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EVALUATION OF DIFFERENT RATES AND TYPES OF MOROCCAN PHOSPHATE ROCKS ON OIL PALM SEEDLINGS

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ABSTRACT

Phosphorus (P) deficiency has consistently been a major limitation in crop production, especially in acidic tropical soils such as those in Malaysia. Since Morocco has the world's largest reserve of phosphate mines, its phosphate rocks (PR) can be examined for their agronomic effectiveness in Malaysian soil. This study investigated the effects of various types of Moroccan phosphate rocks (MPR) as well as Egyptian phosphate rocks (EPR) on the growth performance of different oil palm genotype seedlings. Five different rates of MPR Type B was used to assess the effect of different rate of PR on oil palm seedlings' performance; 0 mg P kg^{-1} (control), 50 mg P kg^{-1}, 100 mg P kg^{-1}, 200 mg P kg^{-1} and 400 mg P kg^{-1}. Meanwhile, four different types of PR were used to assess the effect of different types of PR on oil palm seedlings' performance: MPR Type A, MPR Type B, MPR Type C, EPR and control (no PR application). The results showed that the rates and types of PR application had significant effects on the P concentration and P uptake of oil palm seedlings. MPR Type B at 100 mg P kg^{-1} was found to produce the optimum rate of P concentration and P uptake in the oil palm seedlings. In terms of different sources of PR, MPR Type B was found to provide oil palm seedlings with a higher concentration of P than EPR.

Keywords: Moroccan phosphate rocks, oil palm seedlings, phosphorus fertilisers.

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INTRODUCTION

Malaysia has vast areas of oil palm plantations, which were estimated to be 5.67 million hectares in 2022 (MPOB, 2023). Despite this, the cultivation and production of oil palm are often limited by the available nutrients in the soil, in particular, phosphate. Phosphorus (P) limitations are also a major productivity constraint in many natural (Augustine *et al*., 2003) and managed (Bünemann *et al*., 2011) grassland systems. A study done by Balemi and Negisho (2012) estimated that crop productivity of the world's arable land is limited by a P deficiency of >40% which can severely reduce crop production. This challenge, however, can be easily overcome by applying phosphate fertiliser to raise the P levels in soils. Two main categories of P fertilisers can be identified: 1) water-soluble P fertilisers such as superphosphate, triple super phosphate ad, and diammonium phosphate; and 2) ground phosphate rocks (PR) originating from different mines. As Malaysian soil is highly weathered, acidic and inherently low in P, the application of fertilisers is crucial and can satisfy the nutrient deficiency in acid soils (Chien *et al*., 2011), but however, the cost of fertilisers, particularly of P fertilisers, has increased markedly worldwide (Chien *et al*., 2011; Van Straaten, 2002; 2006). Planters generally choose P fertilisers based on the agronomic efficiencies of the materials and the price. The performances of water soluble phosphate in acid soils are reported to be very low. This is due to the the presence of iron (Fe) and aluminum (Al) in these soils (Basak and Biswas, 2016). Thus, it is not suitable to use in acid

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soil. Direct application of PR has been a standard practice since the 1930s in supplying the P demand of the oil palm crops (Zaharah *et al*., 1996). Zin *et al*. (2001) reported that direct application of PR is highly practical in correcting P deficiency in most Malaysian soils. The use of ground PR also shows a positive result in liming as it has high calcium (Ca) content (Isenmila *et al*., 2006). Furthermore, the PR was found to have significant residual effects in acid soils for at least a few years (Chan, 1981; Tan *et al*., 2015). In addition, several studies have demonstrated that the application of PR directly to the soil was agronomically comparable to phosphate fertilisers of a lower price; PR was also an economically attractive substitute to the use of the more expensive soluble phosphate fertilisers (Chien *et al*., 1990; Chien and Friesen, 1992; Hammond *et al*., 1986; Khasawneh and Doll, 1978; Sale and Mokwunye, 1993). Correa *et al*. (2005) performed a study on corn plants in Ultisol and found an increase in shoot dry matter production when treated with Gafsa PR. The production of crop plants incorporated with Gafsa PR was as sufficient as the production of crop plants treated with triple superphosphate. On the other hand, Barrow (2017) showed that for soybeans, the decrease in soil pH (6 to 4) had increased the phosphate uptake by roots.

