



Effectiveness of different exchangeable cation extractants in predicting nutrient uptake in maize planted in tropical peat of peninsular Malaysia

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Abstract

This study was conducted to determine the effectiveness of different types of exchangeable cation extractants in extracting exchangeable K^+ , Ca^{2+} , and Mg^{2+} . It also aimed to assess the relationship between the amounts extracted and those taken up by maize (*Zea mays* subsp. *Mays*) planted in Sapric and Hemic peat materials. Three different extractants were used to test their effectiveness in extracting basic cations. These are NH_4OAc at pH 7 (T1), NH_4OAc pH 4 (T2) and Mehlich-1 [$0.5 N HCl + 0.025 N H_2SO_4$ (T3)]. Results showed that Mehlich-1 was 96-162 % more effective in extracting calcium and magnesium than NH_4OAc pH 4 while ammonium acetate (pH 4) was 34-46 % higher in extracting potassium in both peat materials than NH_4OAc at pH 7. All of the available nutrients extracted were significantly higher in Hemic compared to Sapric, yet the uptake of these nutrients by the maize was 32-37 % higher in Sapric than in Hemic. Available Ca^{2+} was the most abundant nutrient compared to K^+ and Mg^{2+} , yet the K uptake by maize was the highest regardless of peat materials. This implies that although extracted nutrient levels were higher in Hemic, maize plants performed better in Sapric, indicating that they are selective in nutrient uptake, absorbing only the nutrients required for growth, rather than those most abundant in the soil. Additionally, each basic cation shows a different preference for the extractants used, affecting the suitability of each extractant.

Keywords: Ammonium acetate, calcium, magnesium, maize, Mehlich-1, potassium

Introduction

In agronomy, the adsorption of exchangeable cations as well as cation exchange capacity (CEC) are crucial for the determination of intrinsic soil fertility. They also reflect fertilizer retention capacity as well as plant nutritional potential. These adsorbed cations are in turn available for plants which generate H^+ ions at the level of their small roots which are in contact with the soil solution (Pansu and Gautheyrou, 2006; Espeleta *et al.*, 2017). In agriculture, soil testing is important to measure the amount of plant nutrient available in the soil before planting. It is to make sure that farmers are able to assess the fertility of the soil to improve crop productivity. However, when it comes to peat soils particularly those in tropical regions, standard soil testing procedures may not accurately reflect nutrient availability. This is attributed to their unique properties, such as high organic matter content, low bulk density, and strong acidity. Hence, special consideration must be given to the selection

of extraction methods and interpretation of test results to ensure that nutrient assessments in peat soils are both meaningful and agronomically relevant.

In practice, most laboratories still widely use ammonium acetate at pH 7.0 as a reference for extractant in obtaining the sum of the main exchangeable cations (Ca^{2+} , Mg^{2+} , K^+ , Na^+). The use of NH_4^+ is advantageous because it is typically absent or present only in minimal amounts in the soil exchange complex, thereby preventing significant interference with native nutrient measurements (International Organization for Standardization [ISO], 2023). The Food and Agriculture Organization (FAO) also published a detailed standard operating procedure endorsing this method for routine soil analysis (FAO, 2022). It continues to be widely adopted due to its simplicity, consistency, and relevance across diverse soil types.

Yet, there are different types of chemical extractants that can be used in evaluating these exchangeable cations such as Kelowna II, Ammonium Acetate, AB-DTPA, Mehlich-1 and

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3, CaCl_2 and distilled water (Ramamoorthi and Meena, 2018). However, it has become a challenge in selecting the right and suitable extractant that can extract soil nutrients particularly from peat soils. The suitability of these extractants in extracting plant-available basic nutrients is questionable for acidic tropical peat soils as there are no unique or special extractants to cater the distinctive nature of peat soils. Peat soil has typically been examined using the same technique and extractants over the decades. While ammonium acetate at pH 7.0 demonstrated high universality in predicting plant-available K, Mg, P, Mn, and B (Matula, 2009; Mattila and Rajala, 2022), it still may misestimate the availability of such elements in highly acidic conditions. These findings reinforce the notion that extractant performance is highly soil-dependent, and no single method may suffice for the complex nature of tropical peat soils. This is because the strength of each of the extractants may differ and may not actually imply to the actual nutrients that are taken up by the plants (Kowalenko, 2008; Leikam *et al.*, 2021).

Nevertheless, in order to adopt the different type of extractants for assessment of available cations (K^+ , Ca^{2+} , Mg^{2+}) in tropical peat of Peninsular Malaysia, the relationship between the amounts of cations taken up by plant should be elucidated. Hence, this study was conducted to i) compare the amounts of K^+ , Ca^{2+} , Mg^{2+} extracted by three different extractants which are Ammonium Acetate buffered at pH 4, 7 and Mehlich-1 and ii) to assess the efficiency of these extractants tested in predicting available K, Ca and Mg in tropical peat using maize as a test plant.

Material and Methods

Sampling and Collection of peat materials

The experiment was conducted in greenhouse of Faculty of Plantation and Agrotechnology, Universiti Teknologi MARA, Jasin campus, Malacca, Malaysia ($2^\circ 13' 44.9''\text{N}$, $102^\circ 27' 20.8''\text{E}$) from December, 2021 to March, 2022. The climate is categorized as equatorial rainforest, fully humid (Kottek *et al.*, 2006). Malacca typically receives about 116.13 millimeters (4.57 inches) of precipitation and has 239.12 rainy days (65.51% of the time) annually with 77.5% humidity. The mean annual temperature is around 27.6°C where the average maximum temperature reaches around 32.7°C while the average minimum temperature falls at 24.2°C (Malaysian Meteorological Department, 2019).

The peat materials used in this study were of Sapric and Hemic peat materials where they were collected from a 10-year old oil palm plantation within the faculty itself ($2^\circ 13' 38.1''\text{N}$, $102^\circ 27' 33.4''\text{E}$) as shown in Figure 1. The peatland area is classified as shallow peat having a depth of organic material layer of less than 1.5 m (Lim, 1989). Upon sampling and close observation, the peat materials are classified as Tropohemists. This is categorized when most of the organic materials have decomposed significantly. At this point, the botanical origin of up to two-thirds of the material can no longer be readily identified. The fibres are largely destroyed and can be broken down simply by rubbing them between the fingers. Hemic soil materials become dominant in the subsurface tier, starting as early as 20 cm deep.



