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Calcium Has Been a Neglected Nutrient in Oil Palm Cultivation

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ABSTRACT

The most common soil types in Peninsular Malaysia utilized for oil palm cultivation are Ultisols and Oxisols. They are highly weathered soils with pH 4-5, containing toxic level of Al^{3+}. Besides, the soils are low in CEC and having insufficient amount of Ca and/or Mg to satisfy oil palm requirement. The need to add extra Ca to sustain oil palm production is sometimes overlooked. This paper intends to justify the application of Ca-minerals regularly on Ultisols and Oxisols to maintain their fertility. In normal agricultural practices, Ca is unintentionally added via Ground Magnesium Limestone application. Increase in soil pH that followed further enhances crop growth. However, due to the large area being cultivated with oil palm, it becomes uneconomical to frequently do so. Some Ca is added into the soils during phosphate rock application. There are other sources of Ca that can be considered to get extra Ca, among which are gypsum, Mg-gypsum and wollastonite. Gypsum, if applied onto an Oxisol having high amount of hematite and goethite, not only are Ca and S added, but also its CEC and pH slightly increase. Application of Mg-gypsum is a better option as it also contributes Mg and some micronutrients (Cu and Zn). Besides adding Ca, wollastonite application on the soils slightly increases their pH. Its dissolution in soils produces silicic acid that can be taken up by the crop. This agronomic approach helps prevent or cure the outbreak of basal stem rot disease endemic in oil palm plantations.

***Keywords**: Acidic soil, aluminium toxicity, Ca-mineral, highly weathered soil, oil palm*

INTRODUCTION

Oil palm needs special agronomic practices to sustain its growth and the production of fresh fruit bunches (FFB) in the long run. The fertilization practices conducted in oil palm plantations in Malaysia include the application of primary nutrients NPK, secondary nutrient Mg and the very essential micronutrient B. It seems that calcium (Ca) is never given the attention it so deserves. Unintentionally, in Malaysian agricultural practices, Ca is in the liming materials – i.e., Ground Magnesium Limestone (GML). However, due to large area being planted with oil palm, it becomes uneconomical to frequently carry out liming, unless it is very necessary to do so. Also, it is due to the fact that oil palm is an acid-tolerant plant species that grows quite well at soil pH below 5.0. This notion is consistent with the finding of a research by Auxtero and Shamshuddin (1991) who found that the critical soil pH to sustain its growth was 4.3.

Due to the continuous growing of oil palm on the same plots of land for a long period of time (now is in the 3rd or 4th generation – one generation of oil palm growth cycle is about 25 years) calcium is becoming a limiting factor. This information has not been given due consideration or attention by the powers-that-be and/or estate management nation-wide.

Available natural Ca in the land area under oil palm cultivation in Peninsular Malaysia varies from very low (sandy or loamy soils) to very high (soils formed on limestone). Most of the oil palm in the peninsula are planted on soils derived from igneous, sedimentary and metamorphic rocks of various mineralogical compositions (Shamshuddin *et al.,* 2023). The soils so formed from the above-mentioned rocks can be mostly classified as Ultisols and Oxisols using Soil Taxonomy of the USDA (Soil Survey Staff, 2014). The highly weathered soils, which have been exposed to high leaching environment of the tropics for a long time, are usually devoid of exchangeable Ca and Mg because of their low cation exchange capacity (CEC).

Ultisols and Oxisols are characterized by the dominance of kaolinite and sesquioxides (hematite, goethite and gibbsite) in their clay fraction (Shamshuddin and Fauziah, 2010; Shamshuddin *et al*., 2023). **Figure 1** shows that under normal field conditions typical profiles of the soils are reddish/yellowish in colour (Shamshuddin *et al.,* 2018; Soil Survey Staff, 2018). According to Tessens and Shamshuddin (1983) and Paramananthan (2000), their pH ranged from 4 to 5, with values lower for Ultisols than Oxisols. The lack of available Ca in the soils may not be able to sustain oil palm production in the long run. We believe that Ca deficiency in the highly weathered soils of Peninsular Malaysia can amicably be resolved via application of appropriate amount of Ca-minerals (naturally formed or otherwise).

