

# Comparison of the effectiveness of three extractants in extracting potassium, calcium and magnesium from tropical peat soils

Ameera Abdul Reeza<sup>1</sup>, Aminuddin Hussin<sup>2</sup>, Osumanu Haruna Ahmed<sup>3</sup>

<sup>1</sup> Faculty of Plantation & Agrotechnology, Universiti Teknologi MARA, Melaka Branch, Jasin Campus, Melaka, Malaysia

<sup>2</sup> Department of Land Management, Faculty of Agriculture, Universiti Putra Malaysia, Serdang, Selangor, Malaysia

<sup>3</sup> Department of Crop Science, Faculty of Agricultural Science and Forestry, Universiti Putra Malaysia, Sarawak Campus, Bintulu, Sarawak, Malaysia

---

## SUMMARY

Peat soils are frequently analysed using the same standard methods and extractants as for mineral soils, despite the distinctive nature of organic soils. The extractants used are well-suited for peat soils of near-neutral pH but it is still unclear whether they are suitable for acidic tropical peat soils. The study reported here compared the effectiveness of three standard reagents in extracting potassium, calcium, and magnesium from tropical peat of different degrees of decomposition, collected from three field locations in peninsular Malaysia. Three basic cations ( $K^+$ ,  $Ca^{2+}$  and  $Mg^{2+}$ ) were extracted using Mehlich 1,  $NH_4OAc$  (ammonium acetate) buffered at pH 7 and  $NH_4OAc$  at pH 4. The results showed that raising the pH of the extractant reduced the amounts of  $K^+$ ,  $Ca^{2+}$  and  $Mg^{2+}$  extracted. The average amounts extracted by Mehlich 1 and  $NH_4OAc$  at pH 4 were frequently significantly higher than the amounts extracted by  $NH_4OAc$  at pH 7, in most of the peat types sampled regardless of location. Compared with the extraction using  $NH_4OAc$  at pH 7, the extractions with Mehlich 1 and  $NH_4OAc$  at pH 4 are likely to provide closer estimations of these basic cations, because the pH of the extractants reflects the true pH of tropical peat soils.

**KEY WORDS:** ammonium acetate, basic cations, CEC, Mehlich 1, organic soils, soil acidity

---

## INTRODUCTION

Tropical peatlands occur on the mainland of East Asia as well as in Southeast Asia, Central and Southern Africa, South America, the Caribbean and Central America (Vasander 2014). The highest proportion of these tropical peatlands is found in Southeast Asia, where lowland peatlands make up 56 % of the total tropical peatland area and 6 % of the global area (Page *et al.* 2011). Peatlands in Malaysia cover a total area of 2.7 million hectares, or about 8 % of the country. They are located mostly in low-lying coastal areas and are commonly ombrogenous and oligotrophic in nature with pH ranging from 3.0 to 4.5 (Andriess 1988). Their soils are very low in exchangeable bases and base saturation. Malaysian peats are also low in available nitrogen and have high C/N quotient due to the inherent vegetation, which consists largely of wood (Mutalib *et al.* 1994).

Most peat soils exhibit low levels of readily available potassium, calcium and magnesium. According to Lucas (1982), elements such as calcium and magnesium in their ionic forms are strongly adsorbed onto colloidal organic particles. Apart from that, the low availability is mainly due to the lack of clay minerals and the high presence of metal-

chelating humus in peat soils (Lucas *et al.* 1975, Mathur & Farnham 1985, Mathur & Lévesque 1988). Therefore, base saturation values often appear to be low in tropical peat of oligotrophic status. Another fact is that peat properties are highly pH dependent. According to Andriess (1988), this is because  $H^+$  remains tightly associated with (or fixed to) the functional acid group, causing less exchange with basic cations.

Although the quantities of basic cations in tropical peat appear to be low, their extraction for assessment of availability to plants is still of considerable importance in the context of measuring soil fertility status and thus providing reliable recommendations for the management of agriculture on tropical peat soils. The methods that are used to determine cation availability in peat were not developed specifically for organic soils, which are much less common than mineral soils amongst the range of soil types that are generally tested in agricultural contexts. Thus, peat soils are frequently tested using the same standard methods as for mineral soils, even though the nature of organic soils is different (Anderson & Beverly 1985). Some modified methods have been proposed previously, but these are still essentially similar to those used for mineral soils. For example, Bigger *et*

*al.* (1953) recommended increasing the ratio of soil to extracting solution in order to accommodate the high water adsorption capacity of organic soils; while van Lierop *et al.* (1980) found both higher soil : extractant ratio and prolonged extraction time useful for minimising the effects of variable rewetting time in dried organic soils.

The extractants used are generally dilute solutions of mineral or organic acids, simple salts, or organic and mineral complexing agents (Karam 1993). For determinations of cation exchange capacity (and thus exchangeable potassium, calcium and magnesium), the commonest extractant is 1 N NH<sub>4</sub>OAc (ammonium acetate) buffered at pH 7 (Tan 2005). This extractant is well suited to peat with near-neutral pH and relatively low lignin content, such as the deposits formed beneath mosses and sedges in temperate and boreal peatlands for which many of the standard soil testing protocols were devised. Vasander (2014) mentions that peat forms under very different conditions in the tropics. Tropical peatland is largely covered by evergreen trees and maintained by continuously high litter inputs from these trees into seasonally water-saturated peat deposits where the speed of semisurficial water flow is usually faster than in temperate and boreal peatlands. As the chemical composition of peat materials is predominantly influenced by vegetation, degree of decomposition and the original chemical environment (Andriess 1988), we can expect fundamental differences in colour, texture and possibly chemistry between tropical and temperate/boreal peat. Indeed, tropical peat is often extremely acidic with high lignin content. Thus, the suitability of established standard methods and extractants for tropical peat remains unclear, and the choice of analysis methods for tropical peat soils requires special attention.

