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# Remediation of Acidic Soil with Mission Grass (*Pennisetum polystachion*) Grounds

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## Abstract

Lime ($CaCO_3$) application is the most common practice to neutralise soil acidity before planting. However, the effectiveness of liming depends on its reactivity and interactions with various soil types. Therefore, mission grass (*Pennisetum polystachion*; PP) grounds have been proposed as an alternative for soil acidity remediation, owing to their rapidly decomposable residue and release of basic cations. This study evaluated the ability of PP to increase the pH and the relationship between pH and redox potential (Eh) in loamy soil and sandy soil. The addition of 2.5% (w/w) $CaCO_3$ rapidly increased the pH in loamy soil but gradually decreased the pH in sandy soil, with a value of 7.30 and 7.50, respectively, on day 20. The addition of 2.5% (w/w) PP increased the pH in loamy soil and sandy soil to 5.60 and 6.50, respectively, on day 20. The Eh value in loamy soil was significantly lower after the addition of PP compared with $CaCO_3$ (+50.0 mV and + 200.0 mV, respectively). In sandy soil, the addition of PP produced a lower Eh value on day 20 compared with the addition of $CaCO_3$. The fluctuating Eh values in both soil types were associated with soil moisture, electrical conductivity and organic matter and should be measured systematically with pH. The addition of PP was beneficial in slowly increasing the soil pH over time, thus influencing the favourable reducing condition as indicated by the lower Eh values. The application of PP as an alternative and a complement to the conventional liming practice should be further studied to reduce the adverse impacts on the soil to establish a balance between agricultural productivity and sustainable agriculture.

*Keywords* Remediation, acidic soil, mission grass, *Pennisetum polystachion*

## 1.0 INTRODUCTION

Low soil fertility for crop production is commonly associated with tropical soil, which is characterised by chemical properties such as pH and the cation exchange capacity (CEC) and physical properties such as the soil structure (Mosharrof et al., 2021). In Malaysia, highly weathered Ultisols and Oxisols are the dominant mineral acid soil. Due to the inherent climate conditions, these soils usually have a low pH between 4 and 5 (Qurban et al., 2020). Soil acidification naturally occurs from the oxidation of minerals, causing acids to be released into the soil and aluminium ions ($Al^{3+}$) to be accumulated, subsequently affecting nutrient availability and plant growth (Halim et al., 2018).

Intensive agriculture, for the goal of production, has induced soil acidification. The addition of lime ($CaCO_3$) is the most common practice to neutralise soil to prevent further degradation (Ryan, 2018). Lime is usually incorporated into the soil through tillage practices – ploughing and harrowing – prior to planting due to its low solubility (Andre et al., 2019). Alternatively, surface liming has been established in no-till systems to preserve the soil structure and minimize erosion, although the neutralizing effects are less effective in deeper soil layers (Nunes et al., 2019). Moreover, the effectiveness of liming depends on the reactivity and interactions of lime with various soil types, especially in response to the soil organic carbon (SOC) content, which is vital in nutrient availability and toxicity in acidic soil (Lucas et al., 2021).

In addition to conventional $CaCO_3$, industrial by-products and organic wastes have also been reported to improve soil acidity. Still, they are accompanied by the risk of soil contamination from heavy metals as well as eutrophication from excessive nitrogen (N) and phosphorus (P) contents. Alternatively, there has been mixed effectiveness reported for the application of crop residues regarding soil pH, mainly due to the extent of alkalinity and basic cations in the materials used (Purakayastha et al., 2019). Owing to this, mission grass (*Pennisetum polystachion*; PP) grounds have been proposed as an alternative for soil acidity remediation. *P. polystachion* is less invasive among the grasses of the genus *Pennisetum*, especially compared with, for example, the widely documented Napier grass (*Pennisetum purpureum*). PP is a tall perennial plant naturally well-distributed in some parts of Asia. The common management methods for this undesirable grass include herbicide application, physical removal, cutting and burning (Izaskun et al., 2019). The conversion of PP into a soil acidity remediator could be beneficial in both weed management as well as soil health management. The objectives of this study were to evaluate the ability of PP to increase the soil pH and to investigate the relationship between pH and redox potential (Eh) compared with the conventional addition of $CaCO_3$ to sandy soil and loamy soil in controlled conditions. Loamy soil was chosen because it was acidic soil (pH 3.5-4.5), while sandy soil was chosen because it is less acidic (5.0-6.0).