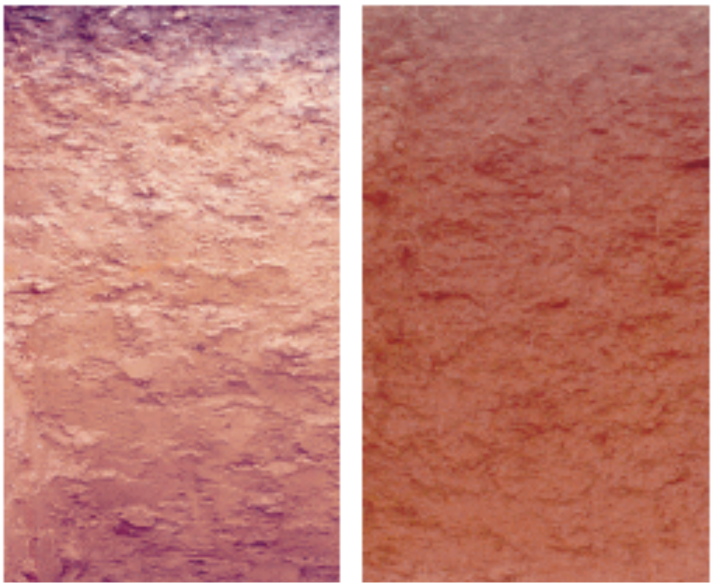

Figure 1. Ultisol (left) and Oxisol (right) are the most common soil types in the upland regions of Peninsular Malaysia

Oil palm has been cultivated in Peninsular Malaysia for more 100 years with yield of >30 t/ha/year (in terms of FFB) under estate management. It is a nutrient-demanding crop that requires high amount of macronutrients (N, P, K, Ca, Mg and S) to sustain its vegetative growth and yield production. It seems that Ca nutrition does not get due attention as much as the others (e.g. Mg). According to IPNI (2003), Ca deficiency in soils of the tropics under oil palm cultivation is seldom reported in conferences and/or journals. Usually, growers in the country assume that Ca is already sufficient, added to agricultural land when Ground Magnesium Limestone is applied to raise soil pH to the level required by oil palm.

Agronomists seem to pay more attention to the supply of the much needed Mg to help enhance photosynthesis. Nevertheless, Ca too is required in large amount by oil palm throughout its productive life for many other reasons. This notion is in line with the finding of a study conducted by Ayanda *et al*. (2020). The researchers conclusively showed in a glasshouse experiment that oil palm seedlings growth depicted Liebig's Law of the Minimum or Limiting nutrient respond to Ca rather that Mg when Mg-gypsum was used.

The need for sufficient availability of Ca in Ultisol in Peninsular Malaysia cropped to oil palm was first highlighted by Shamshuddin *et al.* (2017). This is to make sure that the productivity of oil palm is not negatively impacted or curtailed by insufficient Ca. Phosphate rock normally used to fertilize oil palm trees contains apatite (calcium phosphate), rather than inert Ca source; however, its application in acid soils results in a slow release of the nutrient. Perhaps, apatite behaves like basalt (a basic igneous rock) which has been successfully tested for cocoa cultivation in Peninsular Malaysia (Anda *et al.,* 2013). We intend to justify the need to apply various Ca-minerals on Ultisols and Oxisols in Peninsular Malaysia cultivated with oil palm to enhance soil fertility that in the end sustains its growth and/or production.

METHODOLOGY

Determination of information to show lack of Ca in Ultisols and Oxisols of Peninsular Malaysia under oil palm cultivation has been carried out. In this paper, first and foremost, we made a detailed check and quick review on exchangeable Ca in major soil types in the peninsula as well as other countries of the tropics cropped to oil palm. These data were obtained from literature search through various means (journal papers, books, conference proceedings, etc.) recently published, either locally or overseas. The information so obtained were then compared with the Ca critical level in soil required to sustain the growth and/or production of oil palm in the plantations. The exercise was followed by evaluating the agronomic approaches to increase Ca content in soils via application of various mineral fertilizers containing Ca. The final part was to explain and discuss the implication of adding the Ca-minerals (which also contain other plant nutrients, both macro- and micronutrients) on soil fertility that eventually enhance and/or sustain the productivity of oil palm growing in the fields.

CALCIUM REQUIREMENT OF OIL PALM

The need for the presence of all nutrients in soils at adequate level for oil palm requirement can satisfactorily be explained by the Liebig's Law of the Minimum. The law states that the local yield of terrestrial plants should be limited by the nutrient that is present in the environment in the least quantity relative to its demands for plant growth. Thus, to sustain FFB yield all the year round, the required nutrients must be available in sufficient amount in soil solutions for oil palm uptake via its root system. For all intents and purposes, Ca is one of the nutrients needed by oil palm in high amount. According to Robinson *et al.* (1997), under normal circumstances, Ca concentration in frond 17 of oil palm is ≤0.6%.