The present study was carried out to compare the effectiveness of three soil extractants in extracting potassium, calcium, and magnesium cations from tropical peats with differing degree of decomposition, collected from three locations in peninsular Malaysia.

## METHODS

### Soil sampling and preparation

The peat soil samples used in this study were collected from three locations in Peninsular Malaysia with contrasting land use and water management regimes. The samples were selected on the basis of depth and degree of decomposition, to represent the full range of chemical and physical properties found amongst peat soils in Peninsular Malaysia. We

sampled at two locations in secondary forest, namely Mersing (2° 25' 42.1" N, 103° 50' 10.2" E) in the state of Johor, and Banting (2° 45' 42.3" N, 101° 28' 07.0" E) in the state of Selangor. A third set of samples was taken from a seven-year-old oil palm plantation at Jenjarom, Selangor (2° 52' 20.5" N, 101° 31' 14.1" E). Banting and Jenjarom were visited on the same day in September 2018, and Mersing in November 2018. At each location, an Eijkelkamp peat sampler which extracted 50 cm long cores of diameter 5.2 cm was used to determine the thickness of the peat deposit and the depths of peat layers of different types. The types were Fibric, Hemic and Sapric where Fibric is the least decomposed and Sapric has the highest degree of decomposition (Mutalib *et al.* 1994, Radjagukguk *et al.* 2000, Agus *et al.* 2011, Nasrul *et al.* 2020). Soil pits were then excavated with a trowel and/or a shovel to open up specific peat layers for sampling. Surface (0–30 cm) and subsurface (nominally 30–100 cm and 100–200 cm) samples were collected in 127.5 cm<sup>3</sup> stainless steel core rings (diameter 5.2 cm, height 6.0 cm) or in 100 ml plastic vials if the peat was too wet to be retained in a core ring. For each sampling location and peat type, some samples were preserved in their undisturbed field condition and a composite bulk sample was also collected. All samples were sealed in airtight plastic bags for transportation to the laboratory where they were immediately stored in a refrigerator at 4 °C. For analyses that required air dry peat (particle density, pH, CEC), some material taken from the composite samples was air dried in a greenhouse at 30–32 °C, ground in a mortar and pestle, and passed through a 2 mm sieve.

### Soil analyses

Degree of decomposition was determined using the von Post squeezing method according to Parent & Caron (1993). Fresh peat was squeezed in the palm of the hand, and the proportion of matter along with the colour of the liquid extruded between the fingers was used to classify the peat according to the von Post scale (H1–H10).

Undisturbed peat samples were oven dried to constant weight at 105 °C for determination of bulk density and moisture content (gravimetric method; ASTM 1988). Particle density was measured by the pycnometer method (Heiskanen 1992) using absolute (99.6%) ethanol in preference to water in order to ensure complete saturation of the sample. This was necessary because waxy substances in the plant remains of tropical peats make it difficult to saturate them with water. Total pore space (porosity) was calculated from the bulk density and particle density values.

The determinations of ash and organic matter content were based on the dry-ashing method, which involves the removal of organic matter by combustion of the sample at medium temperature (375–600 °C) in a temperature regulated muffle furnace (ASTM 1988). Total carbon was determined using a TruMac CNS Auto-analyser Version 1.1x (LECO Corporation, St Joseph, MI).

pH was measured potentiometrically in soil suspensions consisting of 1:10 volumetric ratio of air-dried sample to water and 1 M KCl. CEC was determined by adding 100 mL of 0.1 N K<sub>2</sub>SO<sub>4</sub> to peat material that had previously been washed twice with 95 % ethanol. The solution was shaken for 30 minutes and the supernatant was separated by centrifugation and filtered into 100 mL plastic vials. The determination of CEC was completed by analysing the filtered solution using an auto-analyser (LCHAT Instruments QuickChem FIA 8000 Series).

The basic soil cations K<sup>+</sup>, Ca<sup>2+</sup> and Mg<sup>2+</sup> were extracted using NH<sub>4</sub>OAc buffered at pH 7 and pH 4 (close to soil pH), as well as Mehlich 1 (0.05 N HCl+ 0.025 N H<sub>2</sub>SO<sub>4</sub>; dilute double acid method), as outlined in Table 1. All extractions were done on a volume-weight basis. This is of considerable importance when dealing with organic soils (primarily peat soils) so as to reduce the effect of differences in bulk density between different peat types and thus obtain less variable and more reliable results. The extraction procedures for the three extractants were conducted using the same apparatus and equipment for consistency.

For the extraction using NH<sub>4</sub>OAc at pH 7, up to 10 cm<sup>3</sup> of peat was placed in a 100 mL centrifuge tube. Then, 100 mL of NH<sub>4</sub>OAc buffered at pH 7 was added and the mixture was shaken mechanically for 30 minutes. The supernatant solution was separated from the peat material by centrifugation at 2400 rpm for 30 minutes, filtered into 100 mL plastic vials, then made up to 100 mL with NH<sub>4</sub>OAc (Tan 2005).

For the extraction using NH<sub>4</sub>OAc buffered at pH 4, the same method was applied except that the prepared NH<sub>4</sub>OAc was adjusted to pH 4 by adding acetic acid, with constant stirring, until the desired pH was achieved. For the dilute double acid method, 80 ml of 6N HCl and 7 ml of concentrated H<sub>2</sub>SO<sub>4</sub> were diluted in 10 L of distilled water. Then, 5 cm<sup>3</sup> of the peat material was added to 25 mL of the diluted acid mixture (0.05 N HCl and 0.025 N H<sub>2</sub>SO<sub>4</sub>) in a conical flask. The solution was shaken for 15 minutes on a reciprocating shaker at a minimum of 180 oscillations per minute (Mehlich 1984), then the suspension was filtered (Whatman No. 42).