## 2.0 MATERIALS AND METHODS

### 2.1 Soil Preparation

Loamy and sandy soils were obtained from the Research Farm at Universiti Teknologi Malaysia, Pagoh, in Johor, Malaysia. A soil corer was used to collect the soil samples, which were collected 10 cm from the surface. The samples were then homogenised and stored in sealed plastic bags before being immediately transported to the laboratory. They were placed in a drying oven at 60°C for 24 hr. Then, the dried samples were passed through a 1,400 µm mesh size sieve (Chuyanov et al., 2020).

### *2.2* Preparation of PP

PP was obtained from around the vicinity of Pagoh, Johor. The plant species was confirmed by the Institute of Bioscience, Universiti Teknologi Malaysia. The plant parts used in this study were the stems and leaves because they are easy to harvest from the ground. The samples were manually cut into smaller sizes before being dried at 40-50°C for 24 hours until around 10% humidity left. Then, the dried samples were pulverized with a commercial grinder. The grounds were passed through a 500 µm mesh size sieve and stored in sealed plastic bags at room temperature before the subsequent experiment (Getnet et al., 2020).

### 2.3 Experimental Treatments and Design

Table 1 shows the treatment details for sandy soil and loamy soil. The experiment was conducted in controlled conditions at room temperature (25-27°C) and relative humidity (30%-40%). The soil amendments were uniformly mixed into the soil, and the samples were placed in 5 L polybags. Each treatment was carried out in triplicate in a completely randomized design. During the 20-day experiment, the soil moisture was maintained daily at 30% and 40% using an MX-50 Moisture Analyzer (A&D, USA). Each sample was watered manually when the moisture fell below 30%. The soil pH and Eh were analyzed daily in the morning.

### 2.4 Analysis of Soil pH

Soil samples weighing 2 g were mixed with distilled water at a ratio of 1:5 (w/w). The mixtures were vortexed for 1 minute and then incubated for 24 hours (Akshita et al., 2019). The pH was measured using a pre-calibrated FiveEasy Benchtop F20 pH/mV Meter (Mettler Toledo, USA).

**Table 1** Details of the soil treatments.

| Soil type | Treatment | Soil weight (g) | Soil amendment (g) | | Amendment composition (%) |
|---|---|---|---|---|---|
| | | | $CaCO_3$ | PP | |
| Loamy soil | $T_1$ (control) | 1,000.0 | 0.0 | 0.0 | 0.0 |
| | $T_2$ | 975.0 | 25.0 | 0.0 | 2.5 |
| | $T_3$ | 990.0 | 10.0 | 0.0 | 1.0 |
| | $T_4$ | 995.0 | 5.0 | 0.0 | 0.5 |
| | $T_5$ | 975.0 | 0.0 | 25.0 | 2.5 |
| | $T_6$ | 990.0 | 0.0 | 10.0 | 1.0 |
| | $T_7$ | 995.0 | 0.0 | 5.0 | 0.5 |
| Sandy soil | $T_8$ (control) | 1,000.0 | 0.0 | 0.0 | 0.0 |
| | $T_9$ | 975.0 | 25.0 | 0.0 | 2.5 |
| | $T_{10}$ | 990.0 | 10.0 | 0.0 | 1.0 |
| | $T_{11}$ | 995.0 | 5.0 | 0.0 | 0.5 |
| | $T_{12}$ | 975.0 | 0.0 | 25.0 | 2.5 |
| | $T_{13}$ | 990.0 | 0.0 | 10.0 | 1.0 |
| | $T_{14}$ | 995.0 | 0.0 | 5.0 | 0.5 |