Figure 1: Location of the peat materials that were collected from an oil palm plantation in the campus (highlighted in red)



Additionally, there is no continuous mineral layer that is 40 cm or more thick with its upper boundary within that tier (Andriessse, 1988).

The surface (0–15 cm) and subsurface (20–40 cm) soil layers were identified as Sapric and Hemic peat materials, respectively, based on degree of decomposition (H1–H10) according to the von Post scale (von Post, 1922). For Sapric material, it is usually identified at H8-H10 scale (advanced stage of decomposition) where more than 66% of the plant material is broken down. Fibres are minimal or completely unrecognizable. As for Hemic, it is usually identified at H4-H6 scale (moderately decomposed stage of decomposition). About 33% to 66% of the original plant structure is decomposed. Fibres are still present and identifiable in Hemic materials but are weaker and more fragmented than in fibric (less decomposed) peat. These peat materials were collected using Eijkelkamp peat sampler (Royal Eijkelkamp, Netherlands) and placed into 10 burlap sacks each weighing approximately 30 kg. Bulk density was also taken for which undisturbed peat materials were collected using a core sampler of stainless-steel rings (diameter 5.2 cm, height 6.0 cm) using gravimetric method (American Society of Testing Materials, 1988). Upon returning to the greenhouse, both peat materials were air-dried for 3 days to remove excess water so it could be used as a potting medium. After air-dried, they were then transferred into polybags of 16" x 16" (12 L volume) where they were filled with 3.5 kg of moist hemic and sapric peat materials separately.

Experimental design and Treatments

Seeds from the Sweet Asian variety (Asia Manis - SS932), an F1 hybrid of sweetcorn, were used in this study. The variety is classified as non-genetically modified organisms (non-GMO) F1 hybrid maize seeds (Crop Power Pte. Ltd.). The seeds were sown on seedling trays for uniform growth and selection for transplanting into polybags. When the seedlings had grown 4 true leaves (approximately two weeks after sowing), they were then transferred to polybags in the greenhouse. They were grown for 8 weeks (56 days) until they reached the tasseling stage (maximum vegetative growth) from January 2022 to February 2022. The average temperature in the greenhouse was 33.6°C with a mean relative humidity of 53.6%. The maize plants were manually watered with 600 mL of water per polybag twice daily: once in the early morning and again in the late afternoon. Three different types of extractants were used to evaluate the availability of basic cations of K^+ , Ca^{2+} and Mg^{2+} as provided in Table 1. They were treated as treatments where they are referred as Extractant 1(T1) - Ammonium acetate pH 7 (NH_4OAc), Extractant 2(T2) - Ammonium acetate pH 4 (NH_4OAc) and Extractant 3(T3) - Mehlich 1 (0.5 N HCl + 0.025 N H_2SO_4)

following the methods previously published by Reeza *et al.* (2021).

The experiment followed a completely randomised design (CRD) comprising two different peat materials (hemic and sapric) using 3 types of extractants to extract basic cations that were done in 3 replicates. Weekly destructive sampling was conducted for this study where soil and plant samples were collected each week for 8 weeks (56 DAT). Hence, there 48 polybags (2 peat types x 3 replicates x 8 weeks) containing maize plants for this study. Soil samples were also collected every week in each of the polybags designated for the given week and later composited together to represent a single peat type.

Soil and plant analysis

Prior to planting, the peat materials were analysed for pH (Mettler Toledo), which was measured potentiometrically in soil suspensions consisting of a 1:10 volumetric ratio of peat sample to water (Reeza *et al.*, 2021). Exchangeable calcium, magnesium, and potassium were determined using ammonium acetate (NH_4OAc , buffered at pH 4, Bendosen, Norway) (Reeza *et al.*, 2021) and organic matter via loss in ignition method. This involves the removal of organic matter by combustion after placing samples in a muffle furnace at 300–550°C for 6 hr (Sutherland, 1998). It is important to note that no fertilizer was added as this experiment was exclusively done to study the nutrient-supplying ability of the peat materials without any interference from external additives.

During each week, as much as 50 g of soil samples was collected from each plant to determine soil pH, organic matter and organic carbon (ASTM, 1988) and exchangeable K^+ , Ca^{2+} and Mg^{2+} using the three different extractants mentioned in the treatments. Whole maize plants were harvested weekly to measure both fresh and dry biomass. Plants were oven-dried for 72 h at 60°C to constant weight which then measured using an electronic sensitive balance (A & D Instruments, GF Series). These dried plant samples were later milled to bypass via a 0.5 mm sieve in order to perform dry ashing method to determine nutrient content in the plant samples (Sahrawat *et al.*, 2002). Nutrient uptake (potassium, calcium, and magnesium) was then calculated by multiplying plant dry weight by nutrient concentration obtained from dry ashing method ($mg\ kg^{-1}$) according to the following formula (Nigussie *et al.*, 2021):

$$\text{Total nutrient uptake} \left(\frac{mg}{polybag} \right) =$$

$$\text{nutrient concentration in tissue}(mg/kg) \times \text{plant dry weight}(kg/polybag)$$