The concentrations of K<sup>+</sup>, Ca<sup>2+</sup>, and Mg<sup>2+</sup> in the filtrates were determined by atomic absorption spectroscopy (AAAnalyst 400, Perkin Elmer, Waltham, MA) and expressed in µg g<sup>-1</sup> of soil, which is the standard unit (Tan 2005).

### Statistical analyses

The experiment was factorial with three factors, namely: location of peat samples, peat type and extractant type; with a completely randomised design (CRD). Two statistical analyses were conducted. Analysis of Variance (ANOVA) was done to detect significant effects of the extractants, soil types, and locations; while the differences between mean values for extractable K<sup>+</sup>, Ca<sup>2+</sup> and Mg<sup>2+</sup> were compared using Tukey's test at  $p = 0.05$  (Statistical Analysis System 2001).

## RESULTS

### Physical and chemical characteristics of peat material

Chemical and physical characteristics of the different peat types collected from three selected locations are shown in Table 2. The bulk density values for Hemic and Sapric material were consistent with the range of

Table 1. The three extractants used for determination of available K, Ca and Mg.

Extractant	Components	Extraction time (minutes)	Soil : solution ratio	References
Mehlich 1	0.05 N HCl 0.025 N H <sub>2</sub> SO <sub>4</sub>	30	1 : 5	Mehlich (1984)
NH <sub>4</sub> OAc	1 M NH <sub>4</sub> OAc pH = 7.0	60	1 : 10	Tan (2005)
NH <sub>4</sub> OAc	1 M NH <sub>4</sub> OAc pH = 4.0	60	1 : 10	Modified method of Tan (2005)

Table 2. Chemical and physical characteristics of the three different peat types (Sapric, Hemic, Fibric) collected from three sites in Peninsular Malaysia (Mersing, Jenjarom, Banting). The values provided are means of three replicate determinations (n=3) except where marked with an asterisk (\*) when n=6. In each case, standard deviation (SD) is shown in parentheses.

Site	Sampling depth (cm)	Peat type	Bulk density (g cm <sup>-3</sup> )	Particle density* (g cm <sup>-3</sup> )	Porosity (cm <sup>3</sup> cm <sup>-3</sup> )	Von Post ranking	pH*		Moisture content (%)	CEC (meq 100 g <sup>-1</sup> )	Organic matter (%)	Organic carbon (%)
							water	1 M KCl				
Mersing	0–30	Sapric	0.20 (0.02)	1.318 (0.02)	0.85 (0.15)	H9	3.72 (0.11)	2.66 (0.13)	68.60 (1.30)	114.82 (2.34)	91.3 (1.97)	52.43 (0.88)
	40–100	Hemic	0.18 (0.01)	1.498 (0.01)	0.88 (0.12)	H7	3.85 (0.16)	2.90 (0.11)	73.59 (0.50)	97.4 (2.11)	88.0 (1.64)	53.05 (1.17)
	100–200	Fibric	0.08* (0.05)	1.144 (0.05)	0.93 (0.18)	H3	3.80 (0.15)	2.89 (0.20)	89.82 (1.61)	90.6 (1.98)	93.2 (1.26)	55.54 (0.79)
Jenjarom	0–20	Sapric	0.12 (0.05)	1.369 (0.05)	0.91 (0.11)	H9	3.71 (0.11)	2.89 (0.18)	70.20 (1.80)	98.76 (2.42)	84.2 (1.18)	51.95 (1.66)
	30–80	Hemic	0.14 (0.10)	1.154 (0.10)	0.88 (0.16)	H5	3.72 (0.13)	2.78 (0.14)	76.56 (0.72)	93.55 (1.18)	90.3 (2.29)	52.48 (1.18)
	90–150	Fibric	0.08 (0.04)	1.551 (0.04)	0.95 (0.20)	H3	3.84 (0.12)	2.86 (0.11)	85.05 (1.14)	88.37 (1.67)	96.5 (1.78)	55.99 (1.09)
Banting	0–30	Sapric	0.18 (0.02)	0.843 (0.02)	0.79 (0.16)	H8	3.59 (0.14)	2.51 (0.12)	69.50 (0.64)	101.67 (2.33)	92.5 (2.66)	51.28 (0.88)
	40–100	Hemic	0.15 (0.04)	0.841 (0.04)	0.82 (0.09)	H6	3.59 (0.16)	2.27 (0.16)	78.28 (0.53)	95.66 (2.45)	95.5 (2.52)	53.35 (1.12)
	120–250	Fibric	0.08 (0.10)	0.836 (0.10)	0.90 (0.15)	H3	3.75 (0.13)	2.31 (0.12)	87.07 (1.22)	91.29 (1.67)	97.5 (1.66)	56.42 (1.54)

values documented in Soil Taxonomy (1975). They were also similar to values obtained for open agricultural peatland by Könönen *et al.* (2015) and for undegraded South African peats with bulk density 0.1–0.15 g cm<sup>-3</sup> by Gabriel *et al.* (2018). Porosity declined as degree of decomposition increased, Sapric material having the lowest values for porosity (79–90 cm<sup>3</sup> cm<sup>-3</sup>) and Fibric material the highest (90–95 cm<sup>3</sup> cm<sup>-3</sup>). The Sapric peat was very highly decomposed (H8), most of the material being amorphous and exhibiting very indistinct plant structures after squeezing between the fingers; whereas the Fibric peat was very slightly decomposed (H3) with plant structures remaining more distinct after squeezing (Andriess 1988, Zulkifley *et al.* 2013). Also, because the Fibric material was saturated with water at the time of sampling, it contained more moisture than the Sapric surface layer, where the water table was generally found at 30 cm depth regardless of location. This explains the lower value of moisture content in Sapric material (68–70 %) as compared to Fibric material (85–89 %) (Table 2). The range of pH (measured in water) for all peat types was typical for an ombrogenous oligotrophic tropical peat soil (3.0–4.5; Andriess 1988). pH was slightly lower in Sapric (3.59–3.72) than in Fibric (3.75–3.84) material.