### 2.5 Analysis of Soil Eh

Two pieces of carbon felt, which acted as electrodes, were inserted into the soil horizontally and parallel to each other, with a gap of around 10 cm between the top and bottom electrodes. The top electrode acted as the cathode (positive), while the bottom electrode acted as the anode (negative). The electrodes were allowed to equilibrate for 24 hours before being measured with a multimeter (in mV). The measurements were carried out at 1-minute intervals for 10 minutes and then averaged (Hongping et al., 2020). The soil Eh value was categorised as follows: (i) oxidised (> +400 mV), (ii) moderately reduced (+100 to +400 mV), (iii) reduced (+100 to -100 mV) and (iv) highly reduced (-100 to -300 mV).

### 2.6 Statistical Analysis

IBM SPSS Statistics 22 (IBM Corporation, Armonk, NY, USA) was used for statistical analysis. The soil pH and Eh data were analysed using one-way analysis of variance (ANOVA) followed by Tukey's honestly significant different test at the 5% confidence level.

## 3.0 RESULTS AND DISCUSSION

### 3.1 Effects of the $CaCO_3$ and PP Amendments on Loamy Soil pH

Figure 1 shows the effects of the $CaCO_3$ and PP amendments on the loamy soil pH. The highest pH was observed for the soil treated with 2.5% (w/w) $CaCO_3$ at each time except days 4 and 7, although the values were still relatively high before they ended at pH 7.30 on day 20. Interestingly, the pH of the soil treated with 1.0% (w/w) $CaCO_3$ and 0.5% (w/w) $CaCO_3$ presented different trends during the experiment but ended with a similar pH of 7.00 on day 20. All soils subjected to $CaCO_3$ amendment exhibited a lower pH on day 20 relative to the pH on day 1. However, the significant pH increase compared with the control demonstrated the reactivity of $CaCO_3$ when it is mechanically incorporated and thus evenly mixed into loamy soil. As a result, the pH was maintained above 6.00, which is sufficient to reduce potential soil acidity (Nunes et al., 2019).

