

## **Soil nutrient changes in Ultisols under oil palm in Johor, Malaysia** *Patrick Hong Chuan Ng\*, Huang Huang Gan, Kah Joo Goh\**

### **Abstract**

Soil pH, organic C and total N decreased with time in the oil palm agro-ecosystem. However, the decline in soil pH was slight whereas those related to organic C and total N corresponded to the period when the oil palm biomass was burnt or partially burnt at replanting. The large increases in soil organic C obtained with the zero burn replanting technique were favorable. There were large positive changes in soil P and exchangeable K, which might be attributed to the applications of higher rates of phosphate rocks and K fertilizers especially from the 1990s following the results of fertilizer response trials. Exchangeable Mg were lower in burn or partial burn areas but were higher in zero burn areas. This study shows that the soil fertility status of the Ultisols under oil palm in Johor has been enhanced through current fertilizer management practices and zero burn replanting technique.

### **Keywords**

Soil nutrient changes, oil palm, sustainability, zero burn, fertilizer use  
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### **1. Introduction**

The oil palm requires large amounts of nutrients to sustain its growth and production so that high yield levels of 30 tons/ha/yr<sup>1</sup> or more can be achieved and maintained. This is mainly due to the low soil fertility in most Malaysian soils<sup>2</sup>, particularly the Ultisols of Johor<sup>3</sup>. High fertilizer rates are also essential to prevent soil nutrient in balance and in many instances, to build-up the soil fertility so as to ensure that sufficient nutrients are present in the soil solution for maximum uptake by the roots<sup>4</sup>.

Traditionally, soil samples are taken on a regular basis for nutrient analysis and are commonly used in the diagnosis of fertilizer

requirements in oil palms, monitoring soil fertility and ensuring that fertilizers recommended have been applied. Thus, large long-term data on soil nutrients are available for most big plantations. Despite this, changes in soil nutrients under oil palm as influenced by agro-management practices have not been reported. This is particularly important as the issues of soil nutrient changes have since gone beyond their traditional uses and are, nowadays, frequently regarded as one of the most important measures of sustainability and impact on the environment. Tinker<sup>5</sup> pointed out that for an agriculture crop to be sustainable; one of the criteria should include preserving the resource base on which it rests upon whereas Hartemink<sup>6</sup> has also argued that a drop in world food production might be attributed to the decline of soil nutrients. Soil nutrient changes with regards to the impact on the environment would normally be scrutinized from the point of land degradation and potential pollution, which should be avoided in order to be sustainable.

This paper studied the soil nutrient changes of pH, organic carbon, total nitrogen, total and Bray-2 phosphate as well as exchangeable potassium and magnesium in different micro-sites (palm circles and inter-rows) and different soil depths in oil palm plantations. The effects of time and different replanting practices on soil nutrient changes were also studied.

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Address: Advanced Agriecological Research Sdn. Bhd.  
Locked Bag 212 Sg. Buloh Post Office, 47000 Sg. Buloh,  
Selangor Darul Ehsan, Malaysia

Email: Patrick Hong Chuan Ng ([patrickng@aarsb.com.my](mailto:patrickng@aarsb.com.my))  
Huang Huang Gan ([ganhh@aarsb.com.my](mailto:ganhh@aarsb.com.my))  
Kah Joo Goh ([gohki@aarsb.com.my](mailto:gohki@aarsb.com.my))  
\*Corresponding Author

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## 2. Materials and Methods

The data used in this paper were extracted from long-term soil analysis results of samples collected from 21 estates from 1967 to 2000. These estates were located from northern to southern Johor (Figure 1). They covered over 37,000 ha, of which data from approximately 13,000 ha were used. Only analysis data of Ultisols from Johor were reported in this paper and they encompassed 26 soil series, which were mostly developed over igneous rocks, sedimentary rocks and riverine alluvium. Examples of soils in the study area included Rengam series (deep coarse sandy clay soil derived from granite), Bungor series (deep fine sandy clay soil derived from sandstone/shale) and Holyrood series (deep coarse sandy clay loam soil derived from sub-recent alluvium).