The principal mineral in most PR sources is apatite, but these PR sources vary extensively in their physical, chemical, and crystallographic properties (Chien *et al*., 2010). They originate from various places being mined and include marine, igneous, metamorphic, biogenic, and phosphate deposits as a result of weathering. However, most of the PR is extracted from sedimentary marine deposits, and a small amount is obtained from igneous sources. According to Lin and Schorr (1997), PR of sedimentary origin yield typically 30%-35% of phosphorus pentoxide (P_2O_5), whereas those of igneous origin contain marginally higher P_2O_5 at typically 35%-40%. Meanwhile, 90% of PR is being processed as raw material into water-soluble P fertiliser, while some of it is used for direct application to the soil. The direct application of PR can be a source of P for crops, but not all PR is readily available and agronomically effective when applied directly to the soil. This can be attributed to PR's natural variation in reactivity and occurring mineral impurities, such as clay, carbonate (CO_3), Fe, and Al. Furthermore, these properties most often differ with geological location, which will affect their use for direct application. At present, several PR varieties have been used in Malaysia; these are mined from different regions of the world, mostly from Christmas Island, China and Northern Africa. This PR have different reactivity and agronomic effectiveness, and this will eventually affect the performance of the plant. Thus, a reactive source of PR is crucial to improve the soil P levels and boost plant productivity.

Several studies have indicated that PR reserves could be depleted within 50 to 100 years (Cordell, 2010; De Haes *et al*., 2009; Smit *et al*., 2009; Steen, 1998; Vaccari, 2009), whilst others suggest that PR reserves will extend well into the future (Van Kauwenbergh, 2010; Van Vuuren *et al*., 2010). Regardless of these timelines, it is evident that most of the PR reserves are held by only a few countries in Northern Africa, primarily Morocco. According to the USGS (2011), it is estimated that Morocco possesses around 77% of the world's PR reserves.

Some PR from these mines are used for direct application in soils for agricultural purposes. Accordingly, Moroccan phosphate rocks (MPR) have the potential to be a good alternative to P fertilisers in Malaysia. Various P fertilisers have been evaluated for oil palm under nursery and field conditions (Foong, 1993; Foster *et al*., 1988; Goh *et al*., 1994; Ng, 1986). However, there are limited studies on MPR, for oil palm in Malaysia, in terms of its solubility/reactivity in soils and agronomic effectiveness. Therefore, the objective of this study was to evaluate the effects of PR on the growth performance of different oil palm seedling genotypes with different types of MPR applications. This is the first study to investigate the use of MPR on oil palm seedlings in Malaysian soils.

MATERIALS AND METHODS

Experimental Design

Four types of PR from two geological locations were used in this study: PR from 3 different mines in Khouribga, Morocco, hence designated as MPR Type A, MPR Type B, and MPR Type C, and PR from Egypt hence designated as EPR. EPR was used in this experiment because; 1) It is commonly found in Malaysian oil palm plantation/market and 2) EPR is from Northern Africa, which is same as MPR. Thus, it is a good indicator in comparing both phosphate rocks. As a control group, a treatment without the addition of PR was included in the experiment. Before the study, all the PR materials were sampled and subjected to a 2% formic acid and 2% citric acid solubility test. *Table 1* shows the results of the solubility test.

X-ray diffraction (XRD) analysis was also performed (to identify the mineral content) on MPR Type A, Type B and Type C and the results showed the initial presence of Arrojadite, Cacoxenite and Lesukite respectively as their phosphate minerals.