Another important criterion in determining the stage of decomposition is the total percentage of

organic carbon. The higher degree of decomposition resulted in lower carbon content for Sapric (51–52 %) than for Fibric material (55–56 %). The organic matter content was also found to be slightly lower in Sapric (84–92 %) than in Fibric peat (93–97.5 %). However, CEC was higher for Sapric (98–114 %) than for Fibric (88–91 %) material, as found by both Puustjarvi & Robertson (1975) and Lucas (1982).

#### Extractable potassium

The mean values of K<sup>+</sup> extracted from the different peat types using the three different extractants are presented for each sampling location in Figure 1. ANOVA revealed that there is a significant interaction between location and peat type; i.e. the amounts of extractable K<sup>+</sup> differ between the different peat materials collected from each location. This result agrees with the findings of Hillel (2008) and Könönen *et al.* (2015) that, being organic rather than crystalline like most (similarly amorphous) clays, the composition of peats may vary between different locations. For a single type of peat material, the amounts of K<sup>+</sup> extracted by the different extractants were generally significantly different. However, there was no clear pattern in the amounts of K<sup>+</sup> extracted from the different peat materials collected from a single location. Amongst the Banting peats, most K<sup>+</sup> was extracted from Sapric material (56–95 µg g<sup>-1</sup>); whereas for Jenjarom peats

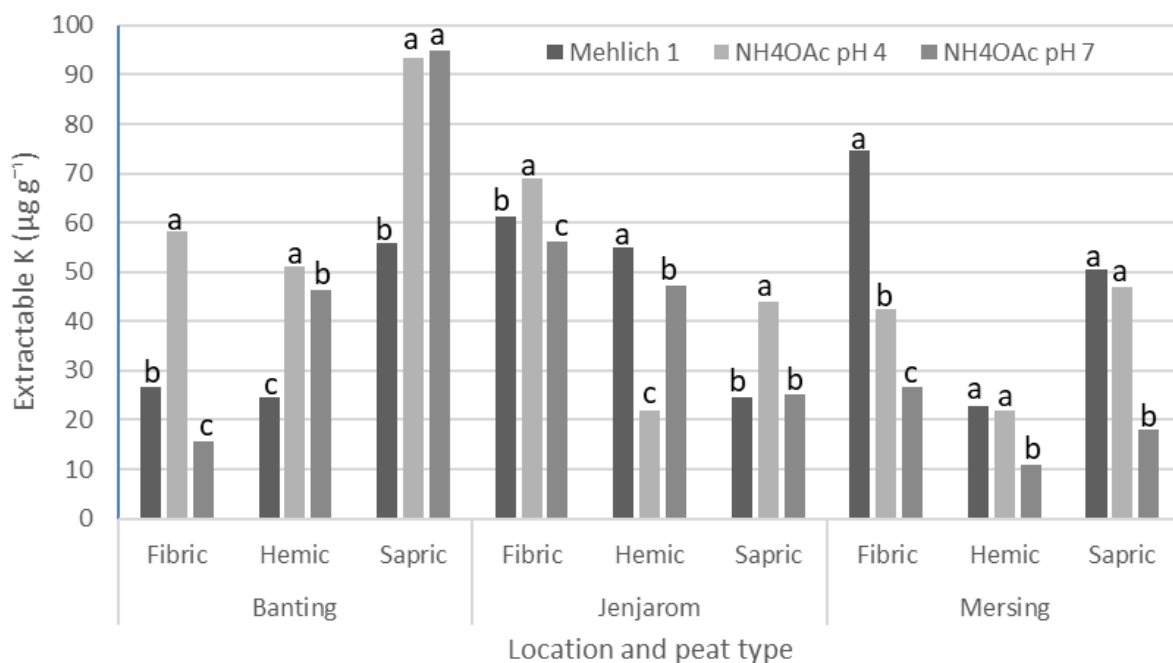


Figure 1. Comparison of the amounts of K<sup>+</sup> obtained, using three different extractants, from Fibric, Hemic and Sapric peat collected at three different locations (Banting, Jenjarom, Mersing) in peninsular Malaysia. Different letters (per peat type and location) indicate significant differences between means (Tukey's test at P = 0.05).



the highest amount of  $K^+$  was extracted from Fibric material (56–69  $\mu\text{g g}^{-1}$ ). Both Fibric (26–74  $\mu\text{g g}^{-1}$ ) and Sapric (18–50  $\mu\text{g g}^{-1}$ ) peats from Mersing showed higher amounts of  $K^+$  extraction than Hemic material (11–22  $\mu\text{g g}^{-1}$ ) from the same location.

### Extractable calcium

The average amounts of  $\text{Ca}^{2+}$  obtained using the three different extractants are shown in Figure 2. ANOVA revealed a significant interaction between location and peat type similar to that found for extractable  $K^+$ . However, all three locations exhibited a similar pattern in the relative amounts of  $\text{Ca}^{2+}$  extracted from the different peat types, with Fibric peat being significantly lowest in extractable  $\text{Ca}^{2+}$  and Sapric peat significantly highest. Another consistent trend that can be seen in Figure 2 is that  $\text{NH}_4\text{OAc}$  at pH 7 extracted the least  $\text{Ca}^{2+}$ , while Mehlich 1 extracted the most, for every site. Also, the amounts of  $\text{Ca}^{2+}$  extracted from all peat types were significantly higher than the amounts of  $K^+$  extracted, regardless of location. On the other hand, the amount of  $\text{Ca}^{2+}$  extracted from Jenjarom peat (all types) was higher than the amounts extracted from peat collected at the other two locations.

