EVALUATION OF DIFFERENT TYPES OF MOROCCAN PHOSPHATE ROCK ON PHOSPHORUS AND OTHER NUTRIENT UPTAKES BY OIL PALM (*Elaeis guineensis* Jacq.) SEEDLINGS

By

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Malaysia has a total of 5.87 million ha of oil palm planted area and it is the world's second largest palm oil producer. Malaysia has also subjected for 25.8% of world's palm oil production and 34.3% of world's oil palm exports. Phosphorus (P) is one of the most essential elements for plant growth but P deficiency is considered to be one of the major limitations for crop production on a global scale, in particular tropical acid soils. To fulfill the P demand for crop production, oil palm plantation in Malaysia has been relying heavily on the use of P fertilizer in particular phosphate rocks (PRs), due to its solubility in acid soils and lower cost. The reactivity of PRs used in Malaysia however are very low and will eventually affect the plant's performance. Recently, PRs from different geographical locations are being transported into the Malaysian market. Moroccan Phosphate Rock (MPR) reserves a large production of phosphate in the market which can be a good alternative to the previous PR deposit. Hence, the aim of this study was to investigate the growth performance of different oil palm genotype seedling applied with different types of MPRs. An incubation study was conducted to evaluate the release of P in acid soils. 700g of two different acid soils (Munchong and Bungor series soils) were incubated with three different types of MPR (Type A, B and C) at the rate of 350 mg P kg^{-1} of soil for 15 weeks. Egyptian Phosphate Rocks (EPRs) was used as a comparison. Apart from that, a field study was also conducted on oil palm seedlings. Different rates and types of PRs was being evaluated for its effectiveness on N, P, K, Ca and Mg uptake. Five different rates of MPR Type B (0, 50, 100, 200 and 400mg P kg^{-1}) were applied two times; first and fourth month of 8 months throughout the study into 20kg of mixture of topsoil (70%) and sand (30%) and put into polythene bag with the size of 20'x20'. While for the different types of MPR, the experiment was conducted simultaneously with the previous experiment. Three types of MPR were used (Type A, B and C) at the rate of 100 mg P kg^{-1} with EPR was chosen as a comparison. 4 months old of oil palm seedlings from two different genotypes (Felda *Yangambi* and Sime Darby *Avros*) were used. The treatments were carried out for 8 months and arranged in a Randomized Complete Block Design (RCBD) with 4replications. Meanwhile, a detection of organic acid from oil palm seedlings root exudates under P-stress condition was performed for the third study. As for the result, the changes of extractable P in soils treated with MPR is higher compared to the EPR. Munchong series soil showed a better soil property in term of nutrient absorption into the soils. The lower amount of Al oxides in Munchong soil series attributed to the higher changes of extractable P in soils. Meanwhile, the rates and types of PR application had a significant effect on the nutrient uptake of the oil palm seedlings. A positive correlation was obtained for all plant nutrients which indicate that application of PRs into the soil improves the nutrient in plant. The rate of PR application at 100 mg P kg^{-1} was found to be the optimum rate for P uptake of the oil palm seedlings. As for different types of PR application, MPR Type B was found to be superior in providing P for plant uptake. Lastly, the detection of organic acid exuded by the plant roots under P- stress condition resulted in the identification of two organic acids; oxalate and citrate. All in all, these findings bring to the conclusion that MPR Type B at the rate of 100mg P kg^{-1} has been identified as an optimum and affective amount in supplying sufficient P and others nutrient (N, K, Ca, and Mg) uptake to the oil palm seedlings. Hence, MPR Type B can be a good alternative to the current PR used in Malaysia.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

PENILAIAN PELBAGAI JENIS BATUAN FOSFAT MOROCCO TERHADAP PENYERAPAN NUTRIEN FOSFORUS DAN NUTRIEN LAIN OLEH ANAK POKOK KELAPA SAWIT *(Elaeis guineensis* Jacq.)

Oleh

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Malaysia mempunyai sejumlah 5.87 juta hektar kawasan tanaman kelapa sawit dan ia merupakan pengeluar minyak sawit kedua terbesar di dunia. Malaysia juga tertakluk kepada 25.8% daripada pengeluaran minyak sawit dunia dan 34.3% daripada eksport kelapa sawit dunia. Fosforus (P) adalah salah satu unsur yang paling penting untuk pertumbuhan tumbuhan tetapi kekurangan P dianggap sebagai salah satu had utama untuk pengeluaran tanaman pada skala global, khususnya tanah asid tropika. Untuk memenuhi permintaan P bagi pengeluaran tanaman, ladang kelapa sawit di Malaysia telah banyak bergantung kepada penggunaan baja P khususnya batu fosfat(PR), kerana keterlarutannya dalam tanah berasid dan kos yang lebih rendah. Kereaktifan PR yang digunakan di Malaysia bagaimanapun adalah sangat rendah dan akhirnya akan menjejaskan prestasi loji itu. Baru-baru ini, batuan fosfat dari lokasi geografi yang berbeza sedang diangkut ke pasaran Malaysia. Maghribi Phosphate Rock (MPR) mempunyai pengeluaran besar fosfat di pasaran yang boleh menjadi alternatif yang baik kepada deposit batu fosfat sebelumnya. Oleh itu, matlamat kajian ini adalah untuk mengkaji prestasi pertumbuhan benih genotip kelapa sawit yang berbeza digunakan dengan jenis fosfat Maghribi yang berbeza. Kajian inkubasi dilakukan untuk menilai pembebasan fosforus dalam tanah asid. 700g dua tanah asid yang berbeza (tanah siri Munchong dan Bungor) diinkubasikan dengan tiga jenis MPR (Jenis A, B dan C) dengan kadar 350 mg P kg^{-1} tanah selama 15 minggu. EPR digunakan sebagai perbandingan. Selain itu, kajian lapangan juga dilakukan terhadap anak benih kelapa sawit. Kadar dan jenis PR yang berbeza telah dinilai untuk keberkesanannya terhadap kepekatan P, K, Ca dan Mg. Lima jenis MPR Type B (0, 50, 100, 200 dan 400 mg P kg^{-1}) telah digunakan dua kali; bulan pertama dan keempat 8 bulan sepanjang kajian ke dalam 20kg campuran tanah atas (70%) dan pasir (30%) dan dimasukkan ke dalam beg polythene dengan saiz