Four month old oil palm seedlings (*Dura* x *Pisifera*) comprising AVROS and Yangambi planting materials were used in this study. The oil palm seedlings were selected according to the average height and frond sizes. On receiving the seedlings from the supplier, they were transplanted into

TABLE 1. THE CHEMICAL AND PHYSICAL CHARACTERISTICS OF THE TWO APPLIED PR FERTILISERS

P sources		P_2O_5 (%)	Solubility as a percent of rocks (%)	
			2% Formic acid	2% Citric acid
MPR	Type A	32.7	17.2	10.3
	Type B	30.8	16.8	10.2
	Type C	31.4	16.9	10.4
EPR		26.6	11.4	9.2

Note: P - phosphorus; P_2O_5 - phosphorus pentoxide; MPR - Moroccan phosphate rocks; EPR - Egyptian phosphate rocks.

prepared polybags (20′ x 20′) containing 20 kg of soil (the soils were allowed to acclimatise for a week before treatment application). The soil used in this study was sandy clay loam; it has a low P content which can be classified as Haplic Hapludox (Soil Survey Staff, 1998). The characteristics of the soils are shown in *Table 2.*

TABLE 2. CHARACTERISTICS OF SOIL

Treatment		Topsoil
pH	H_2O	3.98
Organic carbon (%)		0.29
Total nitrogen (%)		0.03
C/N ratio		0.10
Available P (mg P kg^{-1})		2.57
Exchangeable cations (cmol(+)kg^{-1} soil)	Ca	0.24
	Na	0.05
	Mg	0.07
	K	0.12
Soil texture (%)	Clay	26.78
	Silt	6.22
	Sand	66.99

Note: C/N ratio - carbon/nitrogen ratio; P - phosphorus; H_2O - water; Ca - calcium; Na - sodium; Mg - magnesium; K - potassium.

To assess the effects of different rates of PR application, we applied MPR Type B at the rates of 0 mg P kg^{-1} (control), 50 mg P kg^{-1}, 100 mg P kg^{-1}, 200 mg P kg^{-1} and 400 mg P kg^{-1} to the four month old oil palm seedlings (two genotypes) at an open field area. The treatments were arranged in a randomised complete block design (RCBD) with four replications for each. Meanwhile, to assess the effects of different types of PR application, we treated four different types of PR including control (0 mg P kg^{-1}) with PR at the rate of 100 mg P kg^{-1} per polythene bag. The PRs used were MPR (Type A, Type B, Type C), EPR and control (without PRs). The treatments were arranged in an RCBD with four replications.

After eight months, the plants were harvested, dried, ground, sieved using 1 mm sieve and analysed. The third leaf of each plant was used for plant nutrient analyses of P, K, Ca, and Mg levels. All plant samples were digested using the wet digestion method before further nutrient analysis. The plants' P was determined using the procedure described by Murphy and Riley (1962), with absorbance at 693 nm, while K, Ca, and Mg were analysed using atomic absorption spectrophotometer (AAS).

Statistical Analysis

All the data collected during the study were recorded and analysed using General Linear Models (GLM) analysis by Statistical Analysis System (SAS 9.4) (SAS, 1985). Differences between means were separated using Duncan multiple range test (DMRT) at $P< 0.05$ (Gomez and Gomez, 1980).

RESULTS AND DISCUSSION

Effects of Different Rates and Types of PR Application on Plant Total Dry Weight

The total dry weight of oil palm seedlings with different rates of MPR Type B is presented in *Figure 1*. The result shows that the minimum yield was obtained in the control for both oil palm seedling genotypes with a value of 195.1 g for Yangambi and 290.2 g for AVROS, respectively. The application of PR into the soil had a significant effect on total dry weight compared to the control ($P< 0.0001$). However, no significant effect was observed between the oil palm seedlings with MPR Type B at the rates of 50, 100, 200 and 400 mg P kg^{-1}.

Generally, the application of PR improved the total dry weight of oil palm seedlings. Nevertheless, our study showed that the oil palm seedling genotype treatments had no statistically significant effects on total dry weight. This could be because of the characteristics and nature of PR, where PR are a slow-release fertiliser that require more time to be dissolved completely in soil.

