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Nutrient Uptake in Different Maize Varieties (*Zea mays* L.) Planted in Tropical Peat Materials

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ABSTRACT

Oligotrophic tropical peat soils are usually deemed unsuitable for cropping common crops such as maize due to low pH and nutrient deficiency. This research aims to compare potassium, calcium, and magnesium uptake between different varieties of maize planted in two types of peat materials. This study investigated the growth of selected maize varieties by comparing the nutrient uptake between three different varieties of maize (V1-Asia Manis, V2-Super A, and V3-Pearl Waxy) planted on hemic and sapric, respectively, without any application of fertilisers. Significant interactions were found where different maize varieties responded differently in the nutrient uptake when planted in different peat materials. Super A (V2) significantly recorded the highest uptake for all nutrients (679.71 mg) when planted in hemic, followed by V1 (422.03 mg) and V3 (314.77 mg) when planted in sapric. Super A was found to be superior to the two varieties, where it was more efficient in absorbing nutrients from the peat materials, having significantly higher dry matter weight (26.37 g) than V1 (19.26 g) and V3 (13.67 g). Hemic and sapric could support the growth of all three maize varieties up till the tasselling stage without any fertiliser application.

Keywords: Calcium, growth performance, hemic, magnesium, potassium, sapric

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INTRODUCTION

Maize is an important staple crop in the Industrial Revolution and is in great demand globally, considering its importance as food, animal feed, additives in industrial products, scientific research, and economy (Ayiti &

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Babalola, 2022). The demand and supply for maize worldwide for food and non-food products are usually on the rise, with nearly 15 million metric tons (MMT) used for animal feed, 4.25 MMT for industrial use while 1.36 MMT is used as food (Yadav et al., 2016). Concerning its value for domestic, economic, and industrial use, investing in the increase in maize production is an opportunity for any country.

However, the agriculture sector worldwide faces growing concerns over global grain security (Kalugina, 2014). Such issue has risen due to cultivated land conversion into urban and industrial construction as well as climate change (Hu et al., 2016). During the past decade, the consumption of natural resources has also increased due to the global population rise, and thus, demand for food, fibre, and biofuel has a significant impact on land and fertiliser consumption at local and global scales (Setiyono et al., 2010). Continuous cropping subsequently leads to nutrient mining, a major cause of low crop yields and unsustainable agriculture, especially in parts of the developing world, particularly in Southeast Asian regions.

Due to the scarcity of fertile land, farmers are now turning to marginal land, such as peatland, which has become a target for agricultural development over recent years (Lubis et al., 2019). The latest report by Omar et al. (2022) revealed that Southeast Asia has the largest areas of tropical peatlands in the world, where most peatlands in Southeast Asia are found in Indonesia (20.7 million ha), followed by Malaysia (2.6 million ha). Peatlands as land for farming possess an array of challenges physically, chemically, and biologically. Peatland has low productivity due to the lack of macro and micronutrients available for plants, especially with a low pH of 3.0-5.0 (Lubis et al., 2019; Omar et al., 2022). Previous studies suggested that pineapple is the only crop recommended and grown successfully on this soil, while various other crops are grown, with invariably poor yield. However, recent studies revealed that more crops can be grown in peats. As such, potatoes, sugar beet, celery, onions, carrots, lettuce, and market garden crops are commonly grown in drained fen or light peat soils in temperate regions, yet cereals still produce low yields (Finch et al., 2014). Conversely, several reports have shown that maize can be cultivated in tropical peatlands subject to chemical amelioration, such as liming and fertilisation (Lubis et al., 2019; Suswati et al., 2014, 2015). On the other hand, reports regarding new hybrid maize varieties that are capable of withstanding inadequate soil and climatic conditions have gained much attention (Harou et al., 2017), yet the applicability of these new hybrids to be grown and commercialised in organic soils as in contrast with the more commonly utilised mineral soils are severely limited. Also, most of these studies focussed on primary macronutrients such as N, P, and K in maize planted in mineral soils (Jiang et al., 2017; Ning et al., 2012; Q. Ma et al. 2021; Z. Ma et al., 2022) while other nutrients such as potassium, calcium, and magnesium are lacking especially with regards to planting in peat soils.

