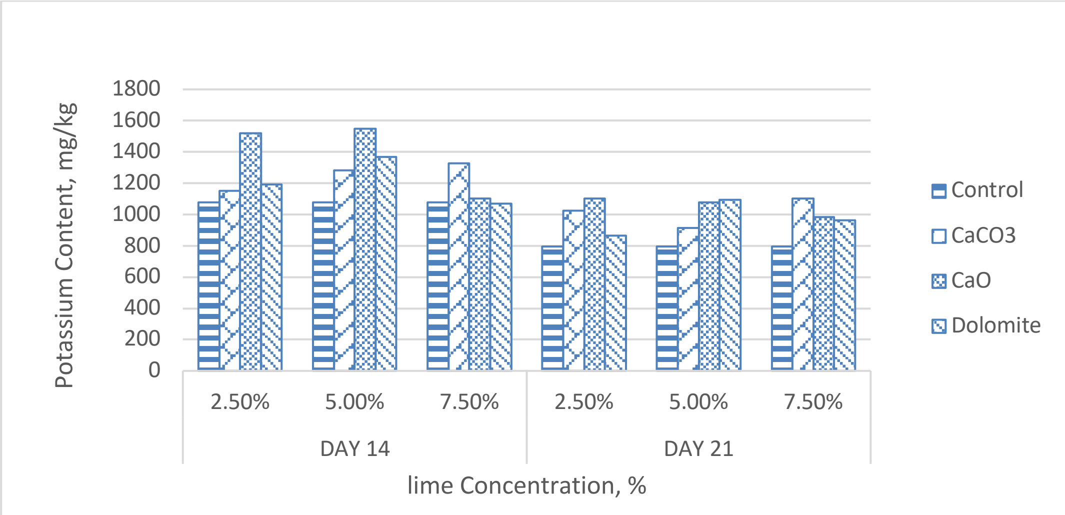


Figure 5: Potassium content in soil treated with calcined GAS shell ($CaCO_3$ and CaO) and dolomite

3.3.4 pH

Figure 6 illustrates the soil's pH over 21 days following the application of GAS shell-based amendments CaO, $CaCO_3$, and dolomite at 2.5%, 5.0%, and 7.5% concentrations, alongside a control.

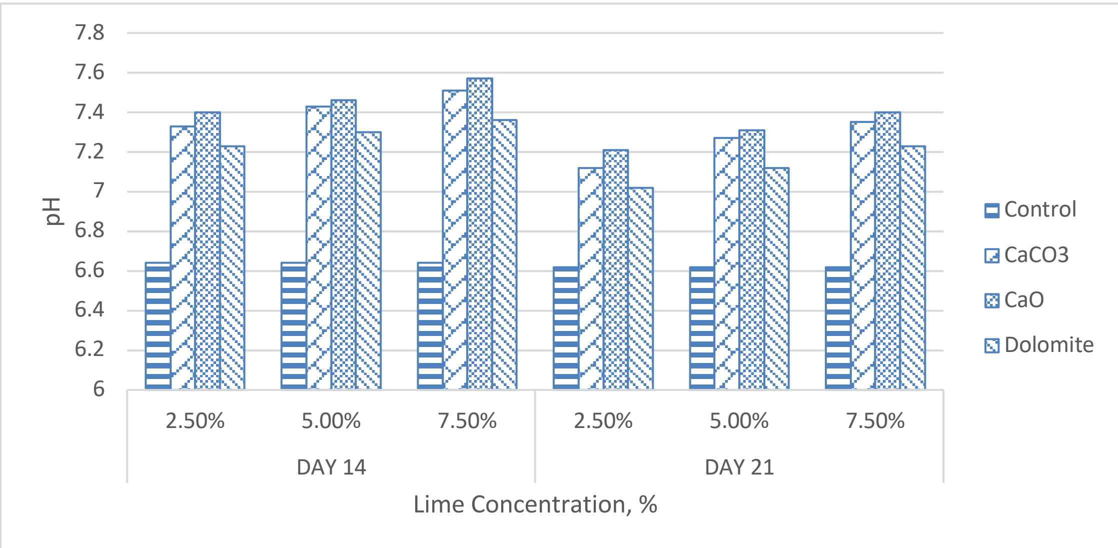


Figure 6: Soil pH after treated with calcined GAS shell ($CaCO_3$ and CaO) and dolomite

Based on Figure 6, the soil's pH treated with CaO was the highest compared to soil treated with $CaCO_3$ and dolomite, while control remained the lowest for both days, 14 and 21. The lime treatment caused greater effect on soil pH as lime produces more calcium hydroxide that neutralizes hydrogen ions (Wang et al., 2020). When comparing pH of soil treated with dolomite to both calcined shell ($CaCO_3$ and CaO), the pH is the lowest. This is in agreement with Takamoto et al. (2023) which stated that soil's pH is significantly higher following calcite and dolomite applications than control. Liming application corrected soil's pH, in turn increased the availability of phosphorus and exchangeable cations in soil (Wakwoya et al., 2022; Beukes et al., 2012). The increase in soil pH is related to the increase in exchangeable cations (Ca, Mg and K) but reducing the amount of Al relative to treatments without lime (Qaswar,2020).

4. CONCLUSION

This research has demonstrated the potential of GAS shells as a sustainable and environmentally friendly calcium source for soil amendment in crop production. Through thermal treatment at 600°C and 900°C, GAS shells were successfully converted into calcium carbonate ($CaCO_3$) and calcium oxide (CaO), respectively. This was validated through FTIR analysis which confirmed the presence of $CaCO_3$ for shells calcined at 600ºC, while the disappearance of this peak at 900°C, representing decomposition of $CaCO_3$ into CaO and CO_2. The application of calcium oxide (CaO) at a 5.0% showed to be the most effective treatment, significantly improving soil pH from 6.6 to 7.4 and increasing the availability of essential nutrients. The impact of this optimal rate led to a measurable increase in nitrogen, phosphorus, and potassium, possibly by creating a favorable environment for microbial activity and the decomposition of organic matter. This study supports the principles of the circular economy by converting GAS shell into sustainable soil amendments, promoting agricultural productivity and environmental resilience.

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