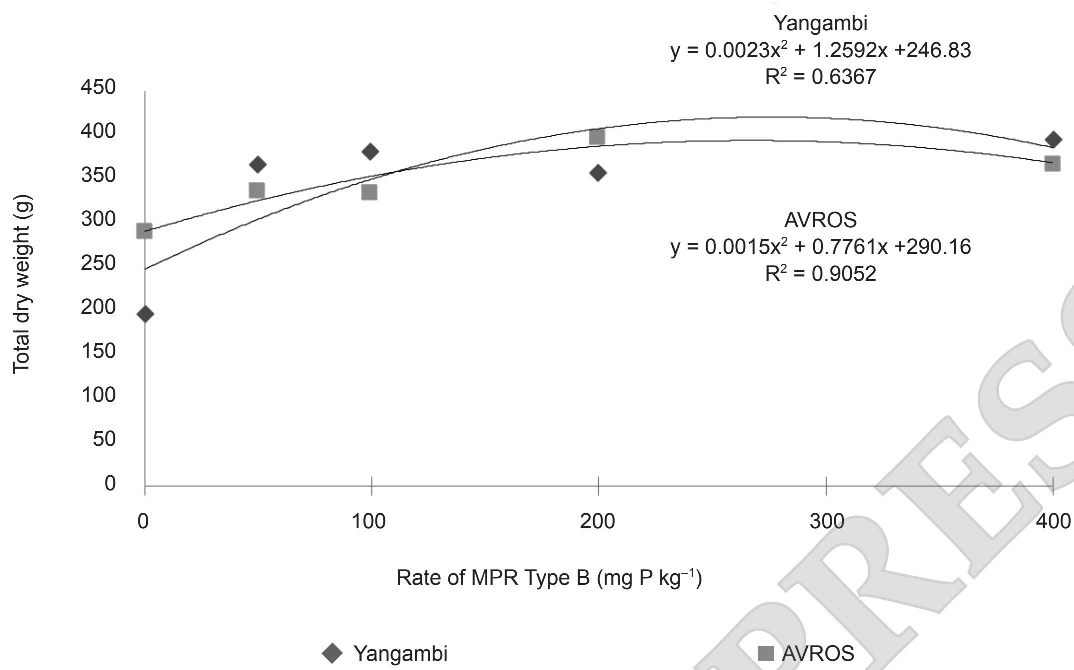


Figure 1. Effect of different rates MPR Type B application and oil palm seedlings genotypes on plant total dry weight.

Meanwhile, a significant interaction in dry weight was found between oil palm seedling genotypes and rates of PR application (P = 0.0124). *Avros* seedlings showed the highest value at the rate of 200 mg P kg^{-1} (397.1 g). Also, a significant interaction was found between oil palm seedling genotype and types of PR application (P = 0.0458), where the *Yangambi* seedling showed the highest value when applied with MPR Type A (490.5 g). Our results showed that different types and rates of PR application did not produce much difference in the total dry weight of oil palm seedlings, which agreed with the study done by Foong (1993) and Syahputra (1997) on oil palm seedlings. Additionally, the study found that there was not much difference between treatments in terms of total dry weight, regardless of the PR source. Thus, dry yield may not be a good parameter in assessing the effectiveness of P sources.

Effects of Different Rates and Types of PR Application on Plant P Concentration and P Uptake

This study found that both the rates and types of PR application influenced the P levels in oil palm leaves. There were significant differences found in the P concentration as affected by the rates of MPR Type B in both genotypes (P< 0.005) (*Figure 2*). The least P concentration was in the control group (0.150% for Yangambi and 0.123% for AVROS), and the highest P concentration was in oil palm seedlings treated with MPR Type B at the rate of 400 mg P kg^{-1} for both oil palm seedlings (0.244% for Yangambi and 0.215% for AVROS). However, there was no significant difference found in the P concentration between oil palm seedlings with MPR Type B application at the rate of 100, 200 and 400 mg P kg^{-1} in both genotypes. Significant differences were also found in the P concentration as affected by the type of MPR in both genotypes (P< 0.005) (*Figure 3*) where the highest P concentration was MPR Type B.

In terms of plant genotype, there were no significant differences found in P concentrations between different oil palm seedling genotypes used in this study. Both of the oil palm seedling genotypes showed a similar trend in P concentration. This result coincides with a study done by Tan *et al*. (2010) on different genotypes of oil palm seedlings treated with Gafsa PR, where the plant total dry weights and P accumulations did not give a clear estimation of the phosphate concentration in the oil palm seedlings.