There is no doubt that Ca is needed in sufficient amount by oil palm throughout its productive life, especially for cell formation in the biomass. The nutrient is very essential to sustain the health and productivity of the crop. Nur Shuhada *et al*. (2016) mentioned that Ca-deficiency in oil palm trees led to membrane leakage of low molecular weight compounds such as sugars and amino acids that result in spreading of certain disease caused by fungi. In their study, the researchers found significant negative correlations between basal stem rot (BSR) disease and the content of Ca in soil as well as in oil palm leaf. The amount of Ca in the leaves of the oil palm under their investigation was 0.09-0.60%.

REACTION OF Ca^{2+} IONS IN SOIL SOLUTION

In the presence of water, Ca-minerals listed in **Table 1** dissolve and release their Ca into soil environment that exists as Ca^{2+} ions, with pKa 12 – thus, it is a basic metal. This means that with high quantity of Ca^{2+} ions in soil solutions, soil alkalinity is likely to increase slightly. In the end, soil solution pH is going upwards. Thus, adding Ca^{2+} into a soil is opposite to what is happening if Al^{3+} (pKa 5.00) and Fe^{2+} (pKa 4.58) exist in soil solution at high amounts.

Table 1: Chemical composition of Ca-bearing minerals

Name	Chemical composition	Elements contained
Dolomite[1] (GML)	$Ca,Mg (CO_3)_2$	Ca, Mg,
Apatite[2] (phosphate rocks)	$Ca_{10}(PO_4)_6(OH,F,Cl)_2$	Ca, P, Cl
Gypsum	$CaSO_4.2H_2O$	Ca, S
Mg-gypsum[3]	$CaSO_4.2H_2O + Mg(OH)_2$	Ca, Mg, S
Wollastonite	$CaSiO_3$	Ca, Si

[1]Dolomite is usually referred to as dolomitic limestone; otherwise, it is commercially sold in Malaysia as Ground Magnesium Limestone (GML).
[2]Apatite is the most important mineral in phosphate rocks.
[3]Mg-gypsum (with some Mn, Zn, and Cu), also known as neutralization underflow (NUF), is a by-product of Lynas Chemical Plant in Pahang, Malaysia.

The hydrolysis of Al^{3+} and Fe^{2+} (acid metals) produces acidity that wreak havoc in soils cultivated with oil palm (Shamshuddin *et al*., 2021):

$$Al^{3+}.6H_2O + H_2O \rightarrow Al^{2+}OH.5H_2O + H_3O^+$$
$$Fe^{2+}.6H_2O + H_2O \rightarrow Fe^{2+}OH.5H_2O + H_3O^+$$

Reaction of $NH_4)_2SO_4$ in soil solution will in the end produces acidity (Miller and Donahue, 1990). Under normal circumstances, applying Ca-minerals in oil palm plantations would offset the drop in soil pH resulting from long-term application of the ammonium fertilizer. Ground Magnesium Limestone is sometimes applied in oil palm plantations to keep soil fertility at bay – i.e., trying to stop the drop in soil pH due to ammonium sulfate application. The OH^- produced by GML dissolution in soil solutions comes from hydrolysis of CO_3^{2-} (Shamshuddin *et al.,* 2018; Shamshuddin, 2022). The OH^- reacts with Al^{3+}, forming amorphous Al-hydroxides, which are neutral with zero net charge. The critical Al^{3+} activities in soil solution for the healthy growth of oil palm is 100 µM (Auxtero and Shamshuddin, 1991).

PHOSPHATE ROCK IN OIL PALM CULTIVATION

In the plantation, without applying phosphate rock (**Table 1**), the roots of oil palm are unable to take in sufficient amount of P needed for its healthy growth. Normally, Ca deficiency seldom occurs provided that the estate management adequately apply phosphate rock at regular interval. Likewise, the area adequately limed with GML to increase soil pH to the level required to sustain crop growth is also not expected to be Ca-deficient.