Given such a situation, it is imperative to assess the potential of peats as a growing media according to the types of peat since different kinds of peat respond differently to the growth and development of crops (Reeza, 2019; Reeza et al., 2021) due to their varied nutrient contents and other abiotic condition. Such information may provide significant importance in understanding the nutrient dynamics of the peat material brought upon by anthropogenic activities. In addition, with the newly introduced hybrid maize variety, there is a possibility that maize can be grown in peat, as these varieties may be able to withstand the acidity of peat materials. It is hypothesised that different maize varieties respond differently when planted in distinct types of peat materials and display different levels of nutrient uptake when planted within the same type. Hence, this research aims to compare the nutrient uptake between different varieties of maize planted in hemic and sapric peat materials. The comparison of the different types of maize varieties can determine which varieties have higher nutrient efficiency and are suitable to be planted in peat. Also, the use of peat can help to expand the area of maize cultivation so that maize will be able to be grown on a larger scale.

MATERIALS AND METHODS

Sampling and Collection of Peat Materials

The experiment was carried out in a greenhouse in the Faculty of Plantation and Agrotechnology, Universiti Teknologi MARA, Jasin campus, Malacca, Malaysia (2°13’44.9”N 102°27’20.8”E) from December 2021 to March 2022. The area’s climate is categorised as equatorial rainforest, fully humid (Kottek et al., 2006) without apparent dry and wet seasons since Malaysia receives rain all year round of 2,600 mm per year. The mean annual temperature is 27.6°C, where the average maximum temperature falls around 32.7°C while the average minimum temperature is 24.2°C (Malaysian Meteorological Department [MetMalaysia], 2019).

Hemic and sapric peat materials were used in this study, where they were collected from a 10-year-old oil palm plantation in the faculty itself (2°13’38.1”N 102°27’33.4”E), where the peat is classified as shallow peat having depth of organic material layer of less than 1.5 m (Lim, 1989). They are classified as Tropohemists since most of the organic materials have been decomposed enough that the botanical origin of as much as two-thirds of them cannot be readily determined, or the fibres can be largely destroyed by rubbing between the fingers and that they have hemic soil materials dominant in the subsurface tier if there is no continuous mineral layer 40 cm or more thick that has its upper boundary in that tier (Andriesse, 1988). Surface (0–15 cm) and subsurface (20–40 cm) soil layers were identified as sapric and hemic peat materials, respectively, based on the degree of decomposition (H1–H10) according to the von Post scale (von Post, 1922). The peat materials were collected using an Eijkelkamp peat sampler and gathered in burlap sacks. Bulk density was also taken where undisturbed peat samples were collected using a core sampler of stainless-steel rings (diameter 5.2 cm, height 6.0 cm) and later were oven-dried to a constant weight at 105ºC (gravimetric method; American Society for Testing and Materials [ASTM], 1988). Upon returning to the greenhouse, the peat materials were air-dried for 3 days to remove the excess water to be used as a potting medium. After the peat materials had dried, they were transferred into polybags (2.5 cm × 2.5 cm), where each polybag was filled with 3.5 kg of hemic and sapric peat materials individually.

Experimental Design and Treatments

There were 3 different hybrid maize varieties utilised in this study, which were V1-Asia Manis (SS932) and V2-Super A (SS232); both are of sweetcorn seeds resistant to rust and stalk rot, while V3-Pearl Waxy (WX100) is categorised as white waxy corn resistant towards rust and southern corn leaf blight. All three varieties are classified as non-genetically modified organisms (non-GMO) F1 hybrid maize seeds (Hefei Hefeng Seeds Co. Ltd., China). Seeds were sown on seedling trays for uniform growth and selection for transplanting into polybags. After the seedlings had grown 4 true leaves around two weeks after sowing, they were transferred to polybags in a greenhouse and were grown for 8 weeks (56 days) until they reached the tasselling stage, where it is the maximum growth stage achieved prior to the productive stage from January 2022 till February 2022. The average temperature in the greenhouse was 33.6°C with a mean relative humidity of 53.6%. As much as 600 ml of daily manual watering was performed on each polybag, which was done twice: early morning and late afternoon.

The experiment followed a completely randomised design (CRD) comprising two different peat materials (hemic and sapric) and three different hybrid maize varieties (V1-Asia Manis, V2-Super A, and V3-Waxy Corn). There were 144 experimental units altogether (2 peat types × 3 maize varieties × 3 replicates × 8 weeks). Destructive sampling was conducted for this study, where soil and plant samples were collected each week for 8 weeks [56 days after sowing (DAS)].