As for the P uptake, there were significant differences for both genotypes at different rates of MPR Type B application (*Figure 4*). The least P uptake was found in the control group, while the highest P uptake was at the rate of 400 mg P kg^{-1} for both Yangambi and AVROS. However, there was no significant difference found at the rate of 100, 200 and 400 mg P kg^{-1}, which suggests 100 mg P kg^{-1} of MPR Type B as the optimum rate.

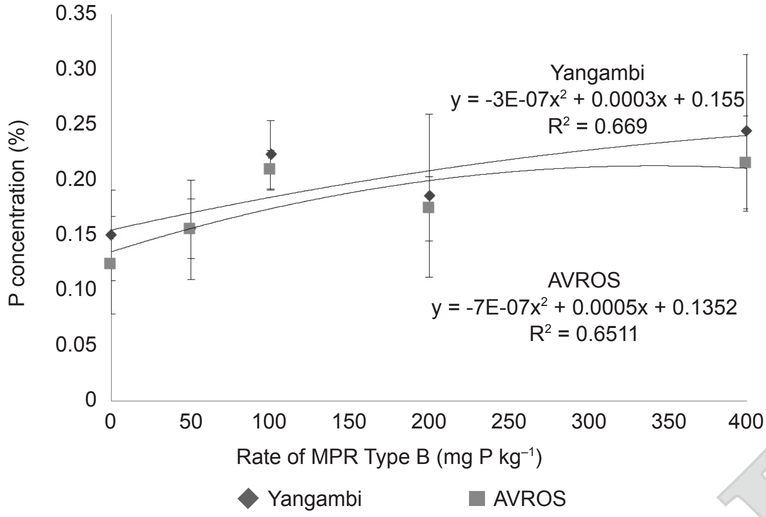
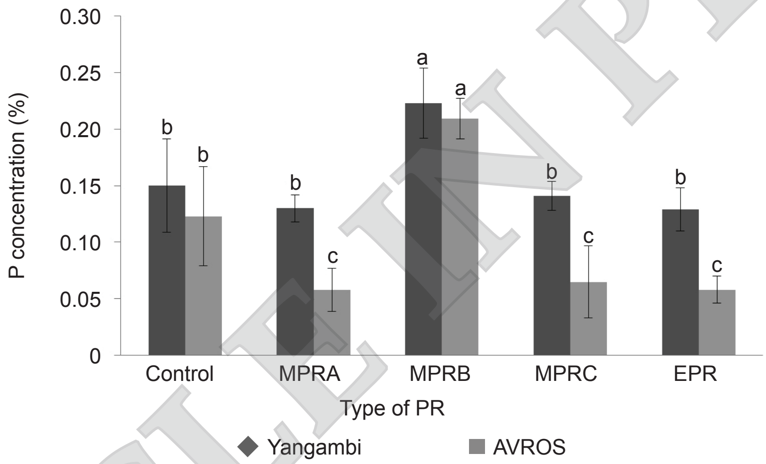


Figure 2. Effect of different rates of MPR Type B application on the P concentration of Yangambi and AVROS oil palm seedlings.



Note: **Mean values with the same letter are not significantly different using DMRT at $P > 0.05$.

Figure 3. Effect of different types of PR application on the P concentration of Yangambi and AVROS oil palm seedlings.

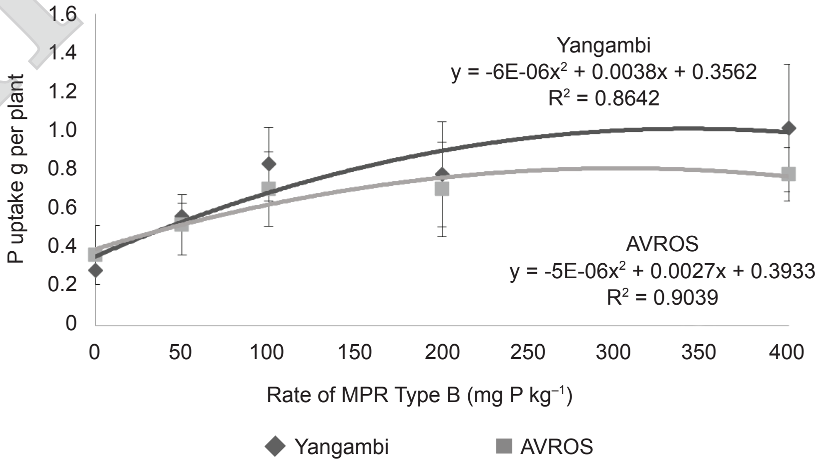


Figure 4. Effect of different rates of MPR Type B (mg P kg^{-1}) application on the P uptake g per plant of Yangambi and AVROS oil palm seedlings.