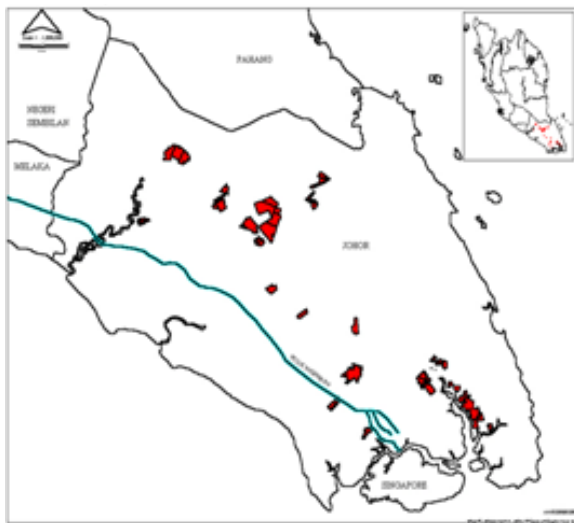


Figure 1- Location of estates in study area

### 2.1 Sampling method

Thirty six soil sampling sites were randomly located in a representative area of each field. At each sampling site, soil samples were collected from two micro-sites of palm circles (PC) and inter-rows (IR) using a 2.5 cm diameter screw auger. At each micro-site, soil samples from two depths of 0 – 15 cm and 15 – 45 cm were extracted. This gave four distinct soil samples (two micro-sites x two depths) for each field, which were each bulked from the soil samples taken from the 36 sampling sites.

### 2.2 Chemical analysis

Each soil sample was analyzed for some or all of the soil chemical properties listed in Table 1. We also restricted the data set to soil samples

where they were collected and analyzed at the same time for two different soil depths and/or sites in each field. Thus, the numbers of samples available were variable for the soil chemical properties (Table 1).

Soil pH was determined in the supernatant suspension of 1:2.5 soil:water. Organic carbon was analysed by the Walkley-Black procedure while total N was extracted using micro-Kjeldahl method. Total P was extracted using 6M HCl whereas available P followed Bray No. 2 procedure. Exchangeable K, Mg and Ca were extracted by leaching the soil sample with 1 M ammonium acetate solution at pH 7.0. K was then determined using flame photometer while Mg and Ca were determined using atomic absorption spectrophotometer. Details of the above analytical methods can be found in Moris and Mohinder<sup>7</sup>.

### 2.3 Soil nutrient changes

Quantifying the rates of change in soil chemical properties is necessary to evaluate if soil fertility decline has occurred. In this paper, the rate of change was calculated for each soil chemical property as follows:

$$\Delta = \left( \frac{x_2 - x_1}{x_1} \right) \times 100\%$$

Where  $\Delta$  = the rate of change in %  
 $x_1$  = the initial value of the variable at sampling time  $t_1$   
 $x_2$  = the final value of the variable at sampling time  $t_2$

The soil samples where  $x_1$  and  $x_2$  were determined came from the same field. The period between the soil samplings ( $t_2 - t_1$ ) varied from 1 to 13 years.

### 2.4 Statistical analysis

The mean, median, minimum, maximum, standard deviation, standard error of mean were calculated to examine the means and distributions of the initial value ( $x_1$ ) and change (%) for each soil chemical property. Since the rate of change (%) for each soil chemical property was not normally distributed, non-parametric statistics and median were used to analyze the data. Wilcoxon's signed rank test<sup>8</sup> was used to investigate the differences in the rate of change (%) of each soil chemical property between the two sites of IR and PC, and between the two soil depths (0-15 cm and 15-45 cm)

**Table 1- Number of soil samples analyzed for each soil chemical property**

Soil chemical properties	Number of soil samples analyzed				
	IR		PC		Total
	0-15 cm	15-45 cm	0-15 cm	15-45 cm	
pH	372	372	372	372	1488
Organic C (%)	599	599	-	-	1198
Total N (%)	599	599	-	-	1198
Total P (mg/kg)	263	263	263	263	1052
Bray-2 P (mg/kg)	400	400	400	400	1600
Exch. K (cmol/kg)	412	412	412	412	1648
Exch. Mg (cmol/kg)	376	376	376	376	1504

In the Wilcoxon's signed rank test, the sample size (Table 2) did not equal to half the number of soil samples collected (Table 1). This was because in calculating the rate of change (%), we took two soil samples ( $x_1$  and  $x_2$ ) that were collected from the same field but at different sampling periods ( $t_1$  and  $t_2$ ). This implied that if a field was sampled twice at two different sampling periods, then the sample size equaled to one. On the other hand, if a field was sampled three times, then the sample size equaled to three, i.e. the rates of change (%) were calculated from  $x_1$  and  $x_2$ ,  $x_2$  and  $x_3$  as well as  $x_1$  and  $x_3$ . The same applies for other soil samples taken at different periods from the same fields i.e. four sampling periods would yield a sample size of four.

