Utilisation of Coconut (*Cocos nucifera*) Shell Ash to Improve Soil pH for Agricultural Purposes

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Utilisation of coconut shell ash (CSA) might improve plant growth, especially in agricultural activities. This study aims to discover the potential of CSA in decreasing soil acidity, especially in soils that use chemical fertilisers or pesticides during crop production. Coconut (*Cocos nucifera*) shells were collected and CSA was produced by pyrolysis. Fourier-transform infrared (FTIR) analysis was then used to determine the chemical composition of CSA. Three different amounts of CSA (1.0, 3.0, and 5.0 g) were added to 10 g of acidic soil (pH 3.81) and control soil (pH 7.1). The usage of coconut shell ash was proven to be effective in increasing soil pH (reduces acidity). The highest increment of soil pH, up to 7.12, was achieved when 5.0 g of CSA was added. This result suggests that utilisation of CSA on soil will benefit plant growth, and therefore can be used as an alternative to the usage of lime at a reasonable cost.

Key words: Acidic soil; coconut shell ash; soil pH

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Generally, agricultural soil possesses many chemicals that can be manipulated, whether as fertilisers or pesticides. Excessive usage of chemical fertilisers in agricultural activities contributes to environmental problems, mainly in the soil [1]. Excess chemical fertilisers will modify soil properties such as pH and surface charge, or even worse, possibly react directly with metal ions in the soil. According to McCauley et al. [2], soil pH indicates acidity or alkalinity and the concentration of hydrogen ions (H^+) in the topsoil. A high quantity of H^+ relates to a low pH value and vice versa. Excess ammonium in soil will oxidise into nitrate and release hydrogen ions. This will increase the amount of hydrogen ions in the ground, which results in soil acidity. The main limiting factors for crop yield and biological process in soil are soil acidity and excess concentration of aluminium ions (Al^{3+}). Bacteriological motion and breakdown of organic matter in soil are interrupted, resulting in ineffective reutilisation of organic waste, and thus nutrient usage will also be affected by the low pH of soil [3,4].

Conventionally, lime is used to increase soil pH. Lime acts as a temporary remedy and must be added to soil yearly [5]. Liming is applied to correct soil pH to the required levels to improve crop growth [6]. According to Zhang et al. [7], calcium oxide (CaO) equivalent is used to measure the liming effect. Liming materials fall into the following four categories: carbonates, oxides, hydroxides, and by-product materials. However, liming materials such as hydroxides are generally overpriced compared to carbonates [8]. This is due to the difficulty in obtaining hydroxides compared to other liming materials. Hydroxides, also known as hydrated lime, slacked lime or builders' lime, are similar to oxides because they are powdery and quickly oxidised. However, many poor farmers cannot afford to use lime [9]. Therefore, further research should be carried out to identify another potential material that can replace liming materials and act as an alternative for improving crop yield.

Coconut (*C. nucifera*) shell is classified as an agricultural waste and its existence in tropical countries is very high [10]. To our advantage, coconut shells are abundant in Malaysia, as Malaysians use a lot of coconut milk in their cooking. Many people tend to do an open burning of coconut shells, which leads to air pollution [1]. Coconut shell ash (CSA) is black carbon formed through the combustion of biomass in muffle furnace, which contributes to the production of carbon dioxide and methane [10]. Using CSA as a natural alternative to lime for agricultural purposes is much more environmentally safe and friendly than any other methods of waste disposal being commonly adopted nowadays. Figure 1 shows the CSA produced after the combustion process.

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Figure 1. Coconut Shell Ash (CSA)

Fourier-transform infrared (FTIR) analysis was used to detect calcium oxide in the CSA because the anion, known as base, in natural liming materials will react and neutralise hydrogen ions in soil. This reaction will decrease the amount of hydrogen ions in the ground, increasing soil pH [11;12]. Hence, this study aims to apply CSA to soil to improve soil pH. The information gained from this study will benefit the agronomists, particularly in identifying cost-effective materials in increasing the pH of soil (reduce soil acidity).

MATERIALS AND METHODS

Sample Collection and Preparation

Coconut shells were collected from a wet market located in Bandar Pusat Jengka, Pahang. About 1 kg of coconut shells was put into a plastic container and kept at room temperature prior to analysis. Then, the shells were crushed into small pieces using mortar and pestle and dried inside an oven at 100°C for 24 hours. The shells were then placed in a ceramic crucible covered with a suitable lid and put in a muffle furnace at 450°C for two hours. The pyrolysis process was done in the absence of oxygen. The resulting ash powder material was cooled overnight until further analyses [10].

Five soil samples were collected from a palm oil agricultural area at five different points around Taman Desa Jaya 2 using a hand auger at similar depths of 0 cm to 20 cm. The collected soil samples were chosen within a 9 m-radius between oil palm trees [1]. The control soil was collected from an undisturbed area in UiTM Jengka, Pahang. The samples were sieved through a 2 mm sieve to remove unwanted materials such as roots, leaves, and stones. About 10 g of soil sample was weighed using an analytical balance. The sample was put into a 50 mL beaker and 10 mL of 0.01 M calcium chloride ($CaCl_2$) was added, at a ratio of 1:2, into the beaker. Then, the suspension was left for one hour at room temperature before the pH reading was measured.