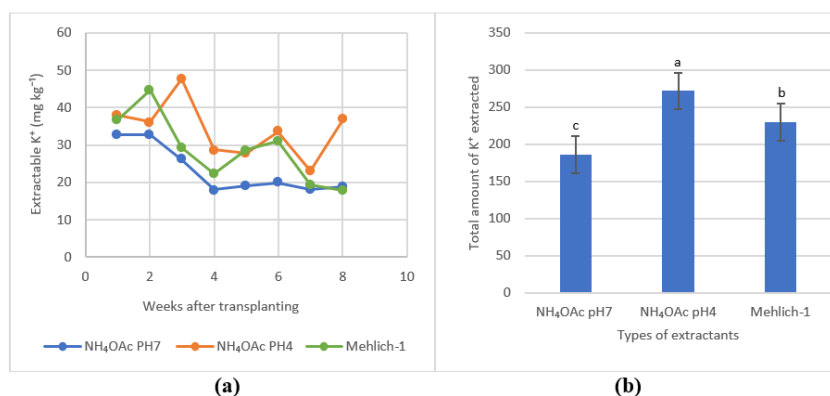
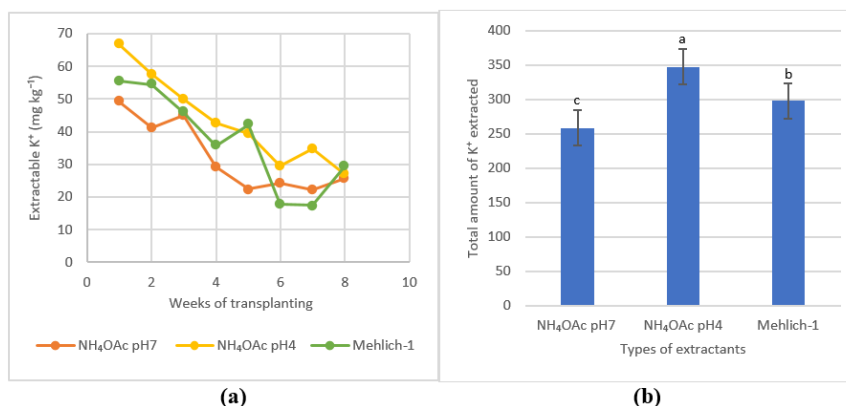


Table 1: Types of extractants treated as treatments applied on sapric peat soil to determine the available of K, Ca and Mg following the method of Reeza *et al.* (2021)

Extractant	Component	Ratio Soil: Solution	Equilibration time
1	1 M NH ₄ OAc (pH 7)	1:10	30 minutes shake 10 minutes centrifuge
2	1 M NH ₄ OAc (pH 4)	1:10	30 minutes shake 10 minutes centrifuge
3	0.5 N HCl + 0.025 N H ₂ SO ₄	1:5	30 minutes shake

Table 2: Selected physical and chemical properties of hemic and sapric peat materials prior to planting maize

Characteristic	Hemic	Sapric	Reference
pH	5.96	5.41	Andriesse (1988)
Organic matter (%)	56.80	69.89	Senga <i>et al.</i> (2023)
Organic carbon (%)	32.90	40.54	Senga <i>et al.</i> (2023)
von Post	H6	H8	Reeza <i>et al.</i> (2021)
Bulk Density (g cm ⁻³)	0.17	0.20	Könönen <i>et al.</i> (2015)

**Figure 2(a): Relationship between amounts of available Potassium (K⁺) extracted during 8 weeks of maize cultivation using different extractants in Sapric materials. (b) Total available K⁺ extracted by different extractants over the same period. Means with different letters differ significantly (Tukey's test, $p \leq 0.05$)****Figure 3(a): Changes in available potassium (K⁺) over 8 weeks of maize cultivation in Hemic materials using three different extractants. (b) Total available K⁺ extracted during the same period. Values are means; error bars indicate standard deviation. Means not sharing the same letter differ significantly (Tukey's test, $p \leq 0.05$)**

Statistical analysis

Analysis of variance (ANOVA) was used to test treatment effects (effects of different types of extractants on soil exchangeable nutrient) while means of treatments with 3 replicates were compared using Tukey's test at $p \leq 0.05$ with $\alpha = 0.05$ (IBM SPSS Statistics version 27.0). Normality of data was analyzed using Shapiro-Wilk and Kolmogorov-Smirnov while homogeneity of variance was conducted using Levene's test. When data are not normally distributed, data transformation was done using log transformation for positively skewed data in order to run the data using ANOVA.

Results

Selected physical and chemical characteristics of sapric materials prior to planting maize

The physical and chemical characteristics of Sapric and Hemic materials prior to planting maize in this study are shown in Table 2. Sapric material had lower pH (5.41) compared to Hemic (5.96), yet these pH values were higher than those typically reported for ombrogenous oligotrophic tropical peat materials. The lower pH in Sapric was attributed to the difference in the degree of decomposition. Interestingly, the organic matter and the organic carbon content in Sapric were higher than that of Hemic.

As a rule in organic soil classification, highly decomposed peats have higher organic carbon values but lesser organic matter content. The degree of decomposition was determined using von Post method and obtained a score of H8 value for Sapric indicating highly decomposed matter with average bulk density of 0.20 g cm^{-3} , while Hemic achieved a score of H6 (moderately highly decomposed) with slightly lower bulk density of 0.17 g cm^{-3} .

Soil exchangeable K^+ , Ca^{2+} and Mg^{2+}

For Sapric materials, extractant 2 ($\text{NH}_4\text{OAc} - \text{pH}4$) was able to significantly extract higher K^+ than the other two extractants as displayed in Figure 2(a) and 2(b) with the least amount of available K^+ extracted using extractant 1 ($\text{NH}_4\text{OAc} - \text{pH}7$). Extractant 2 and 3 extracted 46.17% and 23.64% more than extractant 1, respectively. This indicates that a change in an extractant's pH could lead to a drastic change in the strength of the extractants in extracting a specific cation particularly in soils where cation availability is strongly influenced by pH. This observation was noteworthy considering that both extractant 1 and 2 are of the same extracting reagent with only of different pH values yet extracting significantly contrasting amounts of available K^+

across all weeks throughout 8 weeks of cultivating maize. This can be further justified where extractant 2 was able to extract a total of $271.92 \text{ mg kg}^{-1}$ of K^+ while extractant 1 and 3 extracted $186.03 \text{ mg kg}^{-1}$ and $230.02 \text{ mg kg}^{-1}$ of K^+ , respectively.

For Hemic materials, extractant 2 also extracted significantly higher K^+ compared to other extractants as shown in Figure 3(a) and 3(b). Extractant 2 and 3 extracted 34.28% and 15.27% higher than extractant 1. This can be shown clearly where the quantity of available K^+ extracted throughout 8 weeks of maize planting in Hemic were $347.65 \text{ mg kg}^{-1}$ of K^+ in extractant 2 while extractant 1 and 3 achieved a total of $258.91 \text{ mg kg}^{-1}$ of K^+ and $298.44 \text{ mg kg}^{-1}$ of K^+ , respectively. Such values were higher than those observed in Sapric material. It can be deduced from the decreasing trend of the available K^+ extracted throughout 8 weeks of planting that the strength of extractants are in the following order: $\text{NH}_4\text{OAc pH}4 > \text{Mehlich-1} > \text{NH}_4\text{OAc pH}7$. This also demonstrates that regardless of the types of peat material, extractant 2 (NH_4OAc at pH4) is more suitable in extracting available K^+ compared with NH_4OAc at pH7 and Mehlich-1. Apart from that, both types of peat materials showed a decreasing trend in the pool of available K^+ , indicating depletion of K^+ possibly due to the rapid uptake by the plants or leaching out from the particular soil (Andriess, 1988; Krishnan *et al.*, 2021).