### 3. Results and discussion

The changes to pH, organic C, total N, total P, Bray-2 P, exchangeable K and exchangeable Mg were discussed from the following aspects:

- Site: The different sites where sampling was carried out i.e. in IR and PC
- Depth: Comparison of rates of change in soil nutrients between the two depths i.e. 0- 15 cm and 15 – 45 cm
- Initial value: The initial value,  $x_1$
- Time / period: The soil sampling data were grouped into 3 main periods i.e. 1982 and earlier (coinciding with burning as the main land clearing method), 1983 to 1994 (where partial burning was generally carried out) and post 1994 (where zero burning was the main land clearing method).

#### 3.1 Site, depth and initial value

Table 2 summarizes the sample size for the data used as well as the median initial value of

each parameter for both sites (IR and PC) and depths (0 – 15 cm and 15 – 45 cm) while Table 3 summarizes the % change of each parameter. The sample size for each parameter was different as explained in section 2.2. The initial values (Table 2) obtained were generally within the range of common Ultisols of Johor.

##### 3.1.1 Soil pH

Most crops grow best within a certain soil pH range as soil acidity affects plant growth in many ways. The oil palm is tolerant to high acidity and is able to grow well under a broad range of soil pH from 4.0 to 5.5<sup>4</sup>. Hyperacidity symptoms can be observed when soil pH is below 3.5 as the low pH is deleterious to normal root growth and function<sup>9</sup>.

In general, there was a slight decline in soil pH of less than 3.2 % for both micro-sites and depths (Table 3). The declines in soil pH might be mainly attributed to nitrification process. Therefore, N sources from applied fertilizers, organic manure and legumes containing or forming  $\text{NH}_4^+$  increases soil acidity.

The change in soil pH (Table 3) was more pronounced in the IR (pH lower by 3.2%) compared with the PC and this could have been attributed to the higher initial value of pH in the IR (Table 2), which was more susceptible to change due to the sigmoidal pH buffering curve. Moreover, the lower amount of exchangeable bases in the IR (Table 2) would reduce its buffering capacity against the  $\text{H}^+$  produced from the nitrification process resulting in a larger decline in soil pH.

The lower initial value of pH in the PC (pH = 4.26) could be due to the prolonged concentrated application of N fertilizers in its limited space compared with the IR<sup>10</sup>. Most experimental evidence also supports the view

**Table 2-Sample size and median initial value of each soil chemical parameter**

Parameter / Variable	Median of initial value for each parameter at 2 sites and 2 depths					
	Site			Depth		
	n*	IR	PC	n*	0-15 cm	15-45 cm
pH	472	4.48	4.26	472	4.45	4.30
Organic C (%)	-	-	-	390	1.30	0.92
Total N (%)	-	-	-	390	0.120	0.090
Total P (mg/kg)	320	146.5	216.0	320	212.5	151.1
Bray-2 P (mg/kg)	520	11.6	35.8	520	27.7	15.5
Exch. K (cmol/kg)	538	0.140	0.240	538	0.190	0.170
Exch. Mg (cmol/kg)	478	0.200	0.220	478	0.240	0.179

\* n = sample size

**Table 3 - % change for each soil chemical parameter based on its median**

Parameter / Variable	Median of % change for each parameter at 2 sites and 2 depths					
	Site			Depth		
	IR	P. Circle	p-value	0-15 cm	15-45 cm	p-value
pH	-3.20	-1.97	0.0097 **	-2.48	-2.60	0.0000 **
Organic C (%)	-	-	-	-9.69	-15.76	0.0001 **
Total N (%)	-	-	-	-6.72	-12.50	0.0001 **
Total P (mg/kg)	0.8	-3.9	0.3575 ns	1.9	-4.5	0.0000 **
Bray-2 P (mg/kg)	16.0	-9.5	0.0000 **	6.7	-7.4	0.0000 **
Exch. K (cmol/kg)	15.3	0	0.0031 **	5.1	7.6	0.6643 ns
Exch. Mg (cmol/kg)	-18.5	-3.3	0.1112 ns	-5.9	-18.6	0.0022 **

that the electrical potential gradient maintained by the  $H^+$  efflux pump provides the driving force for active uptake of  $K^+$  across the plasma membrane<sup>11</sup>. Therefore, with more rooting activity for K uptake in the PC<sup>10</sup>, higher extrusion of  $H^+$  would occur resulting in low soil pH. The same would also be expected to occur with  $Ca^{2+}$  and  $Mg^{2+}$  uptake. The  $NO_3^-$  is also leachable to lower depths along with the basic ions of  $K^+$ ,  $Ca^{2+}$  and  $Mg^{2+}$ . As these bases were removed and replaced by more  $H^+$ , soils at lower depths (2<sup>nd</sup> depth of 15 – 45 cm) became slightly more acidic, which was evident from the results in Table 3.