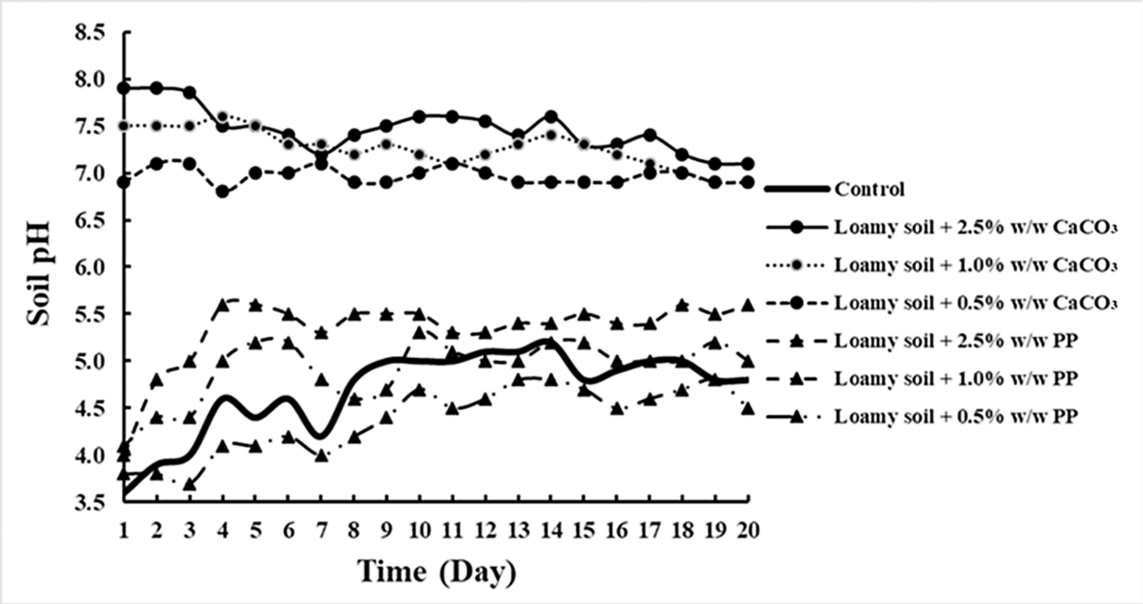

**Figure 1** The effects of $CaCO_3$ and PP amendments on loamy soil pH.

The pH also increased in the soil treated with 2.5% (w/w) PP and 1.0% (w/w) PP, with a pH of 5.60 and 4.90, respectively, although the values were closer to that of the control (pH 4.70). The pH of the soil treated with 0.5% (w/w) PP (4.50) was lower than the control. Contrary to the $CaCO_3$ treatments, all PP treatments produced a higher pH on day 20 relative to the pH on day 1. There was a similar trend for the control, likely due to the natural N loss through ammonia volatilisation in which hydrogen ions ($H^+$) were consumed and contributed to pH stability over time (Sha et al., 2019). This phenomenon is represented by Equation (1).

$$NH_4^+ \leftrightarrow NH_3 + H^+ \quad (1)$$

The less pronounced pH increases with PP treatment compared with $CaCO_3$ treatment was expected due to lower alkalinity and basic cations—because PP did not undergo a thermal process—in addition to the low application rate, the initial soil pH, and the buffering capacity.

## 3.2 Effects of $CaCO_3$ and PP Amendments on Sandy Soil pH

The effects of the $CaCO_3$ and PP amendments on the pH of sandy soil are shown in Figure 2. Similarly to loamy soil, the $CaCO_3$ treatments led to a higher pH than the PP and control treatments. The pH increased sharply on day 1 for the soil treated with 2.5% (w/w) $CaCO_3$ and was lower with the lower $CaCO_3$ percentages, namely 10.40, 9.50, and 8.20, respectively, for 2.5%, 1.0% and 0.5% (w/w) $CaCO_3$. The higher reactivity of $CaCO_3$ in sandy soil may be attributed to better interaction in evenly mixed treatments in addition to the soil texture (Joao et al., 2021). All $CaCO_3$-treated soil samples exhibited a lower pH on day 20 compared with day 1. Interestingly, the pH at the end of the experiment for the soil treated with 1.0% (w/w) $CaCO_3$ was the highest at 7.90, while the soil treated with 2.5% (w/w) $CaCO_3$ had the lowest pH at 7.50, suggesting an insignificant difference in up to 2.5% (w/w) $CaCO_3$ application rates in sandy soil due to the higher pH buffering capacity (Latifah et al., 2018).

All PP treatments increased the pH of sandy soil similarly to loamy soil (up to 1.5 units). On day 20, the soil treated with 2.5% (w/w) PP had the highest pH at 6.50, followed by the soil treated with 1.0% (w/w) PP (pH 6.00) and 0.5% (w/w) PP (pH 5.80). Similarly to the loamy soil, on day 20, the pH for the soil treated with 0.5% (w/w) PP was below the control (pH 5.90). However, the fluctuation trends were insignificant, indicating a better pH buffering capacity in sandy soil compared with loamy soil when amended with PP (Obia et al., 2015). The relatively more stable pH may be attributed to the high carbon-to-nitrogen (C/N) ratio of PP, recycling N predominantly into the soil (Bin et al., 2021).