### Extractable magnesium

The results for extractable  $\text{Mg}^{2+}$  are presented in Figure 3. Statistical analysis (ANOVA) again

indicated a significant interaction between locations and peat types, as described above for  $K^+$  and  $\text{Ca}^{2+}$ . Figure 3 does not show any consistent trend in the amounts of  $\text{Mg}^{2+}$  extracted from the different peat types per location. For Banting peats the highest amount of  $\text{Mg}^{2+}$  was extracted from Sapric material (451–802  $\mu\text{g g}^{-1}$ ), while for Jenjarom peats the highest amount was extracted from Hemic material (359–484  $\mu\text{g g}^{-1}$ ), and for Mersing peats the highest amount came from Fibric material (217–316  $\mu\text{g g}^{-1}$ ). It can also be observed that the solute content (particularly extractable  $\text{Mg}^{2+}$ ) of each peat type differed between the three locations; and that the different extractants yielded distinct values of extractable  $\text{Mg}^{2+}$  for the same type of peat material collected from the same location.  $\text{NH}_4\text{OAc}$  at pH 7 was found to extract significantly less  $\text{Mg}^{2+}$  from a given peat type than the other two extractants regardless of location, while Mehlich 1 consistently extracted the highest amount of  $\text{Mg}^{2+}$ . This observation was similar to the results obtained for extractable  $\text{Ca}^{2+}$ . Across all three locations, the amounts of extractable  $\text{Mg}^{2+}$  obtained from the three types of peat material were generally higher than the amounts of extractable  $K^+$  and lower than extractable  $\text{Ca}^{2+}$ . Hence, amongst the three ionic species studied here, it can be deduced that  $\text{Ca}^{2+}$  was the most abundant extractable cation in the peats we investigated whereas  $K^+$  was the least abundant.

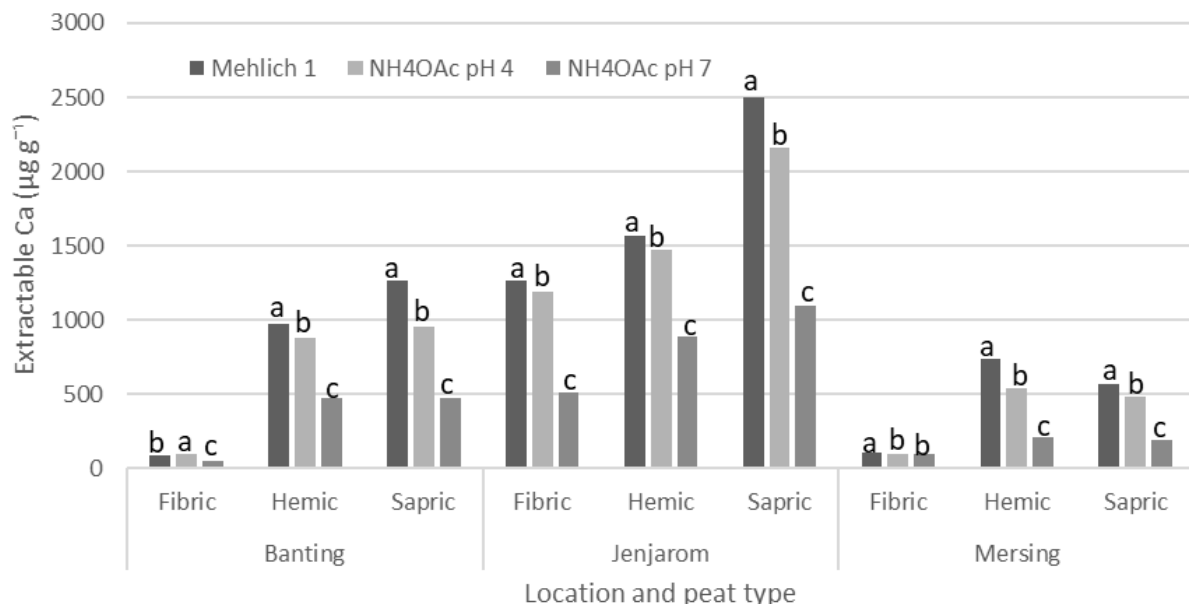


Figure 2. Comparison of the amounts of  $\text{Ca}^{2+}$  obtained, using three different extractants, from Fibric, Hemic and Sapric peat collected at three different locations (Banting, Jenjarom, Mersing) in peninsular Malaysia. Different letters (per peat type and location) indicate significant differences between means (Tukey's test at  $P = 0.05$ ).