This acidifying effect has also been reported in established oil palm plantations<sup>12</sup>, whereby fertilizer applications have been carried out as a routine. From our data, the magnitude of decline in pH also appeared to be larger with a longer lag time in sampling (Figures 2 and 3) i.e. % drop in pH greater when the two samples were taken at longer intervals. Kee *et al.*<sup>10</sup> showed that the surface soil pH after 7 years of applying fertilizers at the highest rate within a circle of about 2 m radius around the palm base on Musang series soil (Typic Paleudult) declined markedly to 3.8 compared with control plots when pH dropped to 4.2, a drop of almost 10%. A decline of about 3% is obtained with the results from this study. The drop in pH although noted, was generally small

and probably negligible to the oil palm, which is tolerant to such conditions.

Nevertheless, soil pH should be prevented from going lower as it is usually used as a criterion of land degradation. Some measures to minimize the reduction of soil pH include the following:

- Broadcasting of fertilizers instead of applying them in a band or concentrating them only to the PC
- Use of ammonium nitrate or urea will have lower acidifying effect. However, urea application should be restricted to clayey soils and properly timed to reduce volatilization losses
- Use of ammonium nitrate should be avoided on sandy soils due to its higher leaching potential
- Application of alkaline fertilizers e.g. magnesium carbonate and empty fruit bunches
- Maintain proper water-table over acid sulphate layers in acid sulphate soils to prevent or reduce the oxidation of sulphite that results in sulphuric acid build-up

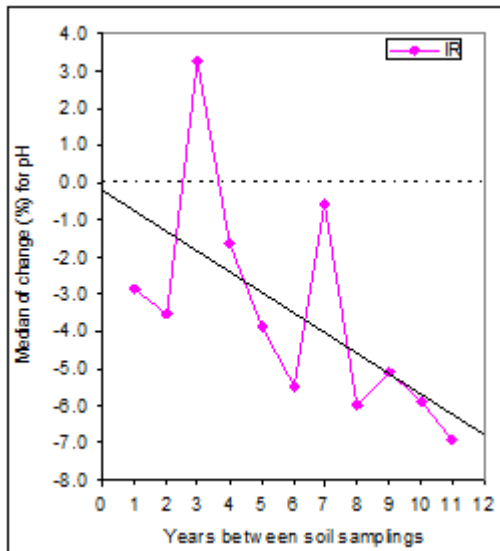


Figure 2- % change in soil pH for IR

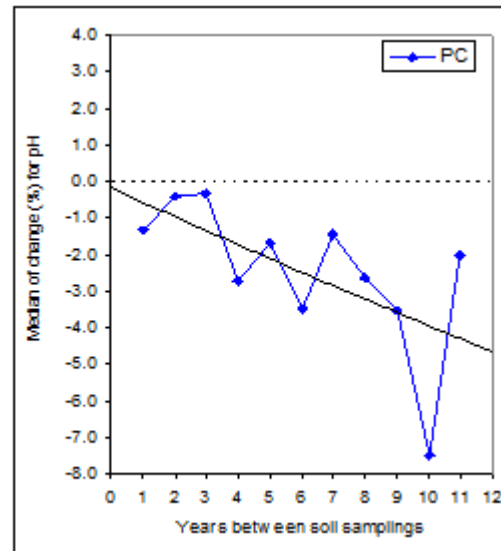


Figure 3- % change in soil pH for PC

### 3.1.2 Soil organic carbon

Managing the soil organic carbon (organic C) would go hand in hand with the management of soil organic matter (SOM) and in oil palm plantations, soil fertility is mainly determined by the management of SOM including soil biological activity, soil nutrient management etc.. Soil fertility management, on the other hand, is a keystone of sustainable agriculture. As the oil palm plantations have many sources of SOM, most of them are produced daily by the living oil palm itself such as pruned fronds, male inflorescences, shed leaf bases and roots as well as palm bio-products of empty fruit bunches (EFB), palm oil mill effluent (POME), decanter sludge, shell and fibre, natural vegetation and legumes. Efficient management of SOM and the soil organic C would then ensure soil fertility, hence sustainability.