IMPACT OF APPLYING GML ON OIL PALM

It is an excellent agronomic practice to raise soil pH in oil palm plantations using GML (Ayanda *et al*., 2020). The soil acidity ameliorant is very good as it contains not only Ca in high quantity, but also Mg (Shamshuddin and Ismail, 1995); both are macronutrients. Adding GML results in enhancement of soil fertility via increasing Ca and Mg as well as reducing negative impact of Al^{3+} and/or Fe^{2+} toxicity. This helps sustain oil palm growth and production in the long run. Due to liming with GML, Al^{3+} and Fe^{2+} activities are reduced via precipitation when soil pH reaches a level >5. The reaction of GML with Al^{3+} in soil solution is shown below:

$$(Ca, Mg) (CO_3)_2 \rightarrow Ca^{2+} + Mg^{2+} + 2CO_3^{2-}$$

$$CO_3^{2-} + H_2O \rightarrow HCO_3^- + OH^-$$
$$Al^{3+} + OH^- \rightarrow Al(OH)_3 \text{ (or amorphous Al-hydroxides)}$$

Oil palm is an acid-tolerant plant species; thus, it can normally be grown on acidic soils with pH <5 (Cristancho *et al.,* 2011a). Notwithstanding, oil palm growth and health are limited or hindered if soil pH is low. The critical soil pH for oil palm healthy growth is 4.3 (Auxtero and Shamshuddin, 1991). Ayanda *et al*. (2020) stated in their paper that the height of oil palm seedlings was positively correlated with increasing soil pH. We believe that oil palm grows better if soil pH is raised to a level >5; however, liming using GML is costly.

Cristancho *et al*. (2007) noted that oil palm root density was negatively correlated with exchangeable Al. This is because the growth of oil palm is curtailed by high concentration of Al in soils (Cristancho *et al.,* 2011b). The researchers noted that the root tips of oil palm under Al stress contained high concentration of oxalic acid, which increased with increasing Al concentration. Growing under stress, oil palm root exudes organic acid which chelate some Al^{3+}, rendering it inactive. This is the mechanism how oil palm growing on acidic Ultisols and Oxisols of the tropical regions of the world can partly defends itself against Al^{3+} toxicity. The result of another study conducted by Cristancho *et al*. (2011c) showed that chlorophyll content in oil palm's frond increased when Al in soil was reduced. In our opinion, it is considered an excellent idea to apply adequate amount of GML on acidic Ultisols and Oxisols under oil palm cultivation from time to time or wherever is necessary.

Continuous application of ammonium sulfate in an oil palm plantation over a long period of time lowers soil pH to less than the critical level for its healthy growth (Shamshuddin *et al.,* 2018). At that time, it is justified for the estate management to consider applying GML at the appropriate rate to keep soil pH in the plantation at the level suitable for oil palm's health. We are not promoting to frequently apply GML on highly weathered soils in the country due to the large area of land being cultivated with oil palm. Lime application is only necessary if and only if soil pH drops to less than 4.3. The concomitant increase of Ca and Mg will further enhance soil fertility that in the end sustains oil palm production in the long run.

IMPACT OF GYPSUM APPLICATION ON SOIL AND OIL PALM

Changes in soil properties

Calcium concentration in soil can also be increased significantly by applying gypsum ($CaSO_4.2H_2O$). The agronomic practice will concomitantly result in increase of SO_4^{2-} ions in the soil environment, which is available for plant uptake. Oil palm needs sufficient S for the production of oil in its fruitlets. In a leaching experiment using soil columns conducted on Ultisol and Oxisol, Ismail *et al.* (1993) incorporated gypsum in their topsoil (0-15 cm depth). They found that some Ca moved to the 15-30 cm zone. The presence of additional Ca in the subsoil somewhat alleviated its acidity. The topsoil Al^{3+} activity in the control treatment of the Ultisol (Bungor Series) and Oxisol (Prang Series) was 36 and 27 µM, respectively.

Further result from the experiment showed that most of the Al species in the gypsum treated soils existed in the form of Al^{3+} and $AlSO_4^+$, with the latter becoming quantitatively the most important with increasing gypsum rate. According to Alva *et al.* (1986), $AlSO_4^+$ was less phytotoxic compared to that of Al^{3+}. The release of $AlSO_4^+$ resulting from gypsum application has, to a certain extent, alleviate Al^{3+} toxicity. Hence, applying gypsum to supply Ca is an excellent agronomic practice to sustain oil palm production on highly weathered soils.