Characterisation of Calcium Oxide in Coconut Shell Ash (CSA)

The chemical composition of the CSA was determined using Perkin Elmer Spectrum TM 100 FTIR-ATR. The crystal plate was washed with acetone before analysis. Background analysis was carried out to discard impurities on the crystal plate itself. Dried CSA was placed on a holder inside the FTIR spectrometer using a spatula. A spectrum was obtained at an infrared (IR) frequency range of 400 to 4000 cm^{-1}, using 64 scans at 4 cm^{-1} resolution.

Utilisation of Coconut Shell Ash (CSA) on Acidic Soil

The initial soil pH was measured before mixing with CSA. The pH value was determined using a pH meter. About 10 g of soil samples were mixed with 1.0, 3.0, and 5.0 g of CSA, respectively. These samples were kept at room temperature for a week. Then, the pH values of the soils were measured. The same method was applied for the control soil [13]. All experiments were carried out in three replicates (n=3) to avoid cross-contamination.

RESULTS AND DISCUSSION

pH and Chemical Composition of Coconut Shell Ash

The CSA was discovered to slightly possess alkaline properties (pH of 7.12). Figure 2 shows a peak observed at 477.10 cm^{-1} representing the calcium oxide functional group [14]. The peak at 1045.68 cm^{-1} represents C-O deformation in secondary alcohol and aliphatic ether or aromatic [15]. The peak at 1397.84 cm^{-1} may represent C-H rocking in alkanes or C-H stretching in methyl and phenolic alcohol. The peaks observed at 1592.82 cm^{-1}, 1906.49 cm^{-1}, and 3061.91 cm^{-1} represent N-H bending in primary amine, Si-H stretching, and C-H asymmetric and symmetric stretching in methyl, respectively. The FTIR analysis by Afolalu et al. [16] exhibited broad range peaks at 3640, 3445 as well as 2929 cm^{-1}, which translates to the presence of OH group in CSA. Whereas sharp-pointed peaks observed at 1612, 1441, 1089, 790, 550, and 460 cm^{-1} indicate the presence of C-H methylene symmetric and aromatic C-C groups.

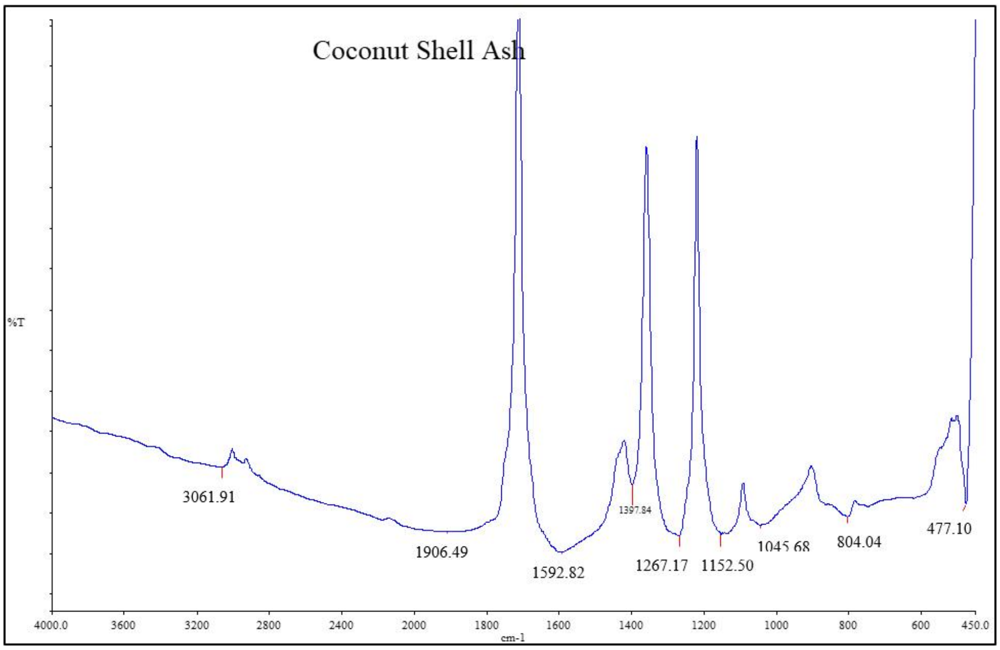

Figure 2. FTIR spectrum of CSA

Effect of Utilising Coconut Shell Ash (CSA) on Acidic Soil

The pH of the soils varied from 3.81 to 4.41 and is considered very acidic. There were increases in the soil pH when 1.0, 3.0, and 5.0 g of CSA were added to 10 g of soil, proving that pH increases with increasing amounts of CSA. Table 1 exhibits the utilisation of CSA on the acidic soils. The highest increment of soil pH was recorded when 5.0 g of CSA was added. Each point (Soil 1, Soil 2, Soil 3, Soil 4, and Soil 5) indicated a different soil origin, and the highest pH value recorded was 7.12 by Soil 4. Control soil recorded high pH values because the sample was chosen from an undisturbed area around UiTM Jengka, Pahang.