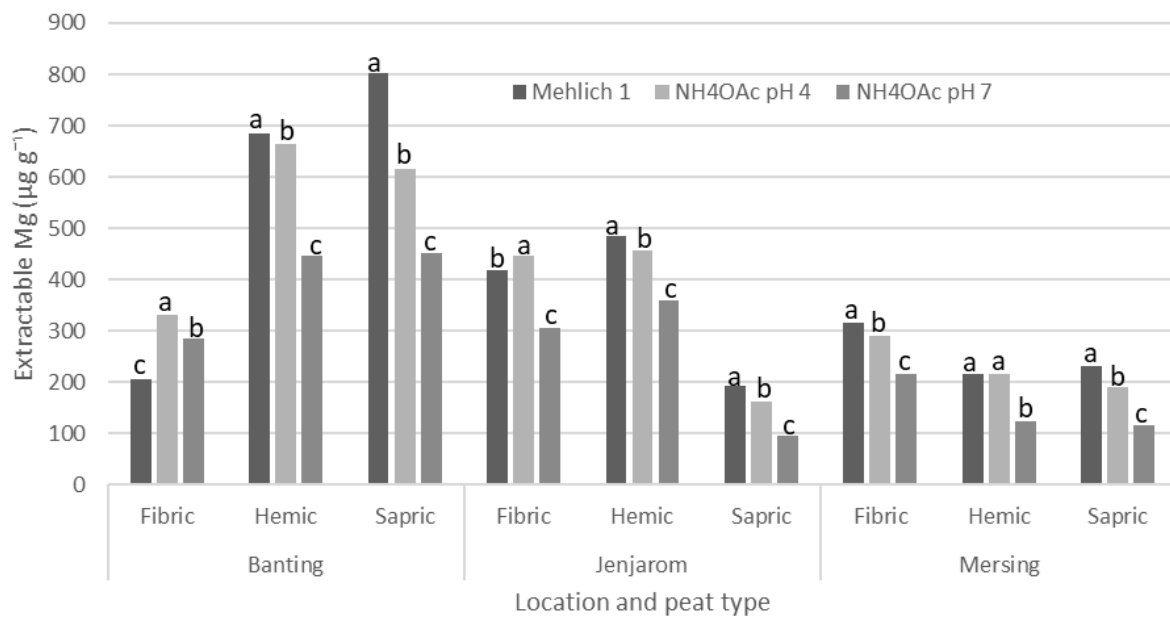


Figure 3. Comparison of the amounts of  $Mg^{2+}$  obtained, using three different extractants, from Fibric, Hemic and Sapric peat collected at three different locations (Banting, Jenjarom, Mersing) in peninsular Malaysia. Different letters (per peat type and location) indicate significant differences between means (Tukey's test at  $P = 0.05$ ).

## DISCUSSION

From the results in Table 2, bulk density was found to be higher in Sapric than in Fibric material. This is because bulk density has a direct relationship with fibre content. The more fibre a soil material contains per unit volume, the lower its bulk density becomes. Thus, Fibric material (which contains more fibre) has a lower bulk density than Sapric material. According to the findings of Huat *et al.* (2009), bulk density has an inverse relationship with organic carbon (OC); the higher the OC, the lower the bulk density. This is in agreement with the results obtained in this study, where the higher degree of decomposition in Sapric peat resulted in lower OC (Table 2) due to its utilisation by microbes for energy enabling decomposition to occur. Hence, lower OC may also imply progressive decomposition. This has resulted in the Sapric peat having lower porosity due to large pores collapsing as ongoing decomposition caused plant remains to structurally degrade, becoming smaller and finally indistinct (Könönen *et al.* 2015). Puustjarvi & Robertson (1975) reported that CEC values in peat showed a direct relationship to degree of decomposition, ranging from 100  $cmol\ kg^{-1}$  for H1 moss peats to 124  $cmol\ kg^{-1}$  for H5 moss peats. The results shown in Table 2 indicate that this finding also applies in the context of tropical peat, since the highly decomposed Sapric material had a higher CEC value than Fibric material.

The Fibric layer is found deepest in the peat profile relative to Hemic and Sapric materials. In general, most of the  $K^+$  obtained from both Mersing and Jenjarom samples was extracted from Fibric material. This might be explained by the fact that potassium is highly susceptible to leaching losses and, therefore, the readily available  $K^+$  (which is mostly the extractable  $K^+$ ) tends to leach down the profile (Brady & Weil 2002). However, the highest average  $K^+$  extraction from Banting peat was found in the top-most Sapric layer of the profile. This may explain the significant interaction effect between locations and the peat soil types. Overall, the quantities of extractable cations ( $K^+$ ,  $Ca^{2+}$  and  $Mg^{2+}$ ) in organic materials are difficult to predict because different cations are complexed to different degrees by the organic compounds (Andriess 1988).

While extractable  $K^+$  was higher in Fibric material, the opposite was observed for extractable  $Ca^{2+}$ , which was higher in Sapric material. This finding agrees with the observation of Lucas (1982) that  $Ca^{2+}$  usually occupies most of the exchange sites in the organic material of peat apart from those occupied by  $H^+$ . Conversely, although a significantly high amount of  $Ca^{2+}$  was found in Jenjarom, the average pH was still low (pH = 3.76) and not statistically different from that of the unadulterated secondary forest in Mersing (pH = 3.79). This suggests that peat soils having extremely high amounts of organic material are highly buffered and

will thus require large amounts of lime to correct their acidity. Because  $\text{Ca}^{2+}$  is not readily susceptible to leaching losses due to its high strength of adsorption, it can accumulate adsorbed onto soil colloids, which explains the high amounts of  $\text{Ca}^{2+}$  extracted from Sapric peat in all three of our sampling locations.

In our results, the average amounts of  $\text{K}^+$ ,  $\text{Ca}^{2+}$ , and  $\text{Mg}^{2+}$  removed by the three extractants appeared to be related to the initial pH of the extracting solution; as the pH of the extractants increased, the amount of  $\text{K}^+$ ,  $\text{Ca}^{2+}$ , and  $\text{Mg}^{2+}$  extracted decreased. This result agrees with the findings of Williams & Jenny (1952). From Figures 1–3 it is evident that both Mehlich 1 and  $\text{NH}_4\text{OAc}$  buffered at pH 4 were generally able to extract significantly higher amounts of extractable cations than  $\text{NH}_4\text{OAc}$  buffered at pH 7. In other words, although the latter is a common extractant usually recommended for soil testing and analysis, it appeared to be inefficient in extracting cations from our tropical peat soils. This can be further clarified based on the fact that the CEC of peat is highly pH-dependant and in turn depends on the pH of the soil solution (in this case, the pH of the extracting solution). This unique characteristic of peat also applies for *Sphagnum* peat in the temperate region, where several studies have found that the distinct variation in pH of the water bathing strata in which *Sphagnum* species are found may cause them to differ in base saturation and CEC. These properties are influenced, in turn, by the pH-dependent exchange of cations and hydrogen ( $\text{H}^+$ ) ions from organic acid fundamental groups (Helling *et al.* 1964, Sumner & Miller 1996, Argo & Biernbaum 1997).