20'x20 '. Walaupun untuk pelbagai jenis MPR, eksperimen ini dijalankan serentak dengan eksperimen sebelumnya. Tiga jenis MPR digunakan (Jenis A, B dan C) pada kadar 100 mg P kg^{-1} dengan EPR dipilih sebagai perbandingan. Buah kelapa sawit berusia 4 bulan dari dua jenis genotip (Felda *Yangambi* dan Sime Darby *Avros*) telah digunakan. Rawatan telah dijalankan selama 8 bulan dan disusun dalam reka bentuk blok lengkap rawak dengan 4replikasi. Sementara itu, pengesanan asid organik dari akar benih kelapa sawit yang dikeluarkan di bawah keadaan P-stress dilakukan untuk kajian ketiga. Hasilnya, perubahan P yang boleh diekstrak dalam tanah yang dirawat dengan MPR adalah lebih tinggi berbanding dengan EPR. Tanah siri Munchong menunjukkan sifat tanah yang lebih baik dari segi penyerapan nutrien ke dalam tanah. Perubahan amaun yang lebih rendah daripada Al oksida dalam siri tanah Munchong disebabkan oleh P yang boleh dieksekusi dalam tanah. Sementara itu, kadar dan jenis aplikasi PR mempunyai kesan yang signifikan terhadap kepekatan nutrien benih kelapa sawit. Kadar aplikasi PR pada 100 mg P kg^{-1} didapati kadar optimum untuk pengambilan P oleh anak benih kelapa sawit. Bagi pelbagai jenis aplikasi PR, MPR Jenis B didapati unggul dalam menyediakan P. Akhir sekali, pengesanan asid organik yang dipancarkan oleh akar tumbuhan di bawah keadaan P-tekanan mengakibatkan pengenalpastian dua asid organik; oksalat dan sitrat. Secara keseluruhannya, penemuan ini membawa kepada kesimpulan bahawa MPR Jenis B pada kadar 100mg P kg^{-1} telah dikenal pasti sebagai jumlah optimum dan berkesan dalam membekalkan serapan P dan nutrien yang lain (N, K, Ca dan Mg) yang mencukupi kepada anak benih kelapa sawit. Oleh itu, MPR Jenis B boleh menjadi alternatif yang baik kepada PR semasa yang digunakan di Malaysia.

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were as follows:

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LIST OF ABBREVIATIONS

AA	Auto Analyzer
AAS	Atomic Absorption Spectrometer
ANOVA	Analysis of Variance
C	Carbon
Ca	Calcium
cPs	Count per second
CRD	Completely Randomized Design
EPR	Egyptian Phosphate Rock
et al.	and others
FAO	Food and Agriculture Organization
GLM	General Linear Models
IFA	International Fertilizer Industry Association
IFDC	International Fertilizer Development Center
K	Potassium
LC-MS	Liquid Chromatography–Mass Spectrometry
LSD	Least Significant Difference
m/z	Mass to charge
Mg	Magnesium
mg P kg^{-1}	Miligram of Phosphorus per Kilogram of Soil
MOP	Muriate Of Potash
MPR	Moroccan Phosphate Rock
N	Nitrogen
P	Phosphorus
PR	Phosphate Rock

RCBD	Randomized Complete Block Design
SAS	Statistical Analysis System
SOA	Sulphate of Ammonium
USDA	United States Department of Agriculture

CHAPTER 1

INTRODUCTION

In Malaysia, oil palm industry plays an essential role in the agricultural development and palm oil production has been known to be one of the main economic contributors of the country. According to the Department of Statistics, Malaysia, in 2016, higher palm oil prices and improved export trade to RM77.85 billion, up from RM67.92 billion. Over the last 100 years, oil palm has been widely and extensively planted in South East Asia, primarily in Malaysia and Indonesia. Currently, Malaysia is the world's second-largest producer of the oil palm's produce after Indonesia. At present, Malaysia has a total of 5.845 million ha of oil palm planted area. The planted areas in Sarawak are 1.56 million hectares, whereas in Sabah, the planted areas are 1.55 million hectares. Meanwhile in Peninsular Malaysia, the planted areas are 2.70 million hectares or 46.6% (MPOB, 2018).

Phosphorus(P) is one of the crucial elements in plant growth and plays vital roles in plant's energy transfer and storage, and also in the growth of roots during the establishment and early growth stages. It is a structural unit of nucleic acids, nucleotides and coenzymes. (Raghothama and Karthikeyan, 2005; Fita et al., 2011). Meanwhile, as compared to other plants, oil palm requires a high amount of nutrients especially macronutrients including P and this adequate supply of nutrients will ensure the optimum growth and yield of the oil palm (Behera et al., 2016).

However, low amount of P nutrient is recognized to be one of the leading limitations for crop production on a global scale, in particular tropical acid. As for the tropical soils, in Malaysia for instant, they are normally acidic and inherently low in available P, which can be a major factor in declining crop production (Chien, 1995; Chien and Menon, 1995). This is due to the presence of oxides and hydroxides of Fe and Al in the acid soils (Owen, 1953; Pusharajah et al., 1977; Kalpage and Wong, 1978; Zaharah, 1979).

The most common practice to overcome this problem is by supplying phosphate fertilizer in the form of soluble P fertilizers; superphosphate, triphosphate and diammonium phosphate. However, the practice of using these fertilizers has been limited (Menon and Chien, 1990; Komolafe, 1997). Nevertheless, one of cheaper sources of P for direct application in tropical soil is phosphate rocks (PRs). The principal mineral in most PR sources is apatite, but these PRs vary extensively in their physical, chemical and crystallographic properties (Chien et al., 2010). Gholizadeh et al (2009) stated that to avoid the cost of doing field trials for the purpose of determining the PRs reactivity, establishing the solubility of PR in citiric acid could be a best formula in predicting their reactivity.