Soil and Plant Analysis

Prior to planting, the peat materials were analysed for pH, 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, Noway) (Reeza et al., 2021) and organic matter via loss in ignition method after placing samples in a muffle furnace at 300–550°C for 6 hr (Sutherland, 1998). Daily manual watering of about 1 L of water per polybag was performed. It is important to note that no fertiliser was added as this experiment was exclusively done to study the nutrientsupplying ability of the peat materials without any interference from external additives.

For every week of destructive sampling, the whole plant was harvested (shoot and root), weighed before oven-drying at 60°C to constant weight, and measured using an electronic sensitive balance. These dried plant samples were then milled to bypass via a 0.5 mm sieve. Soil sampling was also taken weekly to determine the availability of K^+, Ca^{2+}, and Mg^{2+} via NH_4OAc buffered at pH 4 (Bendosen, Noway) (Reeza et al., 2021), while dry ashing method was used 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 the dry ashing method (mg/kg) according to the following formula (Nigussie et al., 2021):

Statistical Analysis

Two-way analysis of variance (ANOVA) was performed to test for differences among the factors (peat types and maize varieties) using SPSS (version 21.0), while means of the treatments were compared based on Tukey's b test at the 5% probability level.

RESULTS AND DISCUSSION

Initial Soil Analysis

Initial soil physicochemical properties for hemic and sapric peat materials are presented in Table 1. It is important to note that the pH of the peat materials is relatively high (pH 5.0–5.7) compared to many other reports (pH 3.2–4.5) of similar region and climate (Afip & Jusoff, 2019; Hikmatullah & Sukarman, 2014). The pH, organic matter (OM), organic carbon (OC), and moisture content were lower in sapric compared to hemic due to the

$$Total\ nutrient\ uptake\left(\frac{mg}{polybag}\right) = Nutrient\ concentration\ in\ tissue\left(\frac{mg}{kg}\right) \times Plant\ dry\ weight\left(\frac{kg}{polybag}\right)$$

Table 1
Initial physicochemical properties for hemic and sapric

Properties	Hemic	Sapric
pH	5.7 ± 0.4	5.04 ± 0.16
OM (%)	73.6 ± 2.94	62.9 ± 2.77
OC (%)	43.0 ± 1.34	36.6 ± 1.71
Moisture content (%)	73.63 ± 3.78	64.21 ± 2.98
Bulk density (g/cm^3)	0.15 ± 0.02	0.21 ± 0.03
von Post	H5	H8
Available K (mg/kg)	66.65 ± 2.60	35.84 ± 3.71
Available Ca (mg/kg)	225.64 ± 4.80	172.05 ± 3.06
Available Mg (mg/kg)	46.86 ± 3.04	35.68 ± 2.14

Note. OM = Organic matter; OC = Organic carbon higher degree of decomposition, as shown in von Post (H8) compared to hemic (H5). Also, available K^+, Ca^{2+}, and Mg^{2+} were lower in sapric than hemic. Such findings were consistent with reports by Reeza et al. (2021) as well as Hikmatullah and Sukarman (2014), where sapric materials commonly display a reduction in OM, OC, and available nutrients due to the advanced degree of decomposition that leads to loss of organic materials and other physicochemical properties. In contrast, bulk density is slightly higher in sapric compared to hemic, justifying the higher maturity of peat soils that will be followed by increasing bulk density value (Hikamtullah & Sukarman, 2014) attributed to a decrease in porosity and fibre content as well as the increase in the mineral matter as a result of the further decomposition process.

However, the available nutrient contents were found to be lower than reports elsewhere (Arabia et al., 2020; Hikmatullah & Sukarman, 2014; Sahfitra et al., 2020), and this is possibly due to the origin of the peatland area, where oil palms have been planted for 10 years that may cause these nutrients to be depleted.

Dry Matter Weight and Nutrient Uptake for Different Maize Varieties Planted in Two Types of Peat Materials

The dry matter (DM) weight for V1, V2, and V3 planted in hemic and sapric peat upon harvest at 56 DAS is presented in Table 2. There were significant differences in DM between varieties, where V2 recorded significantly the highest DM, followed by V1 and V3. However, no significant differences were found when planted in the two types of peat materials except for V3. It can be inferred that although different types of peat materials had no influence on the DM for these hybrid maize varieties, significant discrepancies in their DM weight are evident, where V2 (Super A) yield the highest compared to other varieties.