On the other hand, there were statistical differences in plant P uptake between the control group and different types of PR applications. This indicates that the application of PR into the soil does affect the P uptake in plants. MPR Type B showed the highest P uptake in both oil palm seedling genotypes compared to the others (*Figure 5*).

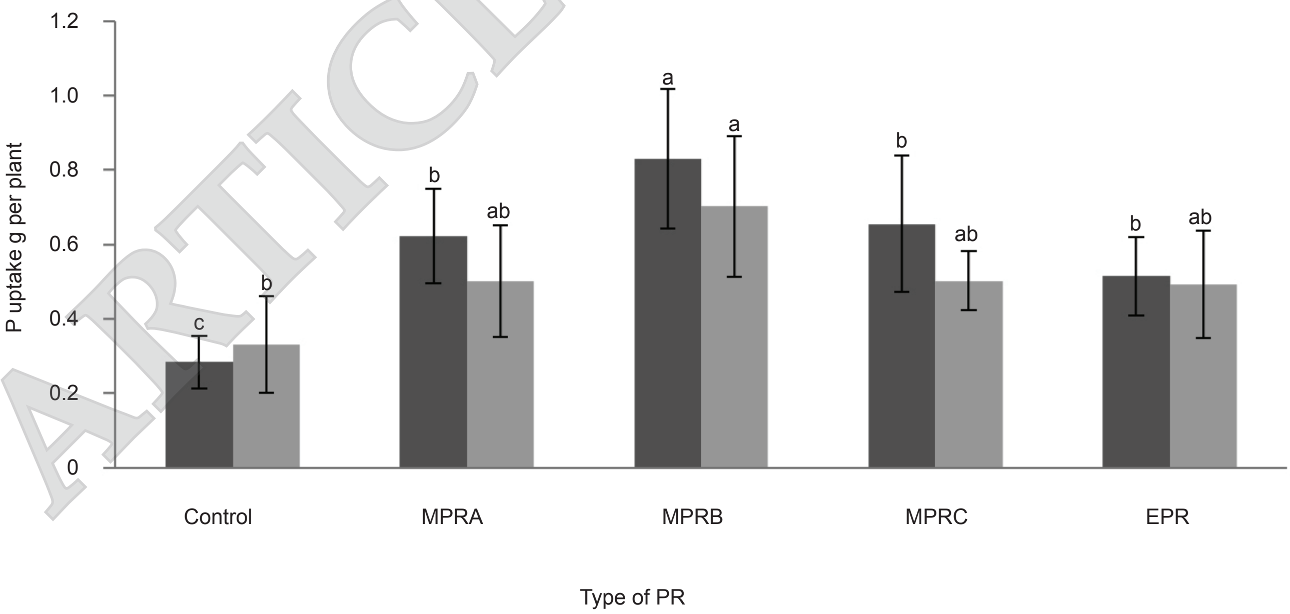
Based on the results above, MPR Type B at the rate of 100 mg P kg^{-1} is the optimum rate of PR application for both genotypes; it is sufficient to fulfil the plant's P requirement. However, in this study, the P uptake of the plant did not correspond to the solubility and P_2O_5 percentage of MPR. This can be attributed to MPR's similar solubility (around 10%) in 2% citric acid, which complies with SIRIM's (2015) requirement for direct application in soil. Thus, all MPRs are suitable for direct application. On the other hand, despite the similar percentage of P_2O_5 of the 3 types of MPR, XRD analysis showed that Type A, Type B and Type C contained Arrojadite, Cacoxenite and Lesukite respectively as their phosphate minerals, which may contribute to the different agronomic performance. Meanwhile, in comparison between different types of MPR (Type A, Type B and Type C) and EPR, the solubility of EPR is lower than MPR which corresponds to the lower P uptake in plants. This result aligned with a study done by Zaharah *et al.* (2014) on matured oil palm, where treatments with high soluble PR showed the highest P concentration compared to the treatment with less soluble PR.