For extractable Calcium (Ca^{2+}), it can be clearly observed that extractant 3 (Mehlich-1) extracted significantly higher amounts of Ca^{2+} compared to those extracted by extractant 1 and 2 throughout 8 weeks planting in both Hemic and Sapric peat materials as displayed in Figure 4 and 5. Interestingly, extractant 2 was significantly the lowest in extracting Ca^{2+} throughout 8 weeks of planting. This observation was in contrast with results for available K^+ where extractant 2 was able to extract higher amounts of cations from the other extractants. As such extractant 3 and 1 extracted 162.8% and 13.9% higher than extractant 2.

This can be clearly observed where extractant 3 managed to extract a total amount of Ca^{2+} ($2,281.68 \text{ mg kg}^{-1}$) in Sapric compared to extractant 1 ($988.95 \text{ mg kg}^{-1}$) and 2 ($868.21 \text{ mg kg}^{-1}$), respectively, over 8 weeks of planting as shown in Figure 4(b). Similarly, extractant 3 and 1 were able to extract 119.69% and 8.72% higher Ca^{2+} compared to extractant 2. This can be shown where extractant 3 extracted $3,676.51 \text{ mg kg}^{-1}$ of Ca^{2+} , followed by extractant 1 ($1,819.43 \text{ mg kg}^{-1}$) while the least extracted was extractant 2 ($1,673.52 \text{ mg kg}^{-1}$) as shown in Figure 5(b). This justifies that Ca^{2+} extracted in Hemic materials were higher than that in Sapric materials regardless of the types of extractants used. This implies that



Exchangeable extractants in nutrient uptake in maize

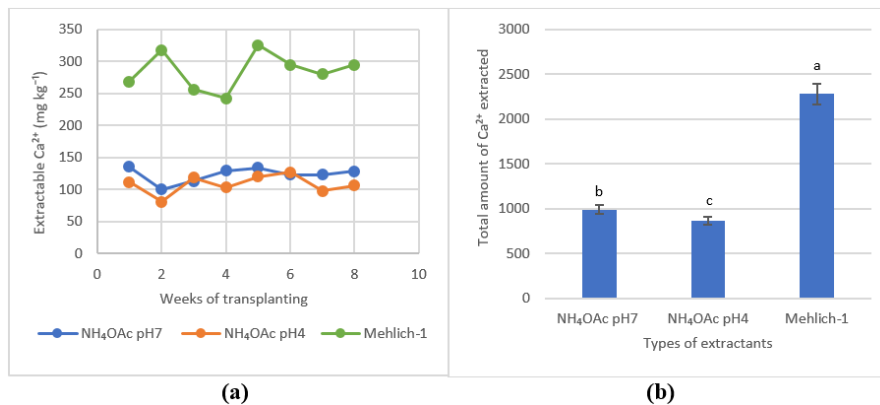


Figure 4(a): Relationship between amounts of available Calcium (Ca^{2+}) extracted during 8 weeks of maize cultivation using different extractants in Sapric materials. (b) Total available Ca^{2+} extracted by different extractants over the same period. Means with different letters differ significantly (Tukey's test, $p \leq 0.05$)

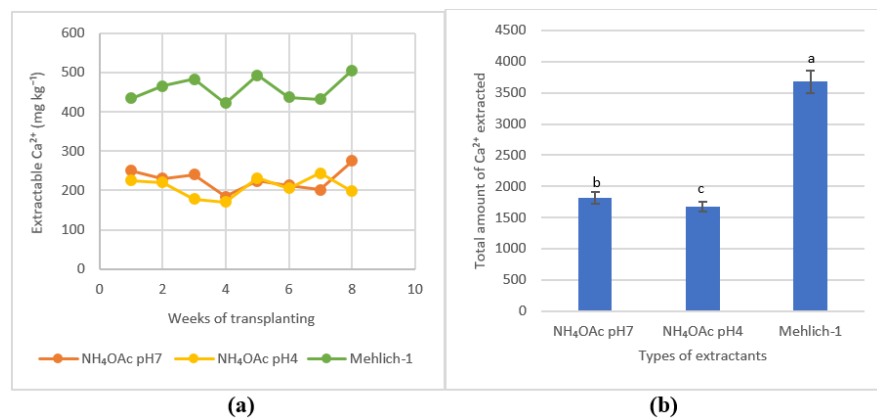


Figure 5(a): Changes in available Calcium (Ca^{2+}) over 8 weeks of maize cultivation in Hemic materials using three different extractants. (b) Total available Ca^{2+} extracted during the same period. Values are means; error bars indicate standard deviation. Means not sharing the same letter differ significantly (Tukey's test, $p \leq 0.05$)

calcium might have moved downward to the lower profile of the lesser decomposed Hemic materials possibly due to rainfall in the oil palm plantation where these materials were initially collected. Hence, it can be deduced from the constant trend of the available Ca^{2+} extracted throughout 8 weeks of planting that the strength of extractants is in the following order: Mehlich-1 > $\text{NH}_4\text{OAc pH7}$ > $\text{NH}_4\text{OAc pH4}$. This is to show that extractant 3 using Mehlich-1 is more suitable in extracting available Ca^{2+} across these two types of peat materials.

Apart from that, it can also be observed that the pattern of Ca^{2+} extracted from the Sapric material regardless of extractant types was constant throughout 8 weeks of planting which is different from the trend observed for K^+ . It is also apparent that the amount of Ca^{2+} extracted irrespective of the

types of extractants used were much higher than the amount of K^+ extracted. Thus, it can be inferred that calcium pool in the Sapric materials is larger than that of K^+ . Additionally, the amount of Ca^{2+} in Sapric material was found to be exceptionally high although its pH is still considered acidic. It is worth mentioning that Sapric material collected was from an oil palm plantation where liming might have been done previously thus contributing to the higher amounts of Ca^{2+} extracted.