Alternatively, there are significant interactions between peat types and maize varieties for nutrient uptake. Different maize varieties responded differently in nutrient uptake when planted in different peat materials (Table 3). Nevertheless, potassium is the most nutrient absorbed by all three varieties, followed by calcium and magnesium. The values obtained from the nutrient uptake in this study are consistent with the reports by Kassim et al. (2011), where the amount of nutrient uptake is in the following order: K > Ca > Mg. Also, V2 significantly recorded the highest uptake for all three nutrients, followed by V1 and V3 regardless of peat materials, justifying the highest DM obtained by V2 (Table 2).

Table 2
Dry matter weight between treatments at 56 days after sowing

Maize varieties	Dry matter weight (g)	
	Hemic	Sapric
V1	18.157^{Ab}	19.26^{Ab}
V2	25.35^{Aa}	26.37^{Aa}
V3	7.12^{Ac}	13.67^{Bc}

Note. Capital letters indicate mean separation between peat types while lowercase letters refer to mean separation among varieties using Tukey at p = 0.05

The K uptake was significantly higher when planted in sapric for V1 (339.55 mg) and V3 (248.453 mg); however, V2 was the only variety that performed better in hemic with the highest amount of K uptake (571.03 mg) compared to other varieties.

A similar observation was found in calcium uptake, where V1 and V3 showed significantly higher calcium absorption in sapric with 58.57 and 44.04 mg/plant, respectively, while V2 performed better in hemic with 73.79 mg/plant. However, no significant differences were obtained in magnesium uptake planted in the two types of peat materials, while significant differences were only detected in the uptake between varieties, where V2 recorded significantly higher magnesium uptake than the other two varieties.

The distinct response in nutrient uptake between varieties was also reported by Fosu-Mensah and Mensah (2016) as well as Singh and Gildhyal (1980), where different types of maize varieties showed significantly different nutrient uptake, particularly macronutrients. Furthermore, according to González-Fontes et al. (2017), genetic variation within and among crops in nutrient uptake efficiency (NUE) is well recognised where genotypic variability affects NUE and nutrient uptake influences some processes and plant mechanisms, including differences in uptake, movement in the root, shoot demand, and biomass production (DM weight).

At this point, no single fertiliser was added to these peat materials, and all the nutrients absorbed by these maize varieties were solely from the peat itself. Based on this study, it can be clearly understood that regardless of the types of peat materials, V2 might be a superior variety due to higher nutrient uptake efficiency as this variety was able to absorb and utilise higher amounts of nutrients (K, Ca, and Mg) resulting in significantly higher DM compared to the other two varieties when planted on the same type of peat materials.

Table 3
Nutrient uptake (K, Ca, and Mg) for different varieties and peat types at 56 days after sowing

Nutrient uptake (mg/plant)	Variety	Peat types	
		Hemic	Sapric
Potassium (K)	V1	273.03^{Bb}	339.55^{Ab}
	V2	571.03^{Aa}	360.22^{Ba}
	V3	158.54^{Bc}	248.45^{Ac}
Calcium (Ca)	V1	44.02^{Bb}	58.57^{Ab}
	V2	73.79^{Aa}	66.64^{Ba}
	V3	19.95^{Bc}	44.04^{Ac}
Magnesium (Mg)	V1	23.91^{Ab}	23.14^{Aa}
	V2	34.89^{Aa}	23.26^{Ba}
	V3	13.77^{Bc}	22.28^{Aa}

Note. Capital letters indicate significant differences between peat types, while small letters indicate significant differences between varieties for a particular nutrient uptake using Tukey at $p = 0.05$

Plant Height at 56 DAS

Plant height has a direct relationship with plant dry weight, which, as the height increases, so does the dry weight since it reflects the biomass of the plant itself. Hence, based on Table 4, the pattern of plant height increment is similar to that of dry weight, as described previously in Table 2. A significant interaction was only detected for V3, whose height was significantly higher in sapric than hemic. Super A significantly showed the maximum height, followed by Asia Manis and Pearl Waxy, regardless of peat materials. Therefore, it can be deduced that when the same type and amount of external sources such as medium of planting, water, sunlight, and nutrient supply are given to the three types of hybrid maize variety, Super A showed the highest and most rapid growth compared to Asia Manis and Pearl Waxy and it can be inferred that Super A is more efficient in using all the external sources to support its growth and development compared to the other two varieties above, hence justifying the name of the variety "Super" as being superior than the other varieties. Apart from that, tassels emerged rapidly at week 6, where the emergence was slightly faster when grown in sapric than hemic, although nutrient availability was significantly higher in the latter.