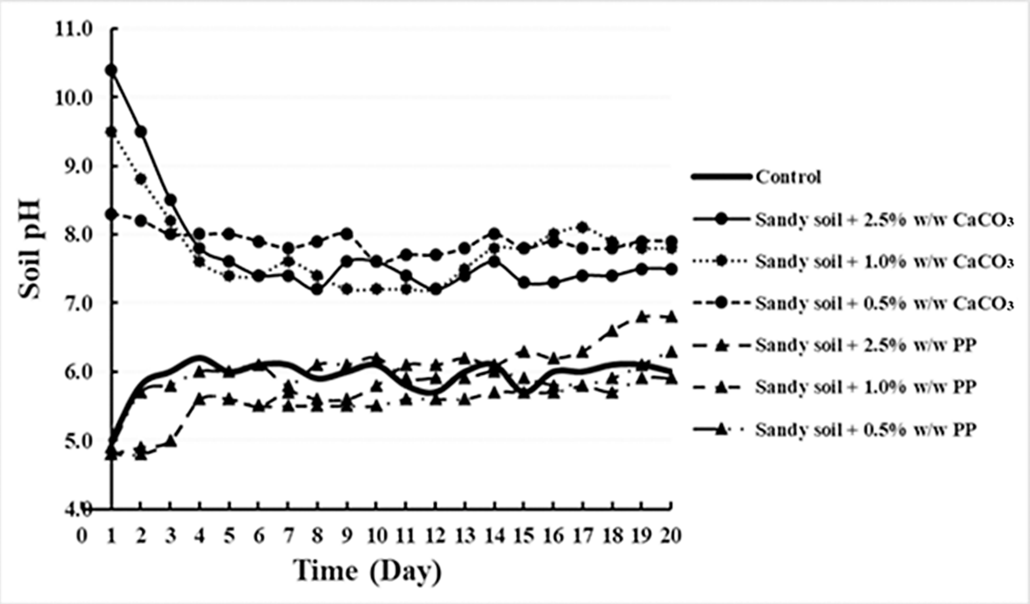

**Figure 2** The effects of $CaCO_3$ and PP amendments on sandy soil pH.

### 3.3 Effects of the $CaCO_3$ and PP Amendments on Loamy Soil Eh

Figure 3 shows the effects of the $CaCO_3$ and PP amendments on the Eh of loamy soil. The Eh values in the control naturally decreased from +195.0 mV on day 1 to +10.0 mV on day 20. All $CaCO_3$ treatments exhibited multiple transitions between oxidized and reduced conditions, except day 16, where soil treated with 1.0% (w/w) $CaCO_3$ showed a significantly lower Eh value of +320.0 mV. The Eh values of all $CaCO_3$ treatments eventually ended at around +200.0 mV on day 20, lower than their respective Eh values on day 1. There was a correlation between the Eh spikes (days 12 and 16) and pH (days 14 and 17), possibly indicating that the soil ecology was capable of oxidising the residual SOC. This phenomenon was then followed by increased pH (Michael, 2018).