Similar observation was found for available magnesium (Mg^{2+}) extracted in Sapric as shown in Figure 6(a) and Hemic materials in Figure 7(a). Extractant 3 was able to obtain the highest amount of Mg^{2+} extracted with 126.12% higher compared to extractant 2 while extractant 1 managed to extract 17.46% more than extractant 2. This can be observed



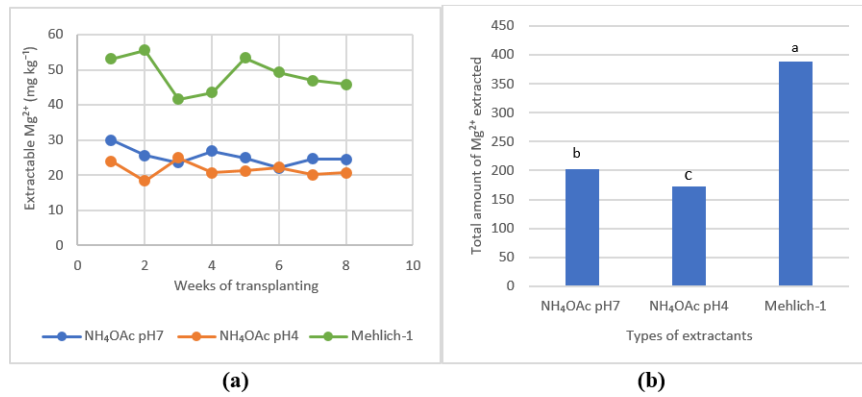


Figure 6(a): Relationship between amounts of available Magnesium (Mg^{2+}) extracted during 8 weeks of maize cultivation using different extractants in Sapric materials. (b) Total available Ca^{2+} extracted by different extractants over the same period. Means with different letters differ significantly (Tukey's test, $p \leq 0.05$)

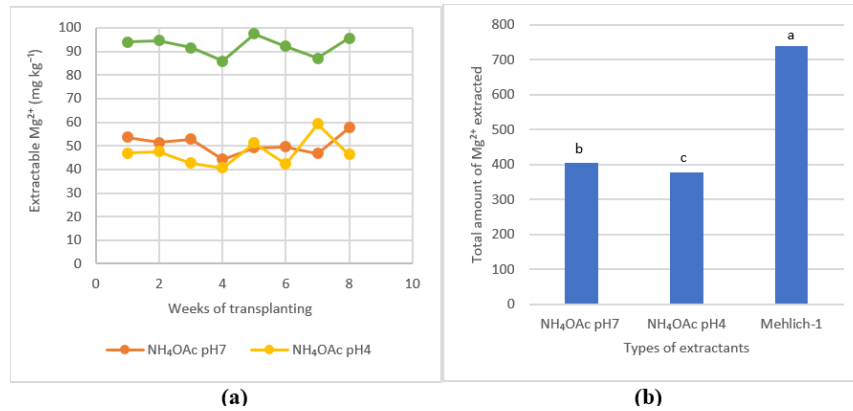


Figure 7(a): Changes in available Magnesium (Mg^{2+}) over 8 weeks of maize cultivation in Hemic materials using three different extractants. (b) Total available Mg^{2+} extracted during the same period. Values are means; error bars indicate standard deviation. Means not sharing the same letter differ significantly (Tukey's test, $p \leq 0.05$)

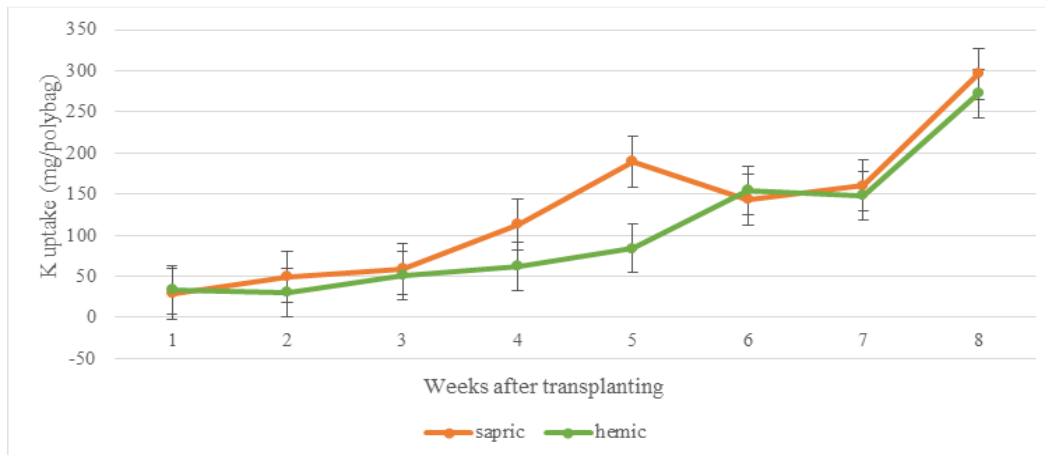


Figure 8: Potassium uptake in maize throughout 8 weeks of planting in Sapric and Hemic peat materials



where the total amount of Mg^{2+} obtained over 8 weeks of planting from extractant 3 was $389.05 \text{ mg kg}^{-1}$, while extractant 1 and 2 extracted 202.1 mg kg^{-1} and $172.06 \text{ mg kg}^{-1}$, respectively, as displayed in Figure 6(b). As for Hemic materials, the total amount obtained by extractant 3 was $738.61 \text{ mg kg}^{-1}$, which was 96.07% higher than extractant 2. This was followed by extractant 1 ($405.37 \text{ mg kg}^{-1}$) with 7.61% higher compared to extractant 2 which extracted the least amount ($376.68 \text{ mg kg}^{-1}$) as shown in Figure 7(b).