Table 4
Plant height between treatments at 56 days after sowing

Maize varieties	Plant height (cm)	
	Hemic	Sapric
V1	159.0^{Ab}	163.0^{Ab}
V2	186.0^{Aa}	180.0^{Aa}
V3	116.0^{Ac}	146.0^{Bc}

Note. Capital letters indicate mean separation between peat types while lowercase letters refer to mean separation among varieties using Tukey at $p = 0.05$

Analysis of Chemical Properties of Peat Materials at 56 DAS

The variation in the uptake of nutrients and DM of these hybrid maize varieties can be justified not only by their different genotypic variability but also by the distinct discrepancies in hemic and sapric's chemical properties during initial and after planting for 56 DAS as shown in Tables 1 and 5, respectively. Based on these tables, it is evident that generally, pH, OM, OC, and available nutrients (K^+, Ca^{2+}, Mg^{2+}) were higher in hemic compared to sapric, yet only V2 showed better growth and uptake of nutrients in hemic while V1 and V3 performed better in sapric.

The differences may be attributed to the different degrees of decomposition of these peat materials, which in turn influence the rate of nutrient release. It agrees with

Table 5
Selected chemical properties for hemic and sapric at 56 days after sowing

Properties	Hemic	Sapric
pH	6.24^{a}	5.8^{b}
OM (%)	69.39^{a}	66.41^{b}
OC (%)	40.25^{a}	38.52^{a}
Available K (mg/kg)	27.42^{a}	24.57^{b}
Available Ca (mg/kg)	326.44^{a}	176.75^{b}
Available Mg (mg/kg)	66.54^{a}	30.32^{b}

Note. OM = Organic matter; OC = Organic carbon; Small letters within rows indicate significant differences between peat types using Tukey at p=0.05

the findings by Veloo et al. (2015), where the stage of decomposition has the most significant effect on crop yield for peat soil. They reported that soils with sapric materials gave significantly better yields than soils with hemic materials, possibly because crop roots are mainly in contact with the highly decomposed sapric material, which is a good rooting and growth medium compared to the hemic material. Another probability is that hemic peat with a higher porosity level may not have good nutrient retention properties compared to sapric with lower porosity characteristics (Veloo et al., 2015).

The pH was found to be increased at 56 DAS irrespective of peat materials, and it was attributed to the rise in available Ca at 8 weeks of planting (Table 5), while there was a profound decrease in available K when compared to the initial condition of the peat materials (Table 1). The decrease in available K can be supported by the substantial uptake of this nutrient ranging between 158–578 mg/plant regardless of maize varieties compared to calcium and magnesium uptake varying between 14–74 mg/plant. Since the uptake of calcium and magnesium was much lower than potassium, the accumulation of these former nutrients was high in these peat materials, increasing pH. It is worth mentioning that all the maize varieties were able to grow well without showing any deficiency symptom of these nutrients up to the tasselling and silking stage, which may suggest that the nutrient content in hemic and sapric peat materials might be sufficient to support the growth these maize varieties since no fertilisers were added.

CONCLUSION

Different maize varieties have different preferences for the types of peat materials being used as a planting medium, and the variety V2 (SS232-Super A) performed better than V1 (SS232-Asia Manis) and V3 (WX100-Waxy Corn) in terms of dry matter weight, potassium, calcium, and magnesium uptake when planted in tropical hemic and sapric peat materials in the following order V2 > V1 > V3. Nonetheless, different maize varieties take up significantly different amounts of nutrients, yet both hemic and sapric could support the growth of maize without any application of fertiliser up till the tasselling stage. Further research can be implemented by extending the duration of the study till the harvesting stage to observe the yield differences between these varieties and elucidate the mechanism of the cause of why different varieties favour different types of soil.

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