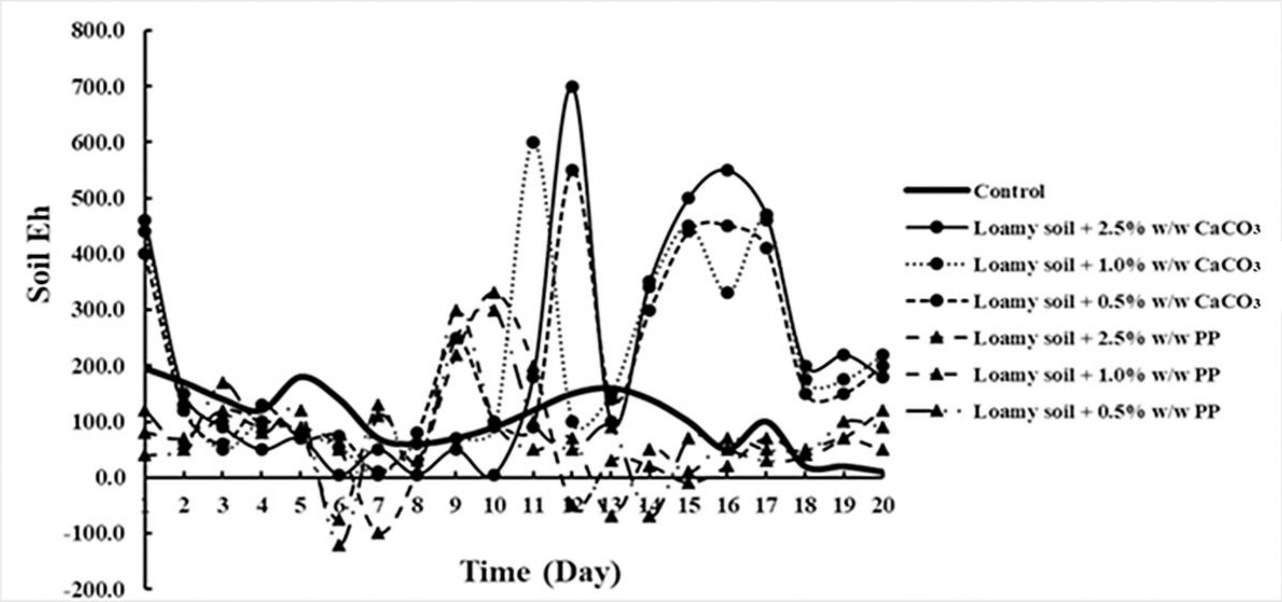

**Figure 3** The effects of $CaCO_3$ and PP amendments on loamy soil Eh.

The PP treatments also exhibited multiple transitions between moderately reduced and reduced conditions, except for the soil treated with 0.5% (w/w) PP on day 6, which showed an Eh value of -140.0 mV, the only highly reduced condition recorded. All PP treatments exhibited relatively similar Eh values between +50.0 and +110.0 mV on day 20 compared with day 1 and fluctuated significantly on day 6 (-100.0 mV), day 10 (+300.0 mV) and day 13 (-50.0 mV). Interestingly, these values coincided with the declining pH of the soil. This phenomenon is most likely due to oxygen depletion by aerobic bacteria reacting to the organic matter (OM) through the application of PP (Sanaz et al., 2019). The Eh represents the oxidation-reduction potential based on the standard hydrogen potential (SHE), while pH represents the activity of $H^+$ (also known as a proton).

### 3.4 Effects of the $CaCO_3$ and PP Amendments on Sandy Soil Eh

Figure 4 shows the effects of the $CaCO_3$ and PP amendments on the Eh of sandy soil. The initial Eh values of all treatments, including the control, were around +50.0 mV and inconsistent with the pH values, mainly due to the sandy soil properties, which are unfavourable for the soil ecology (Michael, 2018). All $CaCO_3$ treatments led to a moderately reduced or reduced condition before transitioning to an oxidized condition at around day 14, when the pH started to decline. The highest Eh value was recorded for the soil treated with 2.5% (w/w) $CaCO_3$ (+670.0 mV) before declining to +350.0 mV on day 20. The unclear inconsistencies between pH and Eh might be attributed to the spatial variability of soil moisture. However, due care was taken to keep the moisture of each sample at ≥ 30%, which is more than the reported 10%-20% for sandy soil (Jeremy et al., 2019).