Shamshuddin and Fauziah (2010) mentioned that gypsum application on a soil increased $AlSO_4^+$ species according to or can be described by the following reactions:

$$CaSO_4.2H_2O + H_2O \rightarrow Ca^{2+} + SO_4^{2-} + 3H_2O$$

$$Al^{3+} + SO_4^{2-} \rightarrow AlSO_4^+$$

The reaction of gypsum in water will impact the chemistry of the soils in some way or another. The following are compelling information published by Shamshuddin and Ismail (1995) when gypsum was applied onto Ultisol and Oxisol in Peninsular Malaysia:

a) SO_4^{2-} released by gypsum were adsorbed by the oxides of Fe (hematite and goethite) existing in the soils; and
b) Ca^{2+} released by gypsum replaced some Al^{3+} at the soil exchange complex.

The former occurs in Oxisols containing high amount of hematite and goethite (sesquioxides), while the latter is more likely to occur in soils with high Al^{3+} such as Ultisols. The pH of Ultisols in Peninsular Malaysia is lower than that of Oxisols (Tessens and Shamshuddin, 1983), implying that Ultisols contain higher Al^{3+} concentration. The adsorption of SO_4^{2-} on the Fe_2O_3 of Oxisols results in release of OH^-; besides, the negative charge (CEC) on its surface is slightly increased (Shamshuddin and Ismail, 1995). As such, the fertility of the Oxisols treated with gypsum is concomitantly enhanced due to increased pH and CEC. Under the circumstances, the productivity of oil palm planted on Oxisols is expected to be slightly improved.

Naturally, Al^{3+} in the soil solutions slowly but surely undergo hydrolysis that in the end releases H^+, slightly lowering soil pH. The reaction is expected to be in operation if gypsum is applied onto an Ultisol having high Al^{3+} activity. This happens due to Ca^{2+} replacing Al^{3+} in the soil exchange complex. However, the negative impact of increasing acidity on oil palm via this mechanism is minimal as Ca^{2+} simultaneously creates some alkalinity (OH^-). If the reaction occurs in Oxisols, the drop in soil pH is offset by the release of OH^- when SO_4^{2-} is adsorbed onto the oxides of Fe (Shamshuddin and Ismail, 1995). Oxisols in Peninsular Malaysia contain more oxides of Fe compared to those of Ultisols (Shamshuddin and Fauziah, 2010).

Impact on oil palm productivity

Gypsum not only is an excellent and/or effective ameliorant for acidic highly weathered soils, but also a supplier of essential Ca and S for oil palm. These two macronutrients are needed in sufficient amount by the crop to sustain its growth and production. Insufficient S in oil palm biomass will negatively impact on the production of oil in its fruitlets.

A study conducted by Nurul Mayzaitul *et al.* (2022) to determine the effects different Ca sources on the growth of oil palm seedlings shows it all. The result of the study clearly indicated that the best treatment was supplying Ca via gypsum addition. They reiterated that applying gypsum to oil palm seedlings at the nursery stage has the advantage of being able to control a disease caused by *Ganoderma boninense* fungi – i.e., basal stem rot disease (BSR). This finding is consistent with that of Nurul Mayzaitul *et al*. (2024) who conducted a similar study on oil palm in plantation. Furthermore, the notion is in agreement with that of an earlier study conducted by Nur Shuhada *et al.* (2016). As such, Ca content in highly weathered soils of the country should be regularly checked and its availability for oil palm uptake has to be seriously taken into consideration in order to alleviate Ca-deficiency.

APPLICATION OF GML IN COMBINATION WITH GYPSUM

A research was conducted by Shamshuddin and Ismail (1995) to alleviate soil acidity problem in the topsoil and subsoil. The soils under investigation were sampled from Prang Besar Estate in Selangor. The soils in the area, planted with oil palm and/or rubber, were Ultisols and Oxisols. It was found beyond doubt that liming the soils with GML only improved the fertility of the topsoil (0-15 cm depth), which is the zone of lime incorporation. This implies that we cannot alleviate soil acidity stress and Al^{3+} toxicity problem in the subsoil (15-30 cm depth) via liming alone. As such, oil palm roots, if present in the subsoil, are still subjected to the low pH stress and/or Al^{3+} toxicity. Under the conditions, the crop is unable to grow normally; eventually, it cannot produce the maximal yield (FFB) that growers are aiming for.