Soil organic C decreased in the sampled micro-sites with a larger decrease of soil organic C at 15-45 cm; 15.76% at this depth versus 9.69% at 0-15cm depth (Table 3). Although this decrease in soil organic C was substantial, it was localized to only the palm circles and the sampled inter rows and may not represent a decline in organic carbon on an agro-ecosystem basis (the sampled micro-sites did not include the pruned frond avenues where substantial amount of the organic carbon are recycled) as exemplified by a simplified oil palm "Carbon Cycle" (Table 4). The carbon supply from the oil palm ecosystem in Table 4 was computed from data of pruned fronds only without considering the following where data are unavailable:

- a) How much is lost as CO<sub>2</sub>
- b) How much is the net return from other palm organic sources e.g. palm bio-products (EFB, POME etc.), male inflorescence, frond buds and root turnover
- c) How much is the contribution of ground vegetation

The 9.7 % and 15.8% reduction in organic C resulted in a total of 710 kg/ha/yr loss in organic C. Nevertheless, annually more than 4,000 kg/ha (Table 4) of carbon can be potentially replenished by the palm's pruned fronds alone. However, no data is currently available to determine the conversion efficiency of pruned fronds to organic C in oil palm agro-ecosystem in the long term.

Chew and Pushparajah<sup>12</sup> reported that organic C increase was not noted in oil palm plantations due mainly to the uneven redistribution of recycled fronds. In general, the IR, where soil sampling is carried out are kept relatively free of pruned fronds and hence no addition of organic matter to this micro-site would occur except from the low density of light vegetation kept by cultural practices, if any. Therefore, the practice of stacking pruned fronds in neat, narrow rows should probably be changed to wider placement covering as much of the IR as possible in view of the above findings. Establishing vigorous shade tolerant perennial leguminous cover crops such as *Mucuna bracteata* may offer another option to build up the SOM<sup>13</sup>.

**Table 4-Simplified oil palm “Carbon Cycle”**

	Particulars	Value	
Carbon supply from Palm	Dry weight of pruned fronds (t/ha/yr) <sup>1</sup>	8.5	
	Total carbon content from pruned fronds (kg/ha/yr) assuming 50% carbon content of dry weight	4,250	
Carbon loss from soil		Depth	
		0 – 15 cm	15 – 45 cm
	Initial value of organic C (%) from Table 2	1.30	0.92
	% Change (from Table 3)	9.69	15.76
	% Loss	0.12597	0.14499
	Total weight of soil (kg), assuming soil bulk density of 1.1 and 1.25 g cm <sup>-3</sup> respectively	1,650,000	3,750,000
	Organic C loss from soil (kg)	2,076	5,437
	Organic C loss from soil (kg/ha) assuming IR makes up 51% of surface area	1,060	2,773
Total organic C loss from soil (kg/ha) for both depths	3,833		
Total organic C loss from soil (kg/ha/yr) for both depths with weighted age of 5.4 years <sup>2</sup>	710		

Source 1: Henson <sup>14</sup>

Note 2: Weighted age from data of Table 3

### 3.1.3 Total N

The Ultisols in Johor have low total N contents with a median value of 0.12 % in the top soil and 0.09 % in the lower depth (Table 2). Total N decreases in both soil depths in tandem with their soil organic C. This implies that most of the total N in the soils is in the organic form. The declines in total N contents contradicted the work of Chew and Pushparajah <sup>12</sup> and Ling *et al.* <sup>15</sup> who reported a lack of changes in soil N under oil palm cultivation.

The drop in total N in the first soil depth was not as accentuated as the second depth (Table 3). This might be ascribed to the higher rooting activity and root turn-over of oil palm in the upper soil depth, which may contribute substantially to the organic C balance <sup>14</sup>. Similarly, the higher biological activity of the top-soil and potential addition of organic matter from the oil palm such as pruned fronds, EFB, POME, and the leguminous cover crops during the palm’s immaturity phase might have mitigated the decrease in soil organic C in the first depth and therefore, total N content (Table 3). Nonetheless, the approaches to enhance SOM as suggested earlier are also appropriate to sustain total N content of the soils.

### 3.1.4 Total and Bray-2 P

The Ultisols in Johor are also generally marginal in P status (Table 2). Phosphate

rocks have been used to supplement the P requirement of the oil palm and positive P responses have been obtained <sup>16</sup>. Despite the regular applications of phosphate rocks in the oil palm estates, total P and Bray-2 P posted increases in the IR only with slight declines in the PC (Table 3). This might be attributed to the policy of applying phosphate rocks in the inter-rows of mature palms and to the legumes in immature palms. Similar observations were reported by Hartemink <sup>6</sup> who detected much higher soil P levels in soils under perennial crops compared with natural forest and Ling *et al.* <sup>15</sup> who found a build-up of P even when the fields were burned for planting. The higher increase in Bray-2 P compared with total P following phosphate rock applications corresponded well to the findings of Zaharah <sup>17</sup>.