Several studies have shown that the application of PR directly to the soils may be agronomically comparable to those phosphate fertilizers at the lower price and economically attractive substitute to the use of the more expensive soluble phosphate fertilizers (Khasawneh and Doll, 1978; Hammond et al., 1986; Chien et al., 1990; Chien and Friesen, 1992 Sale and Mokwunye, 1993). In Malaysia, due to this acid soil conditions, ground PR, especially PR has been widely and extensively used in plantation crops like oil palm and rubber since 1930's (Razman et al., 1999). Zin et al. (2001) also reported that direct application of PRs is very practical in correcting P deficiency in most Malaysian soil as Malaysian soil is highly weathered soil and inherently low in P. The use of ground PR also shows a positive result in liming as it has a high calcium content (Isenmila et al., 2006) and the residual effect of PR was found to be significant in acid soils for at least two to four years (Chan, 1981). Lee and Foong (2003) stated that in Malaysia, 30% of the total production cost of the fresh fruit bunches (FFBs) of oil palm is greatly attributed to the fertilizer cost. Thus, the use of appropriate fertilizer type and rate are crucial in maximizing FFB yields in order to reduce the fertilizer costs which further leads to economic benefits.

At present, a number of PR types have been used with different performance which will attribute to their reactivity. However, the reactivity of the current PRs used in the Malaysian agriculture are relatively low and this will eventually affect the performance of the plant. Morever, as PR is a finite resource and rapid rising demand of PR, several studies have cautioned that large phosphorus production could be reached (Déry and Anderson, 2007; Rosemarin et al.,2009; Cordell et al., 2009; Mórrígan, 2010; Mohr and Evans, 2013). Cordell et al. (2009) reported that world production could reach a maximum at an annual production of 203Mt of PR concentrate around the year 2033, which drive to a debate on whether a "peak phosphorus" was possible or not.

Hence, with a large reserve of Moroccan phosphate rock (MPR) in the market, it can be a good alternative to the previous phosphate rock. Therefore, this study aims to investigate the growth performance of different oil palm seedling genotypes with different types of MPR application. The specific objectives are:

1. To evaluate the release of P in acid soil after incubated with different types of MPR with time.

2. To evaluate the effect of different rates and types of PR application on N, P, K, Ca and Mg uptake by different oil palm seedlings genotypes.

3. To identify the organic acid exuded by roots of oil palm seedlings under P-stress condition

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APPENDICES

Appendix 1 :

The Release of P in Acid Soil After Incubated with Different Types of MPR With Time

Depending Variable : Bray II Extractable P

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Soil	1	22747.3563	22747.3563	11.60	0.0010
Type	3	15968.5041	5322.8347	2.71	0.0498
Time	7	123896.9778	17699.5683	9.02	<.0001
Rep	2	158.6459	79.3229	0.04	0.9604
Soil*Type	3	1630.7689	543.5896	0.28	0.8418
Soil*Time	7	38562.5502	5508.9357	2.81	0.0111
Type*Time	21	44296.2761	2109.3465	1.08	0.3893
Error	86	168699.2334	1961.6190		
Corrected Total	130	432494.4708			

Depending Variable : Munchong series soils

Source of variation	DF	Sum Square	Mean Square	F Value	Pr > F
Type	3	4613.6837	1537.8946	0.64	0.5963
Time	7	135855.9042	19407.9863	8.03	<.0001
Rep	2	2293.1333	1146.5667	0.47	0.6259
Type*time	21	44457.6371	2117.0303	0.88	0.6191
Error	39	94286.8665	2417.6120		
Corrected Total	72	289443.8445			

Depending Variable Bungor series soils

Source of variation	DF	Sum Square	Mean Square	F Value	Pr > F
Type	3	15248.35562	5082.78521	3.39	0.0344
Time	7	35914.33012	5130.61859	3.42	0.0111
Rep	2	8635.02865	4317.51433	2.88	0.0757

Source of variation	DF	Sum Square	Mean Square	F Value	Pr > F
Type*time	21	33739.25761	1606.63131	1.07	0.4319
Error	24	35980.0839	1499.1702		
Corrected Total	57	111692.3288			

Depending variable: Olsen's Extractable P

Source of variation	DF	Sum Square	Mean Square	F Value	Pr > F
Soil	1	339.797599	339.797599	34.22	<.0001
Type	3	71.720134	23.906711	2.41	0.0724
Time	7	3879.928607	554.275515	55.83	<.0001
Rep	2	30.778635	15.389317	1.55	0.2179
Soil*Type	3	73.304750	24.434917	2.46	0.0678
Soil*time	7	478.575250	68.367893	6.89	<.0001
Type*time	21	359.033125	17.096815	1.72	0.0417
Error	89	883.660664	9.928772		
Corrected Total	133	6435.433564			

Depending variable: Olsen Munchong soil series

Source of variation	DF	Sum Square	Mean Square	F Value	Pr > F
Type	3	1.810311	0.603437	0.12	0.9457
Time	7	1386.341843	198.048835	40.50	<.0001
Rep	2	25.305116	12.652558	2.59	0.0888
Type*time	21	148.870985	7.089095	1.45	0.1581
Error	37	180.928677	4.889964		
Corrected Total	70	1844.101505			

Depending Variable Bungor series soils

Source of variation	DF	Sum Square	Mean Square	F Value	Pr > F
Type	3	140.032789	46.677596	2.86	0.0543
time	7	2850.137432	407.162490	24.91	<.0001

Source of variation	DF	Sum Square	Mean Square	F Value	Pr > F
Rep	2	2.197607	1.098804	0.07	0.9351
Type*time	21	435.173225	20.722535	1.27	0.2728
Error	29	474.021326	16.345563		
Corrected Total	62	4233.999146			

Depending variable: pH

Source of variation	DF	Sum Square	Mean Square	F Value	Pr > F
Soil	1	21.73737426	21.73737426	821.94	<.0001
Time	7	1.93801463	0.27685923	10.47	<.0001
Type	3	0.08077194	0.02692398	1.02	0.3866
Rep	2	0.06251595	0.03125798	1.18	0.3096
Soil*time	7	0.77134243	0.11019178	4.17	0.0003
Soil*type	3	2.66381631	0.88793877	33.58	<.0001
Type*time	21	0.48669737	0.02317607	0.88	0.6213
Error	146	3.86115947	0.02644630		
Corrected Total	190	31.80874869			

Depending variable: pH Munchong soil series

Source of variation	DF	Sum Square	Mean Square	F Value	Pr > F
Time	7	1.89354370	0.27050624	17.06	<.0001
Type	3	0.87625329	0.29208443	18.42	<.0001
Rep	2	0.08751084	0.04375542	2.76	0.0712
Type*time	21	0.58073028	0.02765382	1.74	0.0478
Error	61	0.96720583	0.01585583		
Corrected Total	94	4.42717895			