The total amounts of Mg^{2+} extracted from Hemic was higher than those extracted in Sapric implying that lesser decomposed peat materials contained higher amounts of available Mg^{2+} , a similar condition reported previously for available Ca^{2+} . Also, it can be deduced from the constant trend of the available Mg^{2+} extracted that the strength of extractants is in the following order: Mehlich-1 > $NH_4OAc \text{ pH}7$ > $NH_4OAc \text{ pH}4$. This is to show that extractant 3 using Mehlich-1 is more suitable in extracting available Mg^{2+} in both peat materials, a similar observation to those found in Ca^{2+} as well.

Potassium uptake by maize throughout 8 weeks of growth in hemic and sapric peat materials

Figure 8 demonstrate the trend in potassium uptake in maize planted in sapric and hemic peat materials, respectively. Both types of peat materials exhibited an increasing trend in K uptake throughout 8 weeks of planting despite the fact that the available K^+ extracted previously in both peat materials were decreasing throughout the planting period. It is also worth mentioning that during the planting period, the maize plants did show symptom of potassium deficiency after 4 weeks of transplanting in sapric material.

Hence, it can be presumed that Sapric peat materials might not be able to supply sufficient amount of potassium to support the growth and development of maize and that additional fertilizer is required especially since potassium is one of the largest amounts of nutrient being taken up by plants.

In addition, it can be observed that as the maize grew, the amount of potassium it required rapidly increased where the highest amount of potassium uptake by the plant was on week 8 which consumed 296.18 mg when planted in Sapric and 272.68 mg when planted in Hemic. Interestingly, the amount of K taken up in Hemic was lower compared to Sapric albeit the amount of available K^+ extracted from Hemic peat materials was higher than that in Sapric. Nevertheless, such high amount of K uptake at week 8 demonstrate the onset of

the reproductive phase where the maize had begun the phase for silking and tasselling. Such finding is justified by the significantly high amounts of K uptake than calcium and magnesium evaluated in this study.

Calcium uptake by maize throughout 8 weeks of growth in hemic and sapric peat materials

Figure 9 shows that calcium uptake in maize increased throughout 8 weeks of planting irrespective of peat types, similar in potassium uptake mentioned previously. However, the amount of calcium taken up by the maize was lower than that of potassium although calcium was the highest amount of available nutrient in both peat materials. Thus, it can be understood that maize plants are selective in terms of taking up nutrients whereby it only absorbs nutrients that is required for its growth and not because it is abundant in the soil. This is particularly true where calcium was taken up about 5-58 mg/plant/week planting when the peat materials contained almost 300 mg kg^{-1} at any one time. The highest Ca uptake was also observed at week 8 similar to that in K uptake with 58.47 mg when planted in Sapric while about 51.73 mg of Ca uptake when grown in Hemic due to onset of the reproductive phase. The uptake of Ca was higher in Sapric than when cultivated in Hemic although the available pool in Hemic was significantly higher.

Magnesium uptake by maize throughout 8 weeks of growth in hemic and sapric peat materials

The increasing trend in magnesium (Mg) uptake in maize shown in Figure 10 for both peat materials was similar to K and Ca uptake. However, the amount of Mg absorbed by the plant was the least compared to K and Ca irrespective of peat materials. Although low amounts of magnesium taken up by maize, the plant did not show any sign of magnesium deficiency in their leaves. The highest amount of Mg was taken up at week 8 which was about 20.59 mg in sapric while as much as 21.22 mg in hemic, a contrasting observation found previously for K and Ca when both of these nutrients were taken up much higher in sapric compared to hemic, although the amount of Mg absorbed by the maize plant was significantly the lowest compared to these two former nutrients. This can be deduced that among the three nutrients studied, the amount of nutrient uptake by maize is arranged in the following order: Potassium > calcium > magnesium. Overall, from the results gathered on nutrient availability vs. nutrient uptake for potassium, calcium and magnesium, it can be estimated that calcium and magnesium may be sufficient in sapric peat materials to support the growth and development of maize typically Asia Manis variety, while



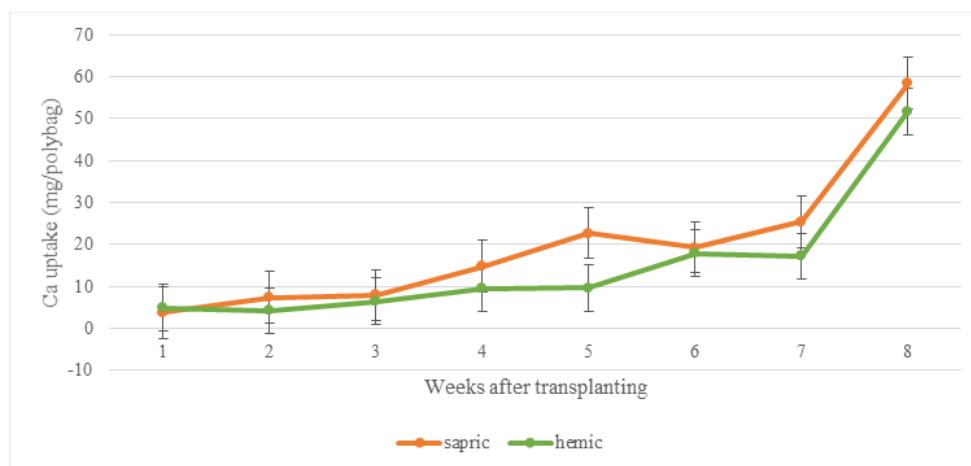


Figure 9: Calcium uptake in maize throughout 8 weeks of planting in Sapric and Hemic peat materials