Previously, Ismail *et al.* (1993) showed conclusively that some Ca moved to the subsoil if gypsum was applied in the topsoil of the Ultisols and Oxisols. The presence of extra Ca contributed by gypsum somewhat improved soil fertility in that zone. In essence, Ca present in the soil solutions can be eventually taken up by oil palm via its root system.

Shamshuddin and Ismail (1995) confirmed the notion that applying GML in combination with gypsum at the appropriate rate resulted in alleviation of the topsoil and subsoil acidity as well as Al^{3+} toxicity. The agronomic practice in the long run improves soil fertility significantly, which is expected to sustain oil palm growth and/or production; eventually, profitability increases. The ameliorative impact of applying the ameliorants on highly weathered soils in Peninsular Malaysia was further articulated by Shamshuddin *et al.* (1997).

IMPACT OF APPLYING Mg-GYPSUM ON OIL PALM

Malaysia is endowed with the availability of large amount of Mg-gypsum, a by-product of Lynas Chemical Plant in Gebeng, Pahang (Shamshuddin *et al*., 2021; Shamshuddin, 2022). The production of rare earth at the Lynas Chemical Plant involves many steps. It starts with lanthanide ore containing rare earth imported from Australia. In the process of extracting the precious rare earth, two contrasting by-products are produced. After undergoing a series of chemical processes, radioactive Water Leach Purification (WLP) residue rich in P is produced. It is followed by the production of Mg-gypsum, which is non-radioactive (**Figure 2**).

Figure 2. A photograph showing Mg-gypsum being stored at the Lynas Chemical Plant in Gebeng, Malaysia (Courtesy of Lynas Malaysia Sdn Bhd)

Land application of Mg-gypsum in an oil palm estate does not result in environmental degradation. This notion is confirmed by Abd Rahim *et al*. (2019) who conducted a study over a period of two years in an oil palm plantation in Bera, Malaysia. Soils in the area under investigation stand to benefit via alleviation of acidity stress and/or Al^{3+} toxicity that enhances oil palm growth and production. Mg-gypsum not only is an excellent soil ameliorant, but also a source of Ca, Mg and S. Oil palm yield will be further elevated by the addition of some essential micronutrients contained in the schedule wastes (**Table 2).**

Table 2: Micronutrients and beneficial elements present in Mg-gypsum

Micronutrient				Beneficial element	
Fe	Mn	Zn	Cu	Si	Se
------ mg kg^{-1} ------					
1368	1175	38.7	127	19.1	0.4

Source: Ayanda *et al.* (2020)

The results obtained by the above-mentioned studies are consistent with the Eleventh Malaysia Plan 2016-2020 initiatives, which looks at managing chemical plant wastes holistically. The initiative states that using wastes as a resource gives an economic value; hence, diverting it away from landfill towards more productive use. If applied repeatedly at suitable rates, Mg-gypsum addition has been known to increase soil pH that alleviates Al^{3+} toxicity common in tropical regions of the globe (Shamshuddin *et al.,* 2021; Shamshuddin, 2022).

The solubility rate of Ca- and Mg-fertilizers usually used for oil palm cultivation has been known to be in the order of: China Kieserite > Mg-gypsum > GML (Shamshuddin *et al.,* 2017). It is imperative to enhance the solubility of Mg-gypsum to be comparable with that of the China Kieserite. When applied onto acidic highly weathered soils of the tropics, it is possible for Mg-gypsum to be dissolved completely in a matter of few weeks. Along the way, Mg, Ca and S as well as the micronutrients mentioned in **Table 2** are released into the soil environment for oil palm uptake to sustain its growth and/or production.

According to Mohd Firdaus *et al.* (2020), the solubility of Mg-gypsum can be further accelerated if it is applied on highly weathered soils in combination with elemental sulphur (S). The oxidation of S in the soils would release some acidity that helps dissolve the alkaline Mg-gypsum (with pH >7) at a higher rate. The mechanism appears to work well if the soils are well drained, which is a normal condition for most Ultisols and Oxisols in Malaysia.

The most abundant element in Mg-gypsum is Ca (20.99%), followed by Mg (7.15%) (Ayanda *et al.,* 2020); the values are comparable to those of GML. As **Table 2** shows, Mg-gypsum contains some micronutrients (Mn, Zn and Cu), with small amount of beneficial elements (Se and Si), but significant nevertheless. According to Najihah *et al*. (2015), if Si was present in oil palm tissues at the appropriate level, the incident of basal stem rot (BSR) disease caused by fungi endemic in Malaysian plantations could be prevented or even cured.