Regression Analysis between Rate of MPR Type B and Plant P Concentration and P Uptake

As there was no statistical difference found in plant genotypes, regression analysis was performed to establish the relationship between the effects of different rates of MPR Type B on plant P concentration and plant P uptake between Yangambi and AVROS oil palm seedlings as shown in *Figure 6* and *7* respectively. The increasing rate of PR significantly increased the plant P concentration [in both seedlings, Yangambi ($R^2 = 0.6554$; $P < 0.001$) and AVROS ($R^2 = 0.5559$; $P < 0.001$)] and plant P uptake [in both seedlings, Yangambi ($R^2 = 0.7386$; $P < 0.001$) and AVROS ($R^2 = 0.6768$; $P < 0.001$)], respectively. From the trend and regression equation, Yangambi seedlings were more responsive towards the rate of MPR Type B compared to the AVROS seedlings as the gradient of the linear line was higher than AVROS seedlings.

Effects of Different Rates and Types of PR Application on Plant Ca Concentration and Ca Uptake

The Ca concentration and Ca uptake in oil palm seedlings for all treatments showed low values. The highest Ca concentration recorded



Note: **Mean values with the same letter are not significantly different using DMRT at $P > 0.05$.

Figure 5. Effect of different types of PR application on the P uptake g per plant of Yangambi and AVROS oil palm seedlings.

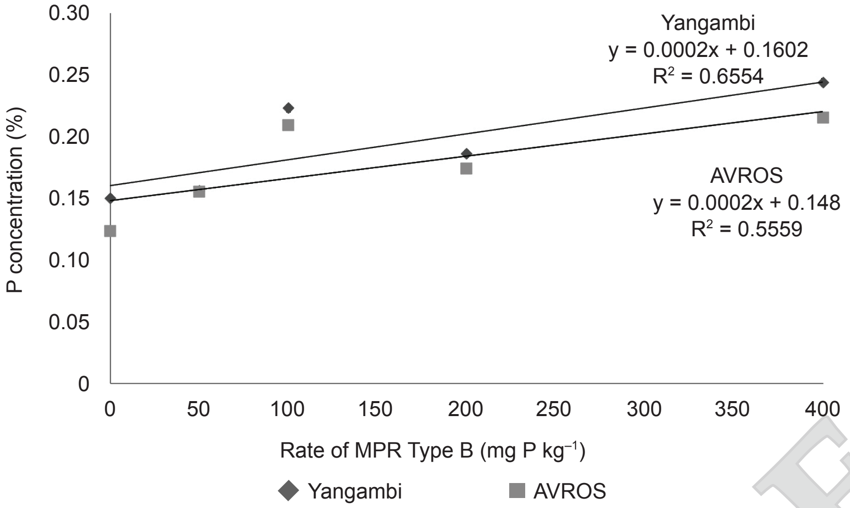


Figure 6. Regression analysis of plant P concentration on Yangambi and AVROS oil palm seedlings.