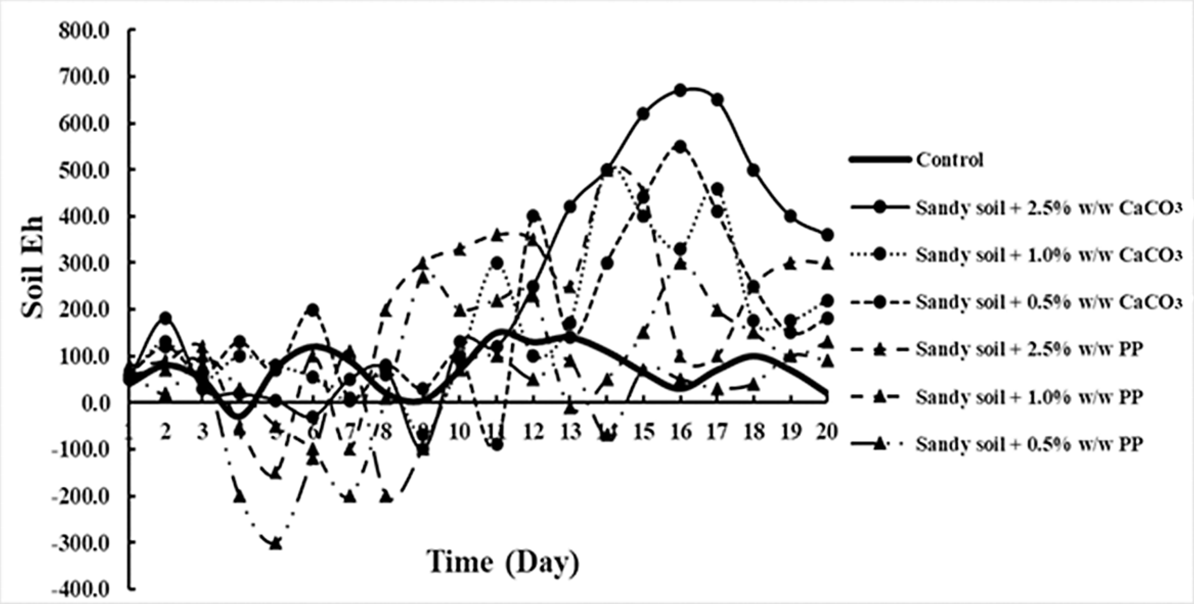

**Figure 4** The effects of $CaCO_3$ and PP amendments on sandy soil Eh.

All PP treatments led to moderately reduced or highly reduced conditions until day 11, except for the soil treated with 1.0% (w/w) PP, which presented a reduced condition (-90.0 mV) on day 14. The highest Eh value was recorded for the soil treated with 2.5% (w/w) PP (+360 mV) on day 14 before ending at +300 mV on day 20, followed by the soil treated with 0.5% (w/w) PP and 1.0% (w/w) PP at around +100 mV. The different reduced conditions can be attributed to the presence of OM through applying PP, which was sufficient to sustain the soil pH (Suzana et al., 2021). Moreover, the Eh values were more affected in sandy soil than in loamy soil based on the exhibited fluctuation, indicating spatial variability of soil moisture, electrical conductivity and OM (Tano et al.,2020).

## 4.0 CONCLUSION

The addition of PP slowly increased the soil pH over time and led to more favourable reducing conditions, as indicated by the lower Eh values. The application of PP as an alternative and a complement to the conventional liming practice should be further studied to reduce the adverse impacts on the soil and to establish a balance between agricultural productivity and sustainable agriculture. The findings from this study should be beneficial in providing more information on the soil buffering capacity for better soil health management beyond pH alone.

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## References

Barthwal, A., Swaroop, N., Rao, P. S., Thomas, T. (2019). Assessment of physical properties of soil in Dehradun district, Uttarakhand, India. International Journal of Chemical Studies, 7(3), 1623–1625.

Auler, A. C., Caires, E. F., Pires, L. F., Galetto, S. L., Romaniw, J., Charnobay, A. C. (2019). Lime effects in a no-tillage system on Inceptisols in Southern Brazil. Geoderma Regional, 16, e00206.

Bin, F., Ling, C., Hongying, H., Ping, Q., Zhenggui, W. (2021). Impact of crops residues on soil health: a review, Environmental Pollutants and Bioavailability, 33(1), 164-173.

D. Chuyanov, G. Shodmonov, I. Avazov, N. Rashidov, S. Ochilov, (2020). Soil preparation machine parameters for the cultivation of cucurbitaceous crops, IOP Conference Series: Material Science and Engineering, 883, 012122.

Halim, A., Sa'adah, N., Abdullah, R., Karsani, S. A., Osman, N., Panhwar, Q. A., Ishak, C. F., (2018). Influence of soil amendments on the growth and yield of rice in acidic soil, Agronomy, 8(9), 165.

Hongpin C., Peng W., Yi G., Ruben K., Peter M. K., Fang-Jie Z. (2020). The within-field spatial variation in rice grain Cd concentration is determined by soil redox status and pH during grain filling, Environmental Pollution, 261, 114151.

Izaskun D., Javier D., Patricia G., Jalel L., Vitaliy B. (2019). Production and characterization of lignin and cellulose fractions obtained from pretreated vine shoots by microwave assisted alkali treatment, Bioresource Technology, 289, 121726.