Depending variable: pH Bungor soil series

Source of variation	DF	Sum Square	Mean Square	F Value	Pr > F
Time	7	0.75919063	0.10845580	3.56	0.0028
Type	3	1.83874479	0.61291493	20.11	<.0001
Rep	2	0.35970208	0.17985104	5.90	0.0045

Source of variation	DF	Sum Square	Mean Square	F Value	Pr > F
Type*time	21	0.52843021	0.02516334	0.83	0.6791
Error	62	1.88943125	0.03047470		
Corrected Total	95	5.37549896			

SOIL	TRMT	TIME (week)							
		1	3	5	7	9	11	13	15
		Mean							
Munchong	MPR A	50.300±21.489 ab	99.271 ± 27.266	83.347 ± 6.292	122.688 ± 14.193	168.422 ± 30.096	228.667 ± 19.104	96.103 ± 10.545	178.301±14.717
	MPR B	38.901 ± 16.796b	72.850 ± 8.816	123.390±29.661	140.251 ± 53.986	206.277 ± 76.353	231.123 ± 12.157	116.578±21.874	208.039 ± 4.160
	MPR C	77.909±46.097 ab	107.583±15.114	96.695 ± 8.390	122.688 ± 0.000	122.500 ± 31.594	134.105 ± 6.947	122.912±97.601	246.275±138.648
	EPR	88.596 ± 24.938a	241.170±158.694	92.740 ± 25.226	100.108 ± 46.127	200.691±102.850	116.912 ± 57.915	68.704 ± 15.917	173.072 ± 51.181
Bungor	MPR A	106.764 ± 6.802	122.723±23.930 ab	145.636±48.240	105.125±3.548	109.468±23.695	119.369 ±59.050	69.293 ± 26.249	110.981 ± 11.092
	MPR B	50.850±0.000	88.881 ± 26.449b	170.848±71.310	167.850±53.223	168.422±37.666	116.913±118.100	59.571 ± 25.448	140.392 ± 30.628
	MPR C	95.542 ± 122.421	155.675 ± 78.088a	123.390±92.283	126.870±106.692	75.958±13.164	134.105±99.800	52.205 ± 29.104	130.588 ± 52.210
	EPR	41.573 ± 34.005	123.614±95.720 ab	126.356±67.116	100.108±102.897	74.096±26.328	57.965 ± 24.315	56.035 ± 34.673	112.287 ± 14.453

The result of Bray II Extractable P on Munchong and Bungor series soils.

** Values followed by a different letter (ab) in a column indicate that means are significantly different between different types of phosphate rock within each week while values without letter indicate that means are not significantly different ($P<0.05$). Data are mean ± standard deviation

SOIL	TRMT	TIME (week)							
		1	3	5	7	9	11	13	15
		Mean							
Munchong	MPR A	13.393±1.274b	7.073±0.773	5.962±1.049a	13.935±3.954	15.177±0.502	13.935±0.304	16.336±0.951	16.000±0.951
	MPR B	17.598±0.425a	5.675±4.214	4.528±0.453b	11.713±1.082	16.596±4.513	13.720±3.041	11.630±1.426	19.193±1.188
	MPR C	13.694±0.601b	4.612±2.191	4.7754237b	13.935±3.346	16.596±6.519	12.215±3.954	18.185±2.139	19.697±2.329
	EPR	17.598±0.425a	5.706±3.223	5.072±0.210a	9.993±0.993	16.478±0.819	13.075±0.912	14.992±2.852	18.185±0.238
Bungor	MPR A	13.393±6.370	4.339±0.000	6.852±0.629ba	15.226±2.129	19.078±0.000	15.871±1.825	21.378±1.426	22.387±2.377b
	MPR B	13.093±5.496	4.977±3.738	9.225±0.629a	9.634±0.304	32.908±5.516	22.108±3.346	21.546±1.188	30.286±2.139a
	MPR C	11.592±6.370	9.078±0.516	7.297±0.000ba	15.441±6.083	17.660±5.015	20.602±10.949	24.740±5.229	28.101±0.475 a
	EPR	10.390±4.672	5.341±2.965	4.775±1.049b	10.495±3.954	24.752±3.009	17.807±2.129	19.361±2.852	20.538±1.664 b

The result of Olsen's Extractable P on Munchong and Bungor series soils.

** Values followed by a different letter (ab) in a column indicate that means are significantly different between different types of phospahte rock within each week while values without letter indicate that means are not significantly different ($P<0.05$). Data are mean ± standard deviation.

SOIL	TRMT	TIME (week)							
		1	3	5	7	9	11	13	15
		Mean							
Munchong	MPR A	5.95±0.133	5.80±0.283	5.83±0.091	5.74±0.189	6.10±0.075	6.01±0.091	6.07±0.195	6.31±0.181
	MPR B	5.89±0.025	6.15±0.185	5.85±0.036	5.96±0.020	6.11±0.113	6.17±0.062	6.06±0.100	6.41±0.091
	MPR C	6.12±0.156	6.24±0.297	6.09±0.049	6.14±0.076	6.36±0.178	6.30±0.031	6.17±0.166	6.39±0.110
	EPR	6.08±0.040	6.11±0.105	6.10±0.038	5.86±0.093	6.51±0.012	6.32±0.035	6.25±0.040	6.34±0.125
Bungor	MPR A	5.76±0.099	5.79±0.165	5.59±0.233	5.30±0.397	5.72±0.226	5.75±0.236	5.76±0.113	5.56±0.218
	MPR B	5.40±0.250	5.61±0.147	5.56±0.132	5.29±0.036	5.48±0.081	5.52±0.121	5.50±0.055	5.47±0.081
	MPR C	5.18±0.440	5.29±0.074	5.35±0.228	5.06±0.101	5.46±0.078	5.29±0.049	5.37±0.212	5.40±0.061
	EPR	5.22±0.456	5.40±0.062	5.46±0.110	5.29±0.070	5.43±0.149	5.24±0.055	5.38±0.026	5.33±0.017

The result of soil pH on Munchong and Bungor series soils.

** Values followed by a different letter (ab) in a column indicate that means are significantly different between different types of phospahte rock within each week while values without letter indicate that means are not significantly different ($P<0.05$). Data are mean ± standard deviation.

Appendix 2.