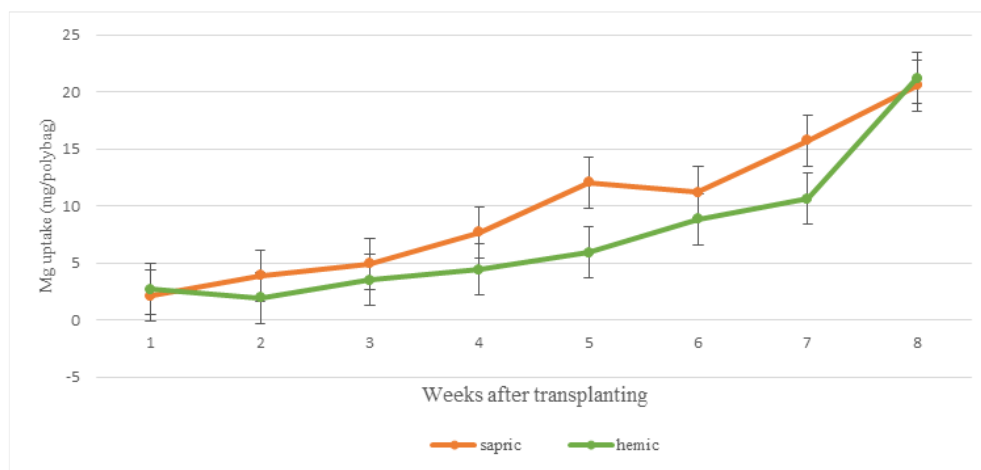


Figure 10: Magnesium uptake in maize throughout 8 weeks of planting in Sapric and Hemic peat materials

potassium might need to be externally supplied by addition of fertilizers so that optimum growth can be achieved. However, it should be emphasized that such abovementioned opinion on nutrient sufficiency may be applicable for a single planting cycle, as nutrients might need to be replenished when multiple cycle of maize planting is undertaken.

Discussion

The soil pH for both peat materials was higher than that of typical ombrogenous oligotrophic tropical peat, which usually ranges between 3.0 and 4.5 (Andriess, 1988). This is not typical for Sapric peat as it usually falls within the range of 3-4 (Goulding, 2016). This difference is likely because the peat materials in this study were collected from an oil palm plantation area. The site may have had a history of previous liming applications. However, the pH in Sapric was lower

than that in Hemic which might be attributed to the difference in the degree of decomposition. Such result was consistent with several reports (Arabia *et al.*, 2020; Reeza *et al.*, 2021; Wahab *et al.*, 2023). Interestingly, the organic matter and the organic carbon content in Sapric was higher than that of Hemic where values are similar to those found in Buhandanda and Lushala peatlands in Republic of Congo (Senga *et al.*, 2023). The average bulk density of 0.20 g cm^{-3} for Sapric was similar to those recorded by Reeza *et al.* (2021) and Senga *et al.* (2023). Bulk density was also higher in Sapric than Hemic and such values were also similar to the open agricultural peatland reported by Könönen *et al.* (2015).

This study also revealed that the calcium contents in soil were far larger than that of potassium. This is because Ca^{2+} can be absorbed and retained in the soil particles better than

K^+ as the latter is profoundly known to be a highly leached nutrient. Several reports have documented that K^+ can be easily lost via leaching as compared to Ca^{2+} (Afari-Sefa *et al.*, 2004; Gunal, 2025). Although highly leached, potassium was the highest nutrient being taken up by the maize since it is considered as an important nutrient for maize plant. Hence, it is transported in high concentration throughout the plant to improve the quality of the crop production and yield of corn (Zhang *et al.*, 2023).

Overall, the results of this study further justify the previous study done by Reeza *et al.* (2021) that Mehlich 1 and NH_4OAc buffered at pH 4 were generally able to extract significantly higher amounts of extractable cations than NH_4OAc buffered at pH 7. Despite the fact that the latter is a common extractant usually recommended for soil testing and analysis, it is proven to be inefficient in extracting cations from tropical peat soils. This can be further justified due to the CEC of peat which is highly pH-dependent and in turn depends on the pH of the soil solution where in this case, the pH of the extracting solution (Yadav *et al.*, 2023). Henceforth, the extraction of available K^+ seems to be favored by using NH_4OAc buffered at pH 4 extractant while both Ca^{2+} and Mg^{2+} prefer Mehlich-1 extractant regardless of peat materials.

According to Reeza *et al.* (2021), when solution pH increases, such as using NH_4OAc buffered at pH 7, some of the H^+ ions will be neutralized. Therefore, more of the H^+ ions rather than the basic cations such as K^+ , are removed from the exchange sites and get neutralized or replaced on the exchange complex. This leads to the deprotonation of pH-sensitive functional groups (like carboxylic acids), generating more negative charges. Therefore, more of the basic cations will be adsorbed onto soil colloids and occupy the negative sites of the functional groups. As a result, the soil's CEC increases, allowing for more effective extraction of base cations such as K^+ , Ca^{2+} , and Mg^{2+} (Kyzioł-Komosińska, 2002).

Another possible reason for the lower values in available cations extracted by NH_4OAc buffered at pH 7 is that that some H^+ ions remain strongly fixed to organic functional groups, potentially due to hydrogen-bonded matrix compaction. Therefore, it is resistant to displacement by NH_4^+ within the limited equilibration time. This limited exchangeability despite higher extractant pH has been demonstrated in a study by Mouvenchery *et al.* (2013) using peat, where kinetic constraints and structural accessibility limited cation uptake even when the final pH was elevated.

It should be clearly taken into consideration that most if not all of the negative charges in these peat materials originate from the dissociation of H^+ from carboxyl, phenoxyl, and hydroxyl functional groups. This is in contrast with mineral soils where negative charges are associated with isomorphic substitution that are uniformly distributed over the surface of the clay minerals. Thus, is considered as permanent charge (Havlin *et al.*, 1999).

Henceforth, the results gathered in this study clearly indicate that extraction of K^+ , Ca^{2+} , and Mg^{2+} using Mehlich 1 and NH_4OAc at pH 4 may provide a better estimation of available basic cations than NH_4OAc at pH 7, because the pH of these extractants is closer to the pH of tropical peat soils.

Conclusion

This study demonstrated the varying effectiveness of different extractants in determining available basic cations (K^+ , Ca^{2+} , and Mg^{2+}) in tropical peat soils. Extraction using NH_4OAc buffered at pH 4 was more representative of field conditions, particularly in estimating plant-available K^+ . Mehlich-1 proved more effective for extracting Ca^{2+} and Mg^{2+} from Hemic and Sapric peat materials. The enhanced nutrient uptake observed in maize cultivated on Sapric peat indicates that more decomposed peat may offer better nutrient availability and thus support improved crop performance. These findings also suggest that maize exhibits selective nutrient uptake based on physiological requirements, rather than soil abundance.