Mg-gypsum accumulated at the Lynas Chemical Plant in Pahang has a great potential in agriculture, particularly as Mg- and Ca-fertilizers as well as soil ameliorant or conditioner. However, its utilization for agriculture is prohibited until and unless a permission is granted from the government – i.e., Department of Environment (DoE), Ministry of Science in Putrajaya. Mg-gypsum is listed as a scheduled waste until further notice.

The level of Mg in an Ultisol treated with Mg-gypsum is comparable to that treated with Kieserite (Ayanda *et al.,* 2020). According to Ayanda (2017), exchangeable Mg and Ca in the untreated topsoil of the oil palm plantation under investigation was 0.23 and 0.64 $cmol_c$/kg soil, respectively. These levels of Ca and Mg concentration are below the sufficiency range for the optimal growth of oil palm in the field (Shamshuddin *et al.,* 2018).

It seems that Mg together with Ca required by crops in the fields can be supplied via liming using GML. However, the large area of land cultivated with oil palm in the country has made lime application very expensive; thus, it is not a viable option. Currently, the standard practice of supplying Mg for oil palm consumption is Kieserite application.

Oil palm is an acid-tolerant plant species; thus, it can tolerate soil acidity till pH 4.3 (Auxtero and Shamshuddin, 1991). However, raising soil pH to a higher level (>5) is believed to significantly enhances its growth. This is because at that pH Fe^{2+} (pKa is 4.58) and Al^{3+} (pKa is 5) are precipitated - they are deactivated and hence no longer toxic to oil palm. As mentioned above, to raise soil pH to a level >5 via GML application is a costly affair. This is where Mg-gypsum comes in to help alleviate soil acidity and Al^{3+} toxicity problems.

Continuous application of Mg-gypsum would add a valuable amount of Ca to the soils and concomitantly supply Mg for oil palm requirement. The alkaline nature of the Mg-gypsum make it possible for the soil pH to slightly increase that enhances oil palm growth.

As discussed by Ayanda *et al.* (2020), sufficient Ca is necessary in Ultisol to sustain oil palm growth and/or production. This is proven by the significant correlation between the height of oil palm seedlings and the level of exchangeable Ca. The critical level of exchangeable Ca was estimated to be 0.9 $cmol_c$/kg. However, the topsoil exchangeable Ca in the plantation was only 0.64 $cmol_c$/kg; as such, it was insufficient for the oil palm requirement.

Exchangeable Ca of more than 0.9 $cmol_c$/kg is rather uncommon for the Ultisols and Oxisols in Peninsular Malaysia under continuous oil palm cultivation. For all we know, about 70% of Malaysia are covered by the two soil types, with the land area covered by Ultisols higher than that of Oxisols. Exchangeable Ca and Mg level for both soil types can be raised accordingly via continuously applying appropriate amount of Mg-gypsum.

A stepwise regression analysis of the soil pH, exchangeable calcium and exchangeable magnesium was run by Ayanda *et al*. (2020). Significant relationship existed between the variables and the height of oil palm seedlings. This means that if soil pH, exchangeable Ca and exchangeable Mg are increased, the growth of the oil palm seedlings is enhanced, which can be achieved by applying sufficient amount of Mg-gypsum.

Further result of the study showed that soil pH was significantly correlated with the height of oil palm seedlings (Ayanda *et al.,* 2020). Using stepwise regression analysis again, it was found that soil pH was the most important factor contributing to the growth of oil palm. This finding is consistent with the notion that oil palm growth is enhanced if soil pH were to be raised to a level above 5 than otherwise is. In reality, Al^{3+} is precipitated as inert Al-hydroxides when soil pH is raised to the level above 5 (Shamshuddin *et al.,* 1991; Shamshuddin and Ismail, 1995). Under the condition, it is no longer toxic to oil palm roots growing in the field.

Ayanda *et al.* (2020) also ran stepwise regression analysis on soil pH and exchangeable Ca and the correlation was significantly positive. After Mg-gypsum is applied, exchangeable Ca will be increased, which in turn, raises soil pH to the level dependent on the rate. This is another benefit of applying Mg-gypsum on highly weathered soils whose natural pH is 4-5.