The Effect of Different Rates and Types of PRs application on N, P, K, Ca and Mg Uptake by Different Oil Palm Genotypes

Effect of Different Rate of PR Application on Dry weight

Source of variation	DF	Sum Square	Mean Square	F Value	Pr > F
Gen	1	1682.8989	1682.8989	0.42	0.5224
Rate	4	197840.4276	49460.1069	12.22	<.0001
Block	3	52707.9090	17569.3030	4.34	0.0092
Gen*Rate	4	58577.3407	14644.3352	3.62	0.0124
Gen*Block	3	12158.6194	4052.8731	1.00	0.4011
Rate*Block	12	83463.3996	6955.2833	1.72	0.0953
Error	44	178055.1075	4046.7070		
Corrected Total	71	558410.6400			

Effect of Different Rate of PR Application on N uptake

Source of variation	DF	Sum Square	Mean Square	F Value	Pr > F
Gen	1	0.4520172	0.4520172	0.19	0.6672
Rate	4	165.4020037	41.3505009	17.14	<.0001
Block	3	22.0347299	7.3449100	3.04	0.0386
Gen*Rate	4	6.8874422	1.7218605	0.71	0.5870
Gen*Block	3	1.9313911	0.6437970	0.27	0.8489
Rate*Block	12	40.7340963	3.3945080	1.41	0.1990
Error	44	106.1430559	2.4123422		
Corrected Total	71	333.0835403			

Effect of Different Rate of PR Application on P uptake

Source of variation	DF	Sum Square	Mean Square	F Value	Pr > F
Gen	1	0.05236180	0.05236180	1.45	0.2349
Rate	4	2.61845509	0.65461377	18.13	<.0001
Block	3	0.22085831	0.07361944	2.04	0.1222

Source of variation	DF	Sum Square	Mean Square	F Value	Pr > F
Gen*rate	4	0.27662940	0.06915735	1.92	0.1247
Gen*block	3	0.21709240	0.07236413	2.00	0.1272
Rate*block	12	0.48141985	0.04011832	1.11	0.3756
Error	44	1.58845878	0.03610134		
Corrected Total	71	5.56535699			

Effect of Different Rate of PR Application on K uptake

Source of variation	DF	Sum Square	Mean Square	F Value	Pr > F
Gen	1	0.1788013	0.1788013	0.06	0.8046
Rate	4	165.1071073	41.2767768	14.30	<.0001
Block	3	56.0515544	18.6838515	6.47	0.0010
Gen*rate	4	25.9470194	6.4867548	2.25	0.0793
Gen*block	3	1.8658319	0.6219440	0.22	0.8852
Rate*block	12	62.9037291	5.2419774	1.82	0.0751
Error	44	127.0202041	2.8868228		
Corrected Total	71	424.5060079			

Effect of Different Rate of PR Application on Ca uptake

Source of variation	DF	Sum Square	Mean Square	F Value	Pr > F
Gen	1	0.00515074	0.00515074	1.89	0.1767
Rate	4	0.11570556	0.02892639	10.59	<.0001
Block	3	0.01273648	0.00424549	1.55	0.2141
Gen*rate	4	0.03552679	0.00888170	3.25	0.0202
Gen*block	3	0.00992640	0.00330880	1.21	0.3169
Rate*block	12	0.03442104	0.00286842	1.05	0.4234
Error	44	0.12022532	0.00273239		
Corrected Total	71	0.33998799			

Effect of Different Rate of PR Application on Mg uptake

Source of variation	DF	Sum Square	Mean Square	F Value	Pr > F

Source of variation	DF	Sum Square	Mean Square	F Value	Pr > F
Gen	1	0.00120790	0.00120790	0.05	0.8167
Rate	4	0.67966913	0.16991728	7.65	<.0001
Block	3	0.16097563	0.05365854	2.42	0.0790
Gen*rate	4	0.21592934	0.05398233	2.43	0.0616
Gen*block	3	0.06000991	0.02000330	0.90	0.4484
Rate*block	12	0.28237927	0.02353161	1.06	0.4153
Error	44	0.97692154	0.02220276		
Corrected Total	71	2.31984832			

Effect of Different Rate of PR Application on Bole Diameter

Source of variation	DF	Sum Square	Mean Square	F Value	Pr > F
Gen	1	1.8956601	1.8956601	0.48	0.4906
Rate	4	169.9667826	42.4916956	10.84	<.0001
Block	3	17.5128559	5.8376186	1.49	0.2313
Gen*rate	4	59.4633292	14.8658323	3.79	0.0101
Gen*block	3	35.8359124	11.9453041	3.05	0.0390
Rate*block	12	119.8089158	9.9840763	2.55	0.0126
Error	42	164.6307543	3.9197799		
Corrected Total	69	558.3184286			

Effect of Different Rate of PR Application on SPAD Meter

Source of variation	DF	Sum Square	Mean Square	F Value	Pr > F
Gen	1	82.0125000	82.0125000	1.79	0.1862
Rate	4	352.2117500	88.0529375	1.93	0.1199
Block	3	153.5580000	51.1860000	1.12	0.3496
Gen*rate	4	130.8587500	32.7146875	0.72	0.5850
Gen*block	3	57.8695000	19.2898333	0.42	0.7380
Rate*block	12	298.0232500	24.8352708	0.54	0.8759
Error	52	2376.944250	45.710466		
Corrected Total	79	3451.478000			

Effect of Different Rate of PR Application on Plant Height

Source of variation	DF	Sum Square	Mean Square	F Value	Pr > F
Gen	1	427.812500	427.812500	3.03	0.0878
Rate	4	8685.050000	2171.262500	15.36	<.0001
Block	3	889.437500	296.479167	2.10	0.1118
Gen*rate	4	2009.000000	502.250000	3.55	0.0123
Rate*block	12	2442.750000	203.562500	1.44	0.1783
Gen*block	3	95.737500	31.912500	0.23	0.8781
Error	52	7350.70000	141.35962		
Corrected Total	79	21900.48750			

Effect of Different Type of PR on Dry Weight

Source of variation	DF	Sum Square	Mean Square	F Value	Pr > F
Gen	1	7409.0091	7409.0091	1.80	0.1896
Type	4	409417.9581	102354.4895	24.92	<.0001
Block	3	72006.5840	24002.1947	5.84	0.0030
Gen*type	4	45553.9892	11388.4973	2.77	0.0458
Gen*block	3	35798.7969	11932.9323	2.91	0.0515
Type*block	12	141389.8488	11782.4874	2.87	0.0100
Error	29	119100.8277	4106.9251		
Corrected Total	56	820329.1932			