Soil texture can profoundly affect many other properties and is considered an important physical property. Thus, USDA Soil Triangle was used to determine the soil texture [2]. All samples in this study were categorised as sandy clay soil. Soil texture determination is important because the amount of CSA needed to increase soil pH varies with cation exchange capacity (CEC), which is a measure of cations attracted to soil particles. Soil CEC is related to a combination of factors, including soil texture, type of clay present, and soil organic matter content. As clay and organic matter contents increase, CEC increases [17]. In turn, the quantity of H^+ that need to be neutralised by lime also increases. Thus, variation in CEC provides the basis for variable lime application rates.

Table 1. Utilisation of coconut shell ash (CSA) on soils (mean ± standard deviation, n=3)

	Soil pH					
	Control	**Soil 1**	**Soil 2**	**Soil 3**	**Soil 4**	**Soil 5**
Without CSA	7.10 ±0.02	4.27 ±0.007	3.87 ±0.06	3.81 ±0.01	4.33 ±0.007	4.41 ±0.02
Amount of CSA added (g)						
1 g	8.08 ±0.01	4.54 ±0.007	4.18 ±0.007	3.97 ±0.01	4.64 ±0.02	4.61 ±0.02
3 g	9.38 ±0.01	5.38 ±0.01	5.51 ±0.02	4.81 ±0.02	5.71 ±0.02	5.18 ±0.01
5 g	9.63 ±0.007	6.46 ±0.007	6.56 ±0.007	5.63 ±0.007	7.12 ±0.01	5.99 ±0.02

Table 2. Constituents of Coconut Shell Ash (CSA)

Compound	***Percent weight (%)***
K_2O	0.83
Na_2O	0.95
CaO	4.98
MgO	1.89
Al_2O_3	24.12
P_2O_5	0.32
SO_3	0.71
SiO_2	37.97
Fe_2O_3	15.48
MnO	0.81

Source: [20]

A previous study by Hart et al. [18] also proved that soil acidification proceeds faster in Madras sandy loam (0.2 pH unit/year) compared to a Nekia silty clay loam (0.1 pH unit/year), indicating that type of soil influences soil pH. Soils with high CEC can bind more cations such as Ca^{2+} or K^+ to the exchange sites (where the ions bind) of clay and organic matter particle surfaces. A high CEC soil will also have a greater buffering capacity, increasing the soil's ability to avoid changes in pH. Soils with high quantities of clay and/or organic matter will typically have higher CEC and buffering capacities than more silty or sandy soils [2]. As soil buffering capacity increases, soil acidification rate decreases since more H^+ ions are needed to change pH. Thus, a sandy soil with low CEC has a faster acidification rate than a soil with moderate to high clay content [18].

In a similar study, Mbah et al. [13] reported that the pH value of soil increased after adding CSA due to the contents of the ash. This result was proven by Amu et al. [19] and Segun and Oluyemisi [20], which showed the contents in CSA that significantly ($p = 0.05$) increase soil pH. Table 2 shows the constituents in the coconut shell ash. Since H^+ is a cation, it will compete with other cations for exchange sites. When soil pH is high (more basic, low concentration of H^+), more base cations will be on the particle exchange sites, and thus will be less susceptible to leaching [2]. Furthermore, acidic soil reacts with lime to form water and carbon dioxide, and carbon dioxide gas is lost to the atmosphere. From this, H^+ is discarded from the solution, increasing the pH of the soil [2]. This reaction continues until all the lime has reacted [17]. According to Kaiser et al. [21], when added to soil, calcium and/or magnesium dissolves from the liming materials, displacing H^+ from the clay particles. It is displaced H^+ that makes soil acidic. The displaced hydrogen then reacts with carbonate to reduce soil acidity. Further analysis using Scanning Electron Microscope with Energy Dispersive Spectrometer (SEM-EDS), or X-ray Diffractometer (XRD) analysis can be run to confirm the presence of the metals mentioned [10].

CONCLUSION

Coconut shell ash can be used as a natural lime replacement in agricultural sectors since it has been proven in this study that there was an increase in soil pH when CSA was utilised on acidic soil. Among all CSA amounts used, for each 10 g of acidic soil, 5.0 g was found to be the most effective compared to 1.0 g and 3.0 g, increasing the soil pH to 7.12 in Soil 4. This pH value is considered approaching neutral, thus making this pH suitable for most plantations. However, the other four samples still showed pH in the acidic range even though the amount used was the same as in Soil 4, which may be due to an insufficient amount of CSA for the sampling points. Further comprehensive research is needed in ensuring the advantages of CSA for agricultural soils.

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CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

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