Build-up of both total and Bray-2P were also noted in the upper layer due to surface applications of P fertilizers, the low dissolution of phosphate rocks and slow migration of dissolved P into the lower soil depth due to P fixation or adsorption by sesquioxides. Thus, most of the dissolved P accumulated in the top 30 cm of tropical soils <sup>17</sup>.

### 3.1.5 Exchangeable K and Mg

Most Ultisols also have low exchangeable cations of K and Mg and those in Johor are no exception (Table 2). Even if complete recycling of EFB and POME produced from the FFB

yield is to be carried out, the nutrients required by the palms for high yield levels are still higher than the nutrient supply from the oil palm agro-ecosystem<sup>1</sup>. Therefore, they need to be augmented by inorganic fertilizers to maintain the yield levels.

The application of inorganic K fertilizers has resulted in positive changes to exchangeable K in the IR and in both soil depths (Table 3). Similar findings have been reported by Ling *et al.*<sup>15</sup> who found a slight increase in exchangeable K. Kee *et al.*<sup>10</sup>, also noted a four-fold increase in exchangeable K, which was evident up to a depth of 60 cm. The build-up of exchangeable K in the IR compared with the PC (Table 3) could be due to the applications of K fertilizers in the former micro-site for mature palms in particular with the wider use of fertilizer spreaders. In addition, pruned fronds and EFB, both containing high amounts of K are also normally applied in the IR.

Exchangeable Mg was noted to decrease for both micro-sites and depths (Table 3) due mainly to the generally high rates of  $\text{NH}_4^+$  fertilizer and KCl fertilizer used; the  $\text{NH}_4^+$  and

$\text{K}^+$  cations are known to cause the soil Mg to leach down due to the ionic exchange between the above cations at the soil complex<sup>10</sup>. The magnitude of drop in exchangeable Mg in the PC, although not statistically significant, was lower compared with the IR. This might be ascribed to the practice of regularly applying Mg fertilizer, Kieserite, in the former micro-site. The negative soil Mg balance should be arrested with closer monitoring of the soil Mg status and the applications of ground magnesium limestone and/or kieserite when the situation warrants it.

### 3.2 Time / Period

The data were also summarized to coincide approximately with the 3 different practices of land preparation for oil palm planting i.e. burning, which was generally the case in 1982 and earlier, partial burning (1983 to 1993) and the zero burn technique<sup>18;19</sup> which is the most common method from 1994 onwards. Only the burnt and zero burnt periods will be discussed in order to avoid complication in the interpretation of the partial burnt period which might include some fields that were fully burnt while others were zero burnt.

**Table 5-Percentage change for each soil chemical parameter for different periods**

Parameter / Variable		Change (%) of each parameter at 2 sites and 2 depths during burnt, partial burnt and zero burnt period*			
		Site		Depth	
		IR	P. Circle	0-15 cm	15-45 cm
pH	Burnt	-3.49	-2.35	-2.41	-3.21
	Partial Burnt	-3.63	-1.04	-1.61	-2.49
	Zero Burnt	-1.75	-2.24	-2.95	-1.59
Organic C (%)	Burnt	-9.63	-	-5.49	-11.67
	Partial Burnt	-18.97	-	-12.43	-24.57
	Zero Burnt	7.77	-	1.87	15.56
Total N (%)	Burnt	-2.38	-	-1.63	-3.88
	Partial Burnt	-14.31	-	-8.08	-19.35
	Zero Burnt	7.03	-	0.00	14.29
Total P (mg/kg)	Burnt	-14.37	-6.72	-6.10	-16.94
	Partial Burnt	9.37	0.00	17.88	-3.28
	Zero Burnt	31.04	-4.26	-12.47	7.80
Bray-2 P (mg/kg)	Burnt	-4.37	-20.82	-3.45	-17.71
	Partial Burnt	30.07	-1.67	20.27	-2.30
	Zero Burnt	38.42	0.89	12.00	72.04
Exch. K (cmol/kg)	Burnt	18.99	0.00	9.72	13.25
	Partial Burnt	8.33	-5.90	0.00	-2.94
	Zero Burnt	1.09	27.71	5.89	9.17
Exch. Mg (cmol/kg)	Burnt	-23.30	8.25	0.00	-16.25
	Partial Burnt	-26.12	-30.71	-26.42	-31.58
	Zero Burnt	58.46	22.79	23.33	58.46

Note\* values quoted are median values

Burning of the organic palm biomass at replanting had little effect on the long term soil pH (Table 5) although short term increase in soil pH had been reported<sup>15</sup> which was attributed to the release of exchangeable bases in the ash. These two results probably indicated that the ash effect on soil pH was temporary and easily nullified by the applications of acidifying fertilizers to the palms.