Effect of Different Type of PR on N uptake

Source of variation	DF	Sum Square	Mean Square	F Value	Pr > F
Gen	1	0.02075229	0.02075229	0.02	0.8876
Type	4	13.77807078	3.44451769	3.38	0.0224
Block	3	13.60063426	4.53354475	4.45	0.0112
Gen*type	4	3.75008443	0.93752111	0.92	0.4663
Type*Block	12	24.16203969	2.01350331	1.98	0.0676
Gen*Block	3	7.53679394	2.51226465	2.46	0.0830
Error	28	28.54085430	1.01931623		
Corrected Total	55	81.56601555			

Effect of Different Type of PR on P uptake

Source of variation	DF	Sum Square	Mean Square	F Value	Pr > F
Gen	1	0.01849200	0.01849200	1.19	0.2849
Type	4	1.55749747	0.38937437	25.03	<.0001
Block	3	0.10191501	0.03397167	2.18	0.1122
Gen*type	4	0.10331685	0.02582921	1.66	0.1872
Type*block	12	0.31243949	0.02603662	1.67	0.1276
Gen*block	3	0.14303756	0.04767919	3.06	0.0443
Error	28	0.43565351	0.01555905		
Corrected Total	55	2.72885855			

Effect of Different Type of PR on K uptake

Source of variation	DF	Sum Square	Mean Square	F Value	Pr > F
Gen	1	3.3684677	3.3684677	1.11	0.3007
Type	4	261.3354949	65.3338737	21.54	<.0001
Block	3	43.0126416	14.3375472	4.73	0.0084
Gen*type	4	24.3437467	6.0859367	2.01	0.1199
Type*block	12	71.9446882	5.9953907	1.98	0.0658
Gen*block	3	12.2238564	4.0746188	1.34	0.2796
Error	29	87.9624500	3.0331879		
Corrected Total	56	511.0248820			

Effect of Different Type of PR on Ca uptake

Source of variation	DF	Sum Square	Mean Square	F Value	Pr > F
Gen	1	0.00436273	0.00436273	9.93	0.0053
Type	4	0.01889089	0.00472272	10.75	0.0001
Block	3	0.00115791	0.00038597	0.88	0.4699
Gen*type	4	0.04864985	0.01216246	27.67	<.0001
Type*block	12	0.00817115	0.00068093	1.55	0.1905
Gen*block	3	0.00024654	0.00008218	0.19	0.9039

Source of variation	DF	Sum Square	Mean Square	F Value	Pr > F
Error	19	0.00835028	0.00043949		
Corrected Total	46	0.11467664			

Effect of Different Type of PR on Mg uptake

Source of variation	DF	Sum Square	Mean Square	F Value	Pr > F
Gen	1	0.06060898	0.06060898	2.29	0.1407
Type	4	1.79082521	0.44770630	16.94	<.0001
Block	3	0.25853149	0.08617716	3.26	0.0356
Gen*type	4	0.29596215	0.07399054	2.80	0.0443
Type*block	12	0.76322427	0.06360202	2.41	0.0262
Gen*block	3	0.28858762	0.09619587	3.64	0.0242
Error	29	0.76634255	0.02642561		
Corrected Total	56	3.89281456			

Effect of Different Type of PR on Plant Height

Source of variation	DF	Sum Square	Mean Square	F Value	Pr > F
Gen	1	742.51875	742.51875	3.91	0.0536
Type	4	16992.58661	4248.14665	22.36	<.0001
Block	3	2031.07508	677.02503	3.56	0.0205
Gen*type	4	2049.62946	512.40737	2.70	0.0412
Gen*block	3	605.42708	201.80903	1.06	0.3736
Type*block	12	2302.64375	191.88698	1.01	0.4543
Error	50	9501.15625	190.02313		
Corrected Total	77	33969.29487			

Effect of Different Type of PR on Bole Diameter

Source of variation	DF	Sum Square	Mean Square	F Value	Pr > F
Gen	1	10.7551814	10.7551814	1.97	0.1665
Type	4	439.5892204	109.8973051	20.15	<.0001
Block	3	14.2247314	4.7415771	0.87	0.4633
Gen*type	4	88.6034079	22.1508520	4.06	0.0064

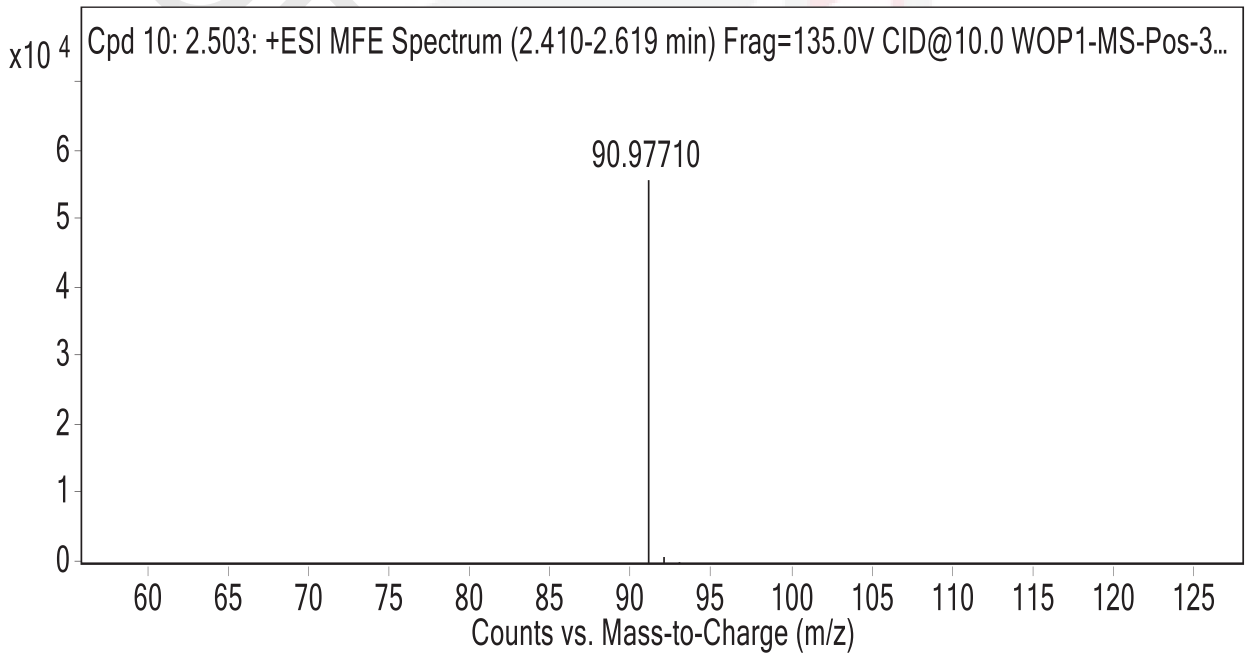
Source of variation	DF	Sum Square	Mean Square	F Value	Pr > F
Gen*block	3	11.2254079	3.7418026	0.69	0.5648
Type*block	12	208.7462126	17.3955177	3.19	0.0020
Error	49	267.205842	5.453180		
Corrected Total	76	1028.292208			