Jeremy C., Alix S., Ludovic P., Olivier H., Robin B., Deonie A. (2019). Effects of soil redox potential (Eh) and pH on growth of sunflower and wheat, Archives of Agronomy and Soil Science, 66, 473-487.

Joao W. B., Carlos A. C. C., Marcio F. A. L., Luis F. M., Luiz G. M., Isabo M. P., Eiko E. K. (2021). Modulation of the soil microbiome by long-term Ca-based soil amendments boosts soil organic carbon and physicochemical quality in a tropical no-till crop rotation system, Soil Biology and Biochemistry, 156, 108188.

Latifah, O., Ahmed, O. H., Majid, N. M. A. (2018). Soil pH buffering capacity and nitrogen availability following compost application in a tropical acid soil, Compost Science and Utilization, 26(1), 1-15.

Lucas A. A., Vitor G. A., Luis Gustavo O. D., Joao Pedro M. F., Amanda P. M., Dionata F., Carolina B., Paulo Cesar F. C., Gustavo D. F., Ignacio A. C., Tales T. (2021). Biological $N_2$ fixation by soybeans grown with or without liming on acid soils in a no-till integrated crop-livestock system, Soil & Tillage Research, 209, 104923.

Getnet, M., Arega, H., Shitaneh, E., & Worku, B. (2020). Determination of appropriate cutting date of perennial elite lowland adaptive forage grass species: chifir bequa (*pennisetum polystachion*). International Journal of Scientific Engineering and Science, 2456(7361), 1-3.

Michael, P. S. (2018). The roles of surface soil carbon and nitrogen in regulating the surface soil pH and redox potential of sulfidic soil materials of acid sulfate soils, Pertanika Journal of Tropical Agricultural Science, 41(4).

Mosharrof, M., Uddin, M., Jusop, S., Sulaiman, M. F., Shamsuzzaman, S. M., Haque, A. N. A. (2021). Changes in acidic soil chemical properties and carbon dioxide emission due to biochar and lime treatments, Agriculture, 11(3), 219.

Nunes, M. R., Denardin, J. E., Vaz, C. M., Karlen, D. L., Cambardella, C. A. (2019). Lime movement through highly weathered soil profiles, Environmental Research Communications, 1(11), 115002.

Purakayastha, T. J., Bera, T., Bhaduri, D., Sarkar, B., Mandal, S., Wade, P., Kumari, S., Biswas, S., Menon, M., Pathak, H., C. W. Tsang, D. (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.

Qurban, A.P., Umme, A. N., Jusop, S., Mohd. Razi, I. (2020). Effects of biochar and ground magnesium limestone application, with or without bio-fertilizer addition, on biochemical properties of an acid sulfate soil and rice yield, agronomy, 10, 1100, 1-14.

Ryan, P. R. (2018). Assessing the role of genetics for improving the yield of Australia's major grain crops on acid soils, Crop and Pasture Science, 69(3), 242–264.

Sanaz S. K., David J. P., Tas T., Benedict W., Maksym P. (2019). Soil acidity, lime application, nitrogen fertility, and greenhouse gas emissions: Optimizing their joint economic management, Agricultural Systems, 176, 102684.

Sha, Z., Li, Q., Lv, T., Misselbrook, T., Liu, X. (2019) Response of ammonia volatilization to biochar addition: a meta-analysis, Science of the Total Environment, 655, 1387–1396.

Suzana K. G. M., Eloise Mello V. de M., Xose Lois O., Tiago Osario F., Marcelo Metri C., Juliet Emilia S. De S., Clistenes Williams A. do N., Laercio Vieira de M. W. N., Valdomiro Severino de S. J, (2021). Occurrence and pedogenesis of acid sulfate soils in northeastern Brazil, 196, 104937.

Tano, B. F., Brou, C. Y., Dossou-Yovo, E. R., Saito, K., Futakuchi, K., Wopereis, M., Husson, O. (2020). Spatial and temporal variability of soil redox potential, pH and electrical conductivity across a toposequence in the Savanna of West Africa, Agronomy, 10(11), 1787.