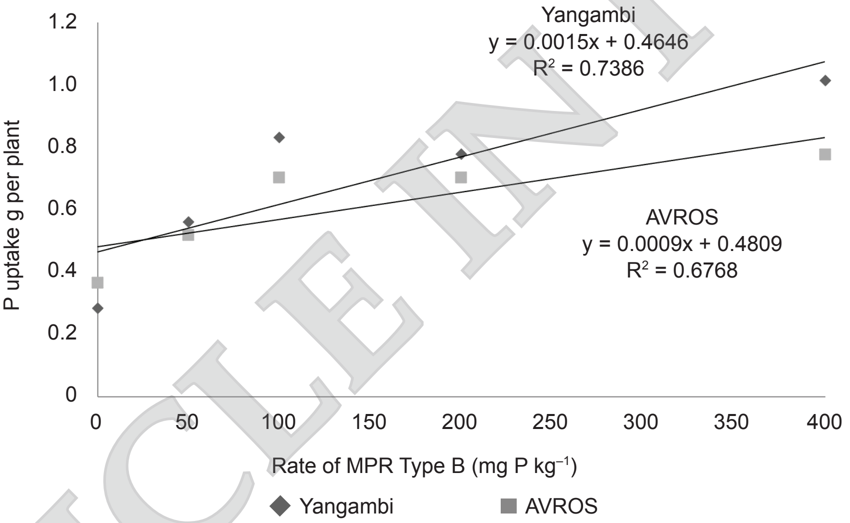


Figure 7. Regression analysis of plant P uptake g per plant on Yangambi and AVROS oil palm seedlings.

was just 0.043%, which is from the Yangambi oil palm seedling treated with 200 mg P kg^{-1} of MPR Type B. The Ca concentration in oil palm seedlings with different types of PR application also showed low values, where the highest value of Ca concentration recorded was 0.034%, in the Yangambi oil palm seedling treated with EPR. Meanwhile, the highest Ca uptake recorded was just 0.185 g in the Yangambi oil palm seedling treated with 200 mg P kg^{-1} of PR. The Ca uptake by oil palm seedlings with different types of PR applications also showed low values. The highest value of Ca uptake recorded was 0.162 g, which was obtained by Yangambi treated with EPR.

As Ca is a major constituent of PR, the release of Ca as affected by the PR application should be positively correlated to the P uptake of the plant (Zaharah *et al*., 2014). There were positive correlations between P concentration and Ca concentration in the oil palm seedlings as affected by different rates of MPR Type B and types of PR (*Table 3*). However, all oil palm seedlings in this experiment showed low values of Ca concentration and suffered from Ca deficiency, thus suggesting that the Ca solubility in PR is low. Therefore, additional Ca application in other forms is required.

Despite the low values of Ca concentration obtained by the oil palm seedlings, application of

TABLE 3. CORRELATION COEFFICIENTS (IN BOLD) AND PROBABILITIES FOR PLANT CONCENTRATION IN OIL PALM SEEDLINGS AS AFFECTED BY DIFFERENT RATES OF MPR TYPE B APPLICATION

Parameters	P	K	Ca	Mg
P	1.00000			
K	**0.46478** (0.1759)	1.00000		
Ca	**0.06610** (0.8560)	**0.08054** (0.8249)	1.00000	
Mg	**-0.07471** (0.8375)	**0.72575** (0.0175)	**-0.17152** (0.6356)	1.00000

Bold values: Pearson's correlation coefficients
Note: P - phosphorus; K - potassium; Ca - calcium; Mg - magnesium.

PR at different rates and types did increase the Ca concentration in the oil palm seedling considerably above the control. This corresponds to the study done by Zaharah *et al.* (2014) on matured oil palm, where the leaf Ca concentration increased with increasing PRs application rates in comparison to the control in both PR of Christmas Islands and Morocco origin. A study done by Dodor (2016) on maize crops also revealed the same trend where the application of African PR increased the Ca content in the crop.

Effects of Different Rates and Types of PR Application on Plant K and Mg Concentration

Based on statistical analysis, there were no significant differences in K and Mg leaf concentration in the oil palm seedlings for both rate and PR type treatments: K and Mg levels in foliar were constant among all treatments. This finding concurs with another study done by Zaharah *et al.* (2014) on peat soils and Charles *et al.* (1998) on Italian ryegrass. K concentration as affected by the different rates of MPR Type B showed a positive correlation (*Table 3*). Conversely, Mg showed a very small negative correlation (r = -0.07471, P = 0.8375) towards P. For different types of PR, the correlation coefficients were the same with the different rates of MPR Type B.

CONCLUSION

MPR was able to supply adequate P in soils for oil palm growth, thus suggesting that MPR is a viable source of P for direct application in Malaysian soils. However, PR from different locations may affect the agronomic effectiveness of the plant; MPR Type B was found to provide the highest levels of P for plant concentration as well as plant uptake. By taking regression analysis into account, our study showed that the Yangambi seedlings are more responsive to plant P concentration and P uptake compared to the AVROS seedlings.

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