Effect of Different Type of PR on SPAD Meter

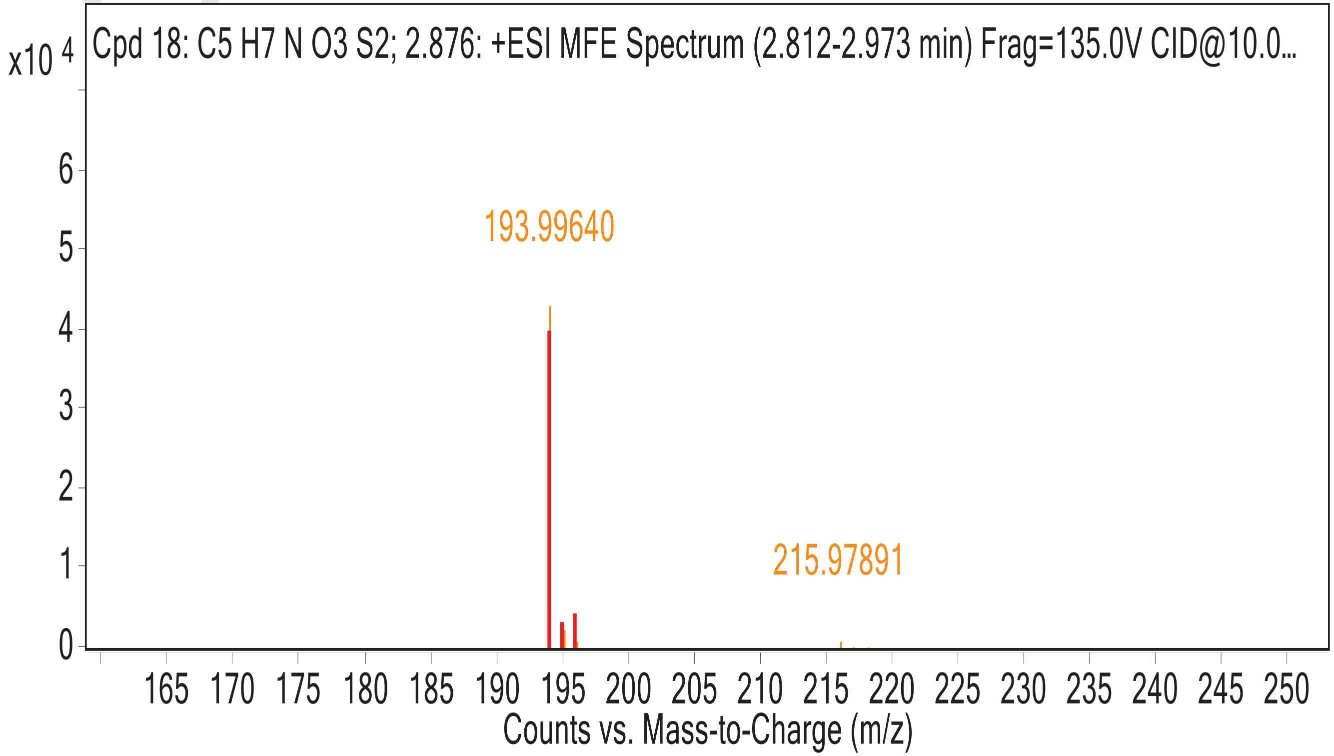
Source of variation	DF	Sum Square	Mean Square	F Value	Pr > F
Gen	1	73.3445000	73.3445000	1.79	0.1872
Type	4	327.2892500	81.8223125	1.99	0.1093
Block	3	189.2710000	63.0903333	1.54	0.2161
Gen*type	4	98.1617500	24.5404375	0.60	0.6660
Gen*block	3	205.9945000	68.6648333	1.67	0.1844
Type*block	12	277.5527500	23.1293958	0.56	0.8611
Error	52	2135.424250	41.065851		
Corrected Total	79	3307.038000			

Appendix 3.