If solution pH increases, as when using  $\text{NH}_4\text{OAc}$  buffered at pH 7, some of the  $\text{H}^+$  ions are neutralised so more of the  $\text{H}^+$  ions, rather than basic cations, are removed into the soil solution. This may create more negative charges on the exchange sites. As a result, more of the basic cations will be adsorbed onto soil colloids and occupy the negative sites of the functional groups. Consequently, these basic cations will not be available to the extractants. Another possible reason is that the hydrogen ion may remain tightly associated with or fixed to the functional group and thus be resistant to the neutralising effect of  $\text{NH}_4\text{OAc}$  buffered at pH 7; in this scenario it may not participate in the ion exchange process.

Most if not all of the negative charges originate from the dissociation of  $\text{H}^+$  from carboxyl, phenoxyl, and hydroxyl functional groups, in contrast to the situation in mineral soils where negative charges are associated with isomorphic substitution, uniformly distributed over the surface of the clay minerals, and considered as permanent charge (Havlin *et al.* 1999). In peat the ion adsorption and exchange is associated

with hydrophilic colloids, namely humic acids and hemicellulose (Volarovich & Churaev 1968), and the main exchange site is the carboxyl radical. Apparently, sites located both on the main surfaces and on loose particles of hydrophilic colloids take part in the ion exchange. This explains not only the high exchange capacity usually found in peat, but also the length of time it takes to reach equilibrium.

Our results indicate that extraction of  $\text{K}^+$ ,  $\text{Ca}^{2+}$ , and  $\text{Mg}^{2+}$  using Mehlich 1 and  $\text{NH}_4\text{OAc}$  at pH 4 could provide a better estimation of available basic cations than  $\text{NH}_4\text{OAc}$  at pH 7, because the pH of these extractants is closer to the pH of tropical peat soils. The effectiveness of the extractants can be further evaluated in field experiments for prediction of the total uptake of plant available  $\text{K}^+$ ,  $\text{Ca}^{2+}$ , and  $\text{Mg}^{2+}$ .

## ACKNOWLEDGEMENTS

We are grateful to Universiti Teknologi MARA and Universiti Putra Malaysia for their financial and technical support during the fieldwork and laboratory experiment.

## AUTHOR CONTRIBUTIONS

AAR and AH sponsored the funding and collected the peat samples from the three different sampling locations; AAR analysed the peat samples and wrote the descriptions of Methods and Results; OHA reviewed the statistical analysis; and all authors contributed to preparation of the Discussion and the final version of the manuscript.

## REFERENCES

- Agus, F., Hairiah, K., Mulyani, A. (2011) *Measuring Carbon Stock in Peat Soils: Practical Guidelines*. World Agroforestry Centre (ICRAF) Southeast Asia Regional Program, Indonesian Centre for Agricultural Land Resources Research and Development, Bogor, Indonesia, 60 pp. Online at: <http://old.worldagroforestry.org/downloads/Publications/PDFS/MN17335.PDF>
- Anderson, D.L., Beverly, R.B. (1985) The effects of drying upon extractable phosphorus, potassium and bulk density of organic and mineral soils of the Everglades. *Soil Science Society of America Journal*, 49(2), 362–366.
- Andriessse, J.P. (1988) *Nature and Management of Tropical Peat Soils*. FAO Soils Bulletin 59, Food