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References

- Afari-Sefa, V., P.K. Kwakye, D. Okae-Anti, A.Z. Moro and M. Nyamiah. 2004. Potassium Availability in Soils - Forms and Spatial Distribution. *The Abdus Salam International Centre for Theoretical Physics (ICTP)* 110: 1-16.
- Andriess, J.P. 1988. *Nature and Management of Tropical Peat Soils*. Rome, Italy: Food and Agriculture Organization of the United Nations. 165 p.
- American Society for Testing and Materials. 1988. *Annual Book of ASTM Standards* (Volume 4.08). Washington, ASTM International, USA. 128 p.
- Arabia, T., H. Basri, Manfarizah, Zainabun and Mukhtaruddin. 2020. Physical and chemical characteristics in peat lands of Aceh Jaya District, Indonesia. *In IOP conference series:*



- Earth and Environmental Science* Vol. 499(No. 1): 012004. IOP Publishing.
- Espeleta, J.F., Z.G. Cardon, K.U. Mayer and R.B. Neumann. 2017. Diel plant water use and competitive soil cation exchange interact to enhance NH_4^+ and K^+ availability in the rhizosphere. *Plant Soil* 414: 33–51.
- FAO. 2022. Standard operating procedure for the determination of exchangeable cations and CEC using 1M ammonium acetate. Food and Agriculture Organization of the United Nations. <https://openknowledge.fao.org/handle/20.500.14283/cc1200en>.
- 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.
- Gunal, E. 2025. Biochar-mediated changes in nutrient distribution and leaching patterns: Insights from a soil column study. *PeerJ*. 13: e18823.
- Havlin, J.L., J.D. Beaton, S.L. Tisdale and W.L. Nelson. 1999. *Soil Fertility and Fertilizers: An Introduction to Nutrient Management*. 6th Edition. Prentice Hall, Upper Saddle River. 499 p.
- International Organization for Standardization. 2023. *ISO/TS 22171:2023: Soil quality — Determination of potential cation exchange capacity (CEC) and exchangeable cations using ammonium acetate solution*. <https://www.iso.org/standard/80535.html>
- Könönen, M., J. Jauhiainen, R. Laiho, K. Kusin, and H. Vasander. 2015. Physical and chemical properties of tropical peat under stabilised land uses. *Mires and Peat* 16(08): 1–13.
- Kottek, M., J. Grieser, C. Beck, B. Rudolf and F. Rubel. 2006. World map of the Köppen-Geiger climate classification updated. *Meteorologische Zeitschrift* 15(3): 259–263.
- Krishnan, K., A.A. Ngerong, K. Ahim, O.H. Ahmed, M. Ali, L. Omar and A.A. Musah. 2021. Mitigating potassium leaching from muriate of potash in a tropical peat soil using clinoptilolite zeolite, forest litter compost, and chicken litter biochar. *Agronomy* 11(10): 1900.
- Kyzioł-Komosińska, J. 2002. Effect of physical properties and cation exchange capacity on sorption of heavy metals onto peats. *Polish Journal of Environmental Studies* 11: 713–718.
- Leikam, D.F., D.B. Mengel, R.E. Lamond and K.A. Janssen. 2021. Comparison of Mehlich-3 and ammonium acetate methods for estimating exchangeable cations in Kansas soils. *Kansas Agricultural Experiment Station Research Reports* 7(8): 3.
- Matula, J. 2009. A relationship between multi-nutrient soil tests (Mehlich 3, ammonium acetate, and water extraction) and bioavailability of nutrients from soils for barley. *Plant, Soil and Environment* 55(4):173-180.
- Mouvenchery, K.Y., A. Jaeger, A.J. Aquino, D. Tunega, D. Diehl, M. Bertmer, and G.E. Schaumann. 2013. Restructuring of a peat in interaction with multivalent cations: Effect of cation type and aging time. *PLoS One* 8(6): e65359.
- Nigussie, A., W. Haile, G. Agegnehu and A. Kiflu. 2021. Growth, nitrogen uptake of maize (*Zea mays* L.) and soil chemical properties, and responses to compost and nitrogen rates and their mixture on different textured soils: Pot experiment. *Hindawi Applied and Environmental Soil Science* 9931763. <https://doi.org/10.1155/2021/9931763>.
- Pansu, M. and J. Gautheyrou. 2006. *Handbook of Soil Analysis: Mineralogical, Organic and Inorganic Methods*. Springer, New York, USA. 993 p.
- Ramamoorthi, V. and S. Meena. 2018. Evaluation of suitable extractant for estimating soil available potassium in soils of Tamil Nadu. *International Journal of Chemical Studies* 6(6): 1662–1666.
- Reeza, A.A., A. Hussin and O.H. Ahmed. 2021. Comparison of the effectiveness of three extractants in extracting potassium, calcium and magnesium from tropical peat soils. *Mires and Peat* 27: 1–10.
- Sahrawat, K.L., K.G. Ravi and J. K. Rao. 2002. Evaluation of triacid and dry ashing procedures for determining potassium, calcium, magnesium, iron, zinc, manganese, and copper in plant materials. *Communications in Soil Science and Plant Analysis* 33(1–2): 95 - 102.
- Senga, P.M., J. Talbot and S. Bonneville. 2023. Tropical peat deposits undergoing land-use change: The case of Buhandanda and Lushala peatlands (Democratic Republic of Congo). *Mires and Peat* 29(09): 1-17.
- Sutherland, R.A. 1998. Loss-on-ignition estimates of organic matter and relationships to organic carbon in fluvial bed sediments. *Hydrobiologia* 389: 153–167.
- Wahab, N., M.K.A. Talib, N.J. Latifah, A. Madun and F. Pakir. 2023. Comparative study of peat properties in Johore Malaysia. *Asia-Pacific Journal of Science and Technology* 28(04): APST–28.
- Yadav, S.P.S., S. Bhandari, D. Bhatta, A. Poudel, S. Bhattarai, P. Yadav, N. Ghimire, P. Paudel, P. Paudel, J. Shrestha and B. Oli. 2023. Biochar application: A sustainable approach to improve soil health. *Journal of Agriculture and Food Research* 11: 100498.
- Zhang, M., Y. Hu, W. Han, J. Chen, J. Lai and Y. Wang. 2023. Potassium nutrition of maize: Uptake, transport, utilization, and role in stress tolerance. *The Crop Journal* 11(4): 1048-1058.