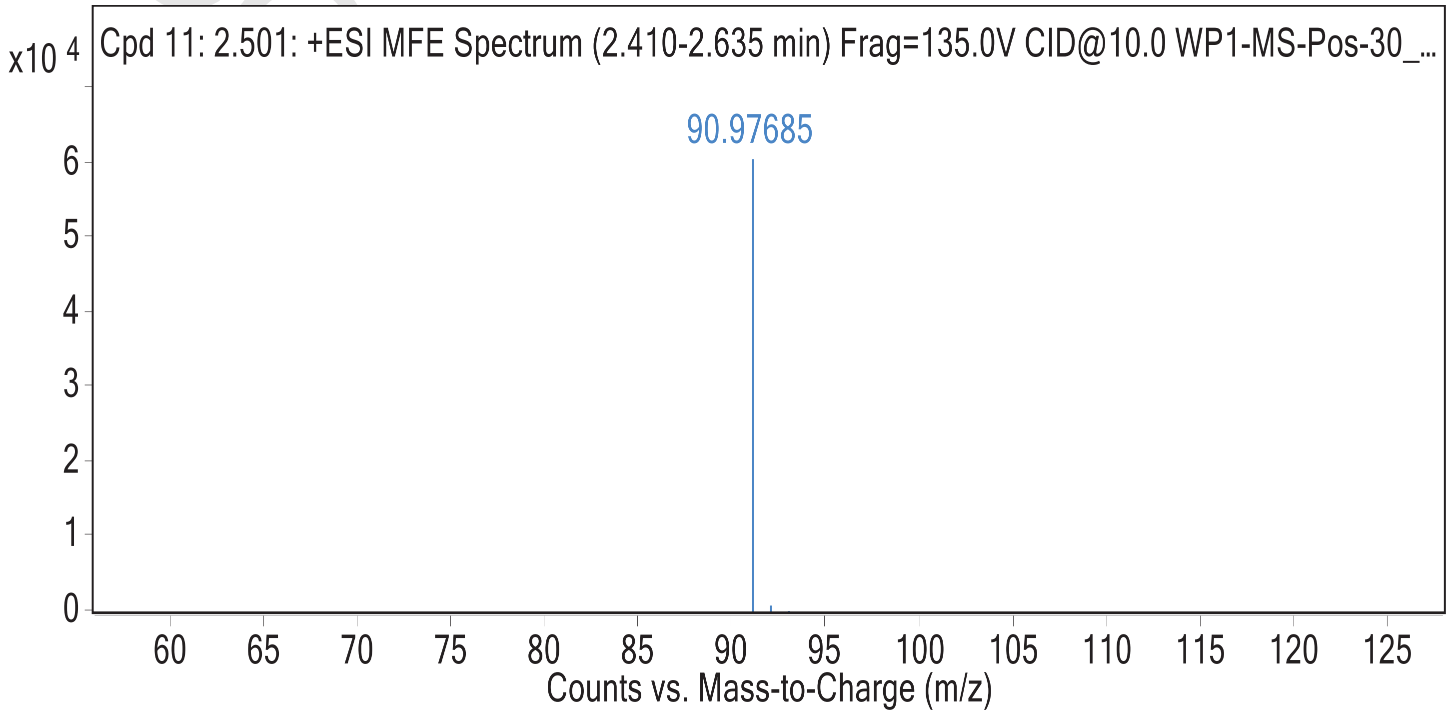
The Extraction and Identification of Organic Acid Exuded by Oil Palm Seedlings under P-Stress Condition.



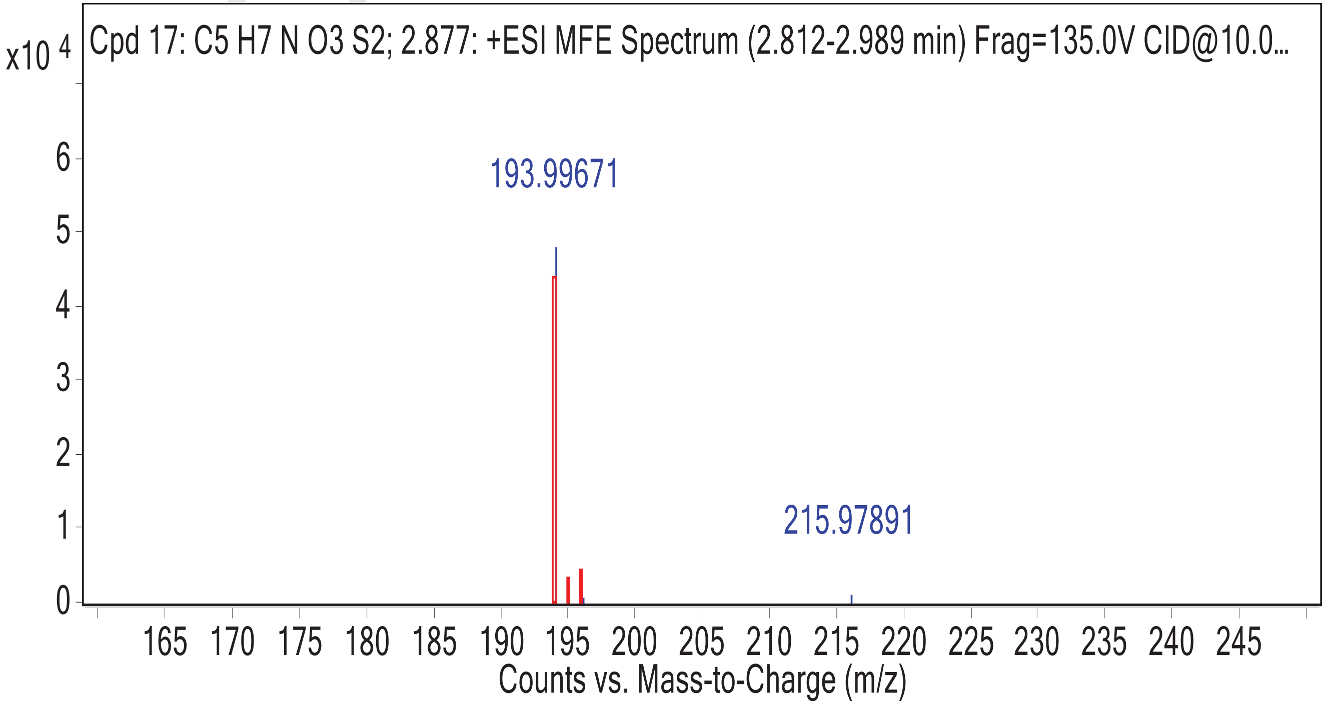
The detection of oxalate in sample with no presence of P.



The detection of citrate in sample with no presence of P.



The detection of oxalate in sample with the presence of P.



The detection of oxalate in sample with the presence of P

BIODATA OF STUDENT

Norakmal Binti Khairuanuar was born on 1st of March 1992 in Kuantan, Pahang. She began her primary school in Sekolah Kebangsaan Felda Neram 1 in 1999. Later she extended her secondary education in Sekolah Menegah Kebangsaan Lembah Bidong (LeBEST) in 2005 and completed her SPM in 2009. She furthered her study in Foundation of Agricultural Science for one year at Universiti Putra Malaysia and continued with her Bachelor Degree in Agricultural Science. She obtained her Bachelor Degree in 2015 and straighforward enrolled to her Master Degree study majors in Soil Science at Department of Land Management, Faculty of Agriculture, UPM with the scholarships from MyMaster by Kementerian Pelajaran Malaysia (KPM). During her study period, she has participated as poster presenter in 10th International Symposium on Plant-Soil Interactions at Low pH (25-28 June 2018).

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