- and Agriculture Organization of the United Nations, Rome, 165 pp.
- Argo, W.R., Biernbaum, J.A. (1997) The effect of root media on root-zone pH, calcium, and magnesium management in containers with impatiens. *Journal of the American Society of Horticultural Science*, 122, 275–284.
- ASTM (1988) *Annual Book of ASTM Standards, Volume 04.08*. American Society for Testing and Materials (ASTM), Philadelphia, 409 pp.
- Bigger, T.C., Davis, J.F., Lawton, K. (1953) The behaviour of applied phosphorus and potassium in organic soils as indicated by soil tests and the relationship between soil tests, green tissue tests and crop yields. *Soil Science Society of America Journal*, 17(3), 279–283.
- Brady, N.C., Weil, R.R. (2002) *The Nature and Properties of Soils*. 13th edition, Prentice Hall, Upper Saddle River NJ, 960 pp.
- Gabriel, M., Toader, C., Faul, F., Roßkopf, N., Grundling, P., van Huyssteen, C., Grundling, A.T., Zeitz, J. (2018) Physical and hydrological properties of peat as proxies for degradation of South African peatlands: Implications for conservation and restoration. *Mires and Peat*, 21, 23, 21 pp.
- Havlin, J.L., Samuel, T.L., Nelson, W.L., Beaton, J.D. (1999) *Soil Fertility and Fertilizers: An Introduction to Nutrient Management*. Sixth edition, Prentice Hall, Upper Saddle River NJ, 499 pp.
- Heiskanen, J. (1992) Comparison of three methods for determining the particle density of soil with liquid pycnometers. *Communications in Soil Science & Plant Analysis*, 23(7&8), 841–846.
- Helling, C.S., Chesters, G., Corey, R.B. (1964) Contribution of organic matter and clay to soil cation-exchange capacity as affected by the pH of the saturating solution. *Soil Science Society of America Proceedings*, 28, 517–520.
- Hillel, D. (2008) *Soil in the Environment: Crucible of Terrestrial Life*. Elsevier, UK, 303 pp.
- Huat, B.B.K., Asadi, A., Kazemian, S. (2009) Experimental investigation on geomechanical properties of tropical organic soils and peat. *American Journal of Engineering and Applied Sciences*, 2(1), 184–188.
- Karam, A. (1993) Chemical properties of organic soils. In: Carter, M.R. (ed.) *Soil Sampling and Methods of Analysis*, Lewis Publishers, Boca Raton, 459–471.
- Könönen, M., Jauhiainen, J., Laiho, R., Kusin, K., Vasander, H. (2015) Physical and chemical properties of tropical peat under stabilised land uses. *Mires and Peat*, 16, 08, 13 pp.
- Lucas, R.E. (1982) *Organic Soils (Histosols): Formation, Distribution, Physical and Chemical Properties and Management for Crop Production*. Research Report 435, Michigan State University Agricultural Experiment Station, East Lansing, 77 pp.
- Lucas, R.E., Rieke, P.E., Shickuna, J.C., Cole, A. (1975) Lime and fertilizer requirements for peats. In: Robinson, D.W., Lamb, J.G.D. (eds.) *Peat in Horticulture*, Academic Press, London, 40–70.
- Mathur, S.P., Farnham, R.S. (1985) Geochemistry of humic substances in natural and cultivated peatlands. In: Aiken, G.R., McKnight, D.M., Wershaw, R.L., MacCarthy, P. (eds.) *Humic Substances in Soil, Sediment and Water*, Wiley-Interscience, New York, 53–85.
- Mathur, S.P., Lévesque, N.P. (1988) Soil tests for copper, iron, manganese and zinc in Histosols 2: The distributions of soil iron and manganese in sequentially extractable forms. *Soil Science*, 145, 102–110.
- Mehlich, A. (1984) Mehlich-3 soil test extractant: a modification of Mehlich-2 extractant. *Communications in Soil Science and Plant Analysis*, 15(12), 1409–1416.
- Mutalib, A.A., Lim, J.S., Wong, M.H., Koonvai, L. (1994) Characterization, distribution and utilization of peat in Malaysia. In: Aminuddin, B.Y. (ed.) *Proceedings of the International Symposium on Tropical Peatland, Kuching, Sarawak, 6–10 May 1991*, Malaysian Agricultural Research and Development Institute (MARDI), 7–16.
- Nasrul, B., Maas, A., Utami, S.N.H., Nurudin, M. (2020) The relationship between surface topography and peat thickness on Tebing Tinggi Island, Indonesia. *Mires and Peat*, 26, 18, 21 pp.
- Page, S.E., Rieley, J.O., Banks, C.J. (2011) Global and regional importance of the tropical peatland carbon pool. *Global Change Biology*, 17(2), 798–818.
- Parent L.E., Caron, J. (1993) Physical properties of organic soils. In: Carter, M.R. (ed.) *Soil Sampling and Methods of Analysis*, Lewis Publishers, Boca Raton, 441–458.
- Puustjärvi, V., Robertson, R.A. (1975) Physical and chemical properties. In: Robinson, D.W., Lamb, J.G.D. (eds.) *Peat in Horticulture*, Academic Press, London, 23–38.
- Radjagukguk, B., Hastuti, S., Kurnain, A., Sajarwan, A., Kurniawan, R.E.K. (2000) *Panduan Analisis Laboratorium untuk Pambut (Laboratory Analysis Guide for Peat)*. Uni Eropa - Universitas Gadjah Mada, Yogyakarta, 52 pp. (in Indonesian).
- Statistical Analysis System (2001) SAS/STAT

- Software. Statistical Analysis System Institute, Cary, NC.
- Sumner, M.E., Miller, W.P. (1996) Cation exchange capacity and exchange coefficients. In: Sparks, D.L. (ed.) *Methods of Soil Analysis, Part 3: Chemical Methods*. SSSA Book Series No. 5, Soil Science Society of America (SSSA), Madison, Wisconsin, 1202–1229.
- Tan, K.H. (2005) *Soil Sampling, Preparation and Analysis*. Second edition, Taylor & Francis Group, Boca Raton, 623 pp.
- van Lierop, W., Martel, Y., Cescas, M.P. (1980) Optimal soil pH and sufficiency concentrations of N, P and K for maximum alfalfa and onion yields on acid organic soil. *Canadian Journal of Soil Science*, 60, 107–117.
- Vasander, H. (2014) Overview of types of peatlands. In: Biancalani, R., Avagyan, A. (eds.) *Towards Climate-Responsible Peatlands Management, Mitigation of Climate Change in Agriculture Series 9*, Food and Agriculture Organization of the United Nations (FAO), Rome, 15–18.
- Volarovich, M.P., Churaev, N.V. (1968) Application of methods of physics and physical chemistry to the study of peat. In: Robertson, R.A. (ed.) *Transactions of the 2<sup>nd</sup> International Peat Congress, Leningrad, Volume 2*, HMSO, Edinburgh, 819–831.
- Williams, D.E., Jenny, H. (1952) The replacement of non-exchangeable potassium by various acids and salts. *Soil Science Society of America Proceedings*, 16, 216–221.
- Zulkifley, M.T.M, Ng, T.F., Raj, J.K., Ghani, A., Shuib, M.K., Ashraf, M.A. (2013) Definitions and engineering classifications of tropical lowland peats. *Bulletin of Engineering Geology and the Environment*, 72, 547–553.
- Submitted 17 Jul 2019, revision 29 Sep 2020  
Editor: Olivia Bragg

---

Author for correspondence:

Dr Ameera Abdul Reeza, Senior Lecturer, Faculty of Plantation & Agrotechnology, Universiti Teknologi MARA, Melaka Branch, Jasin Campus, 77300, Merlimau, Melaka, Malaysia  
Tel: +606 2645303 (office), +6019 6629423 (mobile); E-mail: ameera@uitm.edu.my