With the zero burn technique, soil organic C was higher in the IR and in both depths (Table 5). Variable results have been reported. Sly and Tinker<sup>20</sup> found that slight depression of organic C would be obtained if burning was carried out during land clearing. Similarly, Ling *et al.*<sup>15</sup> reported reduction of soil organic C by burning in a jungle clearing although slight increase in the top-soil organic C was noted twelve months after the land clearing. Khalid *et al.*<sup>21</sup> also found that different replanting policies of partial burning, stacking and pulverizing resulted in varied increases in soil organic C with the latter two methods yielding the highest increases.

In general all the major soil nutrients of total N, total P, Bray-2 P and exchangeable Mg increased during the zero burnt periods. Soil exchangeable K, on the other hand, were higher when burning was carried out. This was agreeable with the observations made by Sly and Tinker<sup>20</sup> that burning depressed nitrogen and decreased soil magnesium and calcium but gave larger exchangeable K. The increase in total N during the zero burnt period corresponded with the build up in soil organic C, which implied a large return of N from the previous palm biomass. On the other hand, the large positive changes in Bray 2-P and exchangeable K in the PC could be attributed to the increased P and K fertilizer rates applied to the palms following the higher yield responses to these nutrients<sup>22</sup>. The build up of soil exchangeable Mg with zero burn replanting technique will require further work to ascertain.

### 3.3 Extreme soil nutrient changes

Although the median values of soil nutrient changes in the Ultisols under oil palm in Johor

were favourable in the light of sustainability, land degradation and the environment, there were extreme values for all the soil chemical properties (Appendices 1-4). These extreme values (which could have coefficient of variation up to 900%) could be outliers due to sampling or analytical errors but, nevertheless, it is still prudent to scrutinize them because excessive soil nutrient depletion (negative values) and build-up (positive values) are both detrimental to the oil palm agro-ecosystem. Long term nutrient depletion is known to cause yield declines in many agricultural crops<sup>6</sup> whereas excessive build up of N and P can cause ground water pollution and eutrophication, respectively. In general, the data showed that build up of soil nutrients including Total P, Bray-2 P and exchangeable K and Mg are generally dominant compared with soil nutrient depletion in the Ultisols under oil palm in Johor.

## 4. Conclusions

This study indicates that soil pH, organic C and total N decreased with time in the oil palm agro-ecosystem. However, the decline in soil pH was slight whereas the degree of organic C and total N changes corresponded to whether the oil palm biomass was burnt or partially burnt at replanting. The large increases in soil organic C as a result of carrying out the zero burn replanting technique were favourable.

There were large positive changes in soil P and exchangeable K, which might be attributed to the applications of higher rates of phosphate rocks and K fertilizers especially from the 1990s and onwards. However, excessive build up of soil nutrients on the highly weathered tropical soils of Ultisols should be avoided due to their generally low nutrient holding capacities, which may increase the risk of pollution. On the other hand, nutrient depletion should also be prevented as they, commonly, lead to lower production in the long term. Thus, close monitoring of the changes in soil nutrients in the oil palm estates is essential.

This study shows that the soil fertility status of the Ultisols under oil palm in Johor was enhanced through the use of sound fertilizer

management practices and zero burn replanting technique.

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**Appendix 1:** Descriptive statistics for the initial values ( $x_i$ ) of soil chemical properties at two sites

Soil chemical Properties	Site	No. of paired samples	Mean	Median	Min.	Max.	SD	SE of mean
pH	IR	472	4.50	4.48	3.38	5.84	0.34	0.02
	PC	472	4.29	4.26	3.49	5.80	0.33	0.02
Organic C (%)	IR/PC	-						
Total N (%)	IR/PC	-						
Total P (mg/kg)	IR	320	171.45	146.47	42.00	617.93	91.71	5.13
	PC	320	254.82	216.00	41.86	995.00	144.65	8.09
Bray-2 P (mg/kg)	IR	520	18.47	11.55	1.30	108.30	18.95	0.83
	PC	520	44.74	35.80	2.10	149.80	35.53	1.56
Exch. K (cmol/kg)	IR	538	0.17	0.14	0.04	0.96	0.12	0.01
	PC	538	0.29	0.24	0.03	1.71	0.20	0.01
Exch. Mg (cmol/kg)	IR	478	0.25	0.20	0.02	1.45	0.21	0.01
	PC	478	0.29	0.22	0.03	1.99	0.24	0.01