IMPACT OF WOLLASTONITE APPLICATION ON OIL PALM

For all we know, silicon (Si) is mainly found in soil in the form of quartz (SiO_2). The mineral is resistant to chemical weathering although existing under tropical conditions. Only a small amount of quartz dissolves in water to release its Si into soil environment. Even if it is eventually dissolved in water, the time taken to do so is very long. Silicon if present in oil palm tissues is believed to help prevent or even cure BSR disease endemic in the plantations. As such, it is worthwhile to consider applying a mineral containing both Ca and Si soluble in water in oil palm plantations. The reason being to get Ca and Si in their available form for crop uptake. A mineral that serves the purpose well is calcium silicate ($CaSiO_3$), which is otherwise known as wollastonite. It is known that wollastonite is mineralized in the environment by thermal metamorphism of impure limestone (Whitten and Brooks, 1972).

It would be a good agronomic practice to apply wollastonite at the appropriate rate from time to time to alleviate Ca deficiency in Ultisols and Oxisols cropped to oil palm. On its dissolution, soil acidity is slowly reduced via gradual release of Ca^{2+} and SiO_3^{2-}. According to Azman *et al*. (2023), the ions would continuously filling the exchange sites, resulting in reducing the potential of extra (free) H^+ availability in the soils. Hence, applying wollastonite on highly weathered soils helps increase their fertility slightly.

It seems that Si is a beneficial element that helps sustain crop growth and/or production. Among the crops that take in a lot of Si from soils are sugarcane and rice. According to Munevar and Romero (2015), oil palm is also a Si accumulator. The beneficial effects of Si are associated with its high level of deposition in plant tissues that enhances their strength and rigidity. Besides, Si in plants alleviates biotic and abiotic stresses they are facing with.

Ma *et al.* (2001) stated that plants take in Si exclusively in the form of mono-silicic acid [$Si(OH)_4$]. The researchers explained that the silicic acid was transported to the shoot of the plants, which later was polymerized as silica gel on the surface of leaves and stems. We tend to believe that Si is taken up by oil palm in the plantations in the form of $Si(OH)_4$.

So far, we are not sure or have any knowledge on how much available Si should be present in soils so that it is sufficient for oil palm requirement to grow healthily in the plantation. A study is therefore necessary in due course to determine the required level of available of Si in Ultisols and Oxisols cropped to oil palm in the country.

Wollastonite dissolves in water to produce SiO_3^{2-} according to the following reaction:

$$CaSiO_3 \rightarrow Ca^{2+} + SiO_3^{2-}$$

The SiO_3^{2-} so produced will be undergoing many hydrolysis steps that in the end would produce H_4SiO_4 (Azman *et al.,* 2023). We are of the opinion that oil palm will take in the necessary amount of Si from soils in the form of silicic acid for its requirement. In so doing, BSR disease endemic in the oil palm plantations is likely to be prevented or even cured (Najihah *et al.,* 2015). A special research should be conducted in due course to validate the notion and/or confirm the results obtained by Azman *et al*. (2023) and Najihah *et al*. (2015).

CONCLUSION

The most common soil types in the upland regions of Peninsular Malaysia are Ultisols and Oxisols. These are the soils in the peninsula where oil palm is mainly cultivated. The soils, with high acidity (pH of 4-5) containing toxic level of Al^{3+} in their soil solutions, are dominated by kaolinite and oxides of Fe. Exposed continuously to high rainfall under tropical environment, the soils are usually deficient in Ca and Mg that affect oil palm production.

Mg-deficiency that negatively impact oil palm productivity receives much attention from the powers-that-be or growers, but it is not the case for Ca. The need to have sufficient available Ca in soils for the requirement of oil palm is sometimes overlooked. Unintentionally, in Malaysian agricultural practices, Ca is in the liming materials (GML). Due to large area being cultivated with the crop, it becomes uneconomical to frequently apply GML at a high rate. Note that some Ca are added into the soils during application of phosphate rock.

There are other sources of Ca which are equally effective to alleviate Ca-deficiency – i.e., gypsum, Mg-gypsum and wollastonite. Gypsum, if applied on Oxisols, not only Ca and S deficiency are alleviated, but also CEC and pH are slightly increased. Mg-gypsum is even better as it also supplies micronutrients (Cu and Zn). Wollastonite not only adds Ca and slightly increases soil pH, but also produces silicic acid that can be taken up by oil palm. In so doing, basal stem rot disease endemic in plantations can be prevented or even cured.

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