Note: IR denotes Inter-row; PC denotes Palm Circles

**Appendix 2:** Descriptive statistics for the initial values ( $x_i$ ) of soil chemical properties at two depths

Soil chemical properties	Depth (cm)	No. of paired samples	Mean	Median	Min.	Max.	SD	SE of mean
pH	0-15	472	4.48	4.45	3.53	5.80	0.37	0.02
	15-45	472	4.32	4.30	3.38	5.84	0.31	0.01
Organic C (%)	0-15	390	1.34	1.30	0.36	3.50	0.46	0.02
	15-45	390	0.97	0.92	0.31	2.39	0.37	0.02
Total N (%)	0-15	390	0.12	0.12	0.04	0.24	0.04	0.00
	15-45	390	0.09	0.09	0.03	0.19	0.03	0.00
Total P (mg/kg)	0-15	320	252.77	212.50	45.10	995.00	146.66	8.20
	15-45	320	173.50	151.07	41.86	563.00	90.34	5.05
Bray-2 P (mg/kg)	0-15	520	38.19	27.65	1.80	148.50	33.83	1.48
	15-45	520	25.02	15.45	1.30	149.80	27.12	1.19
Exch. K (cmol/kg)	0-15	538	0.25	0.19	0.04	1.40	0.18	0.01
	15-45	538	0.22	0.17	0.03	1.71	0.17	0.01
Exch. Mg (cmol/kg)	0-15	478	0.32	0.24	0.02	1.99	0.26	0.01
	15-45	478	0.22	0.18	0.02	1.06	0.17	0.01

**Appendix 3:** Descriptive statistics for the rates of change (%) of soil chemical properties at two sites

Soil chemical properties	Site	No. of paired samples	Mean	Median	Min.	Max.	SD	SE of mean
pH	IR	472	-2.50	-3.20	-29.35	35.95	10.68	0.49
	PC	472	-1.27	-1.97	-27.24	35.44	9.52	0.44
Organic C (%)	IR/PC	-						
Total N (%)	IR/PC	-						
Total P (mg/kg)	IR	320	18.5	0.8	-83.1	402.2	78.2	4.4
	PC	320	12.8	-3.9	-84.2	254.5	65.4	3.7
Bray-2 P (mg/kg)	IR	520	113.6	16.0	-98.0	1594.8	251.8	11.0
	PC	520	62.2	-9.5	-370.1	2336.4	236.4	10.4
Exch. K (cmol/kg)	IR	538	51.4	15.3	-90.5	863.0	133.8	5.8
	PC	538	27.6	0.0	-93.5	588.9	98.8	4.3
Exch. Mg (cmol/kg)	IR	478	29.3	-18.5	-94.1	1020.0	131.6	6.0
	PC	478	43.8	-3.3	-90.7	942.9	147.1	6.7

**Appendix 4:** Descriptive statistics for the rates of change (%) of soil chemical properties at two depths

Soil chemical Properties	Depth (cm)	No. of paired samples	Mean	Median	Min.	Max.	SD	SE of mean
pH	0-15	472	-1.24	-2.48	-29.35	35.95	10.81	0.50
	15-45	472	-2.53	-2.60	-27.40	32.03	9.36	0.43
Organic C (%)	0-15	390	-4.88	-9.69	-61.67	151.56	32.33	1.64
	15-45	390	-9.17	-15.76	-76.00	134.69	35.09	1.78
Total N (%)	0-15	390	0.90	-6.72	-64.71	183.33	36.77	1.86
	15-45	390	-3.93	-12.50	-66.67	200.00	37.20	1.88
Total P (mg/kg)	0-15	320	24.3	1.9	-73.4	402.2	79.0	4.4
	15-45	320	7.0	-4.5	-84.2	303.8	63.5	3.5
Bray-2 P (mg/kg)	0-15	520	112.4	6.7	-97.4	2336.4	279.3	12.2
	15-45	520	63.4	-7.4	-370.1	1423.5	203.5	8.9
Exch. K (cmol/kg)	0-15	538	40.8	5.1	-91.2	863.0	124.7	5.4
	15-45	538	38.3	7.6	-93.5	575.0	111.3	4.8
Exch. Mg (cmol/kg)	0-15	478	44.6	-5.9	-93.1	942.9	149.1	6.8
	15-45	478	28.4	-18.6	-94.1	1020.0	129.2	5.9