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SOIL NUTRIENT DYNAMICS AND PALM GROWTH PERFORMANCE IN RELATION TO RESIDUE MANAGEMENT PRACTICES FOLLOWING REPLANTING OF OIL PALM PLANTATIONS

Keywords: Nutrient dynamics, residue management, oil palm residue, oil palm replanting, zero burning.

KHALID, H*; ZIN, Z Z* and ANDERSON, J M**

* Malaysian Palm Oil Board, P.O. Box 10620, 50720 Kuala Lumpur, Malaysia.

** Department of Biological Sciences, University of Exeter, U.K.

The policy of zero burning practices for replanting of oil palm plantations is currently considered desirable since it avoids air and water pollution and may also enable the development of more economically sustainable practices based on nutrient supply from organic matter management. Under the standard zero burning practices, young palms are planted between widely-spaced windrows of residues from the old stands. This practice maximizes the spatial and temporal uncoupling between the release of nutrients from the decomposing residues and plant uptake. An improved understanding of the spatial and temporal patterns of nutrient release and plant uptake will enable better management of the synchrony between these processes and greater conservation of nutrients. Studies were carried out on the establishment and growth of young palms planted into the palm residues which were chopped, shredded or pulverized without additional inputs of inorganic fertilizer. The preliminary results of palm responses to the techniques established were impressive as a consequence of improving nutrient synchrony and the beneficial effects of organic mulching on soil properties to crop production. It is concluded that these methods of planting and residue management improved the spatial integration of nutrient release and uptake by the rooting systems of young palms. The supply of nutrient requirement that is partly provided by the recycling of biomass can reduce the use of inorganic ferti-

lizers to optimize growth rates of the immature palms. Savings in fertilizers resulting from these practices could reduce the production costs as well as contributing towards environmental conservation.

INTRODUCTION

Replanting of oil palm is normally carried out after about 25-30 years due to harvesting problem and other economic considerations. Under zero burning practices, a large residual biomass from the previous stand is present on site at the time of replanting (Khalid Haron *et al.*, 1996). The main utilizable components of oil palm biomass are the trunk and fronds which can be recycled in the field as organic matter or removed and converted to value-added products. Removal of oil palm biomass has implications for plantation management in terms of nutrients and organic matter to maintain soil fertility. Using oil palm residues to provide plant nutrients for succeeding oil palm crops is not a new practice, but its potential and management to maximize its utilization has not been fully explored. Appropriate management of this biomass following felling may enable the carry over of its nutrient content to support the growth of the following rotation. This could provide a significant supplement, particularly for N and K, for the high external inputs of fertilizers required to maintain maximum yield potential.

Under the zero burning practices, young palms are planted between the widely-spaced windrows of residues from the old plantation. This practice maximizes the spatial and temporal uncoupling between the release of nutrients from the decomposing residues and plant uptake. To improve efficiency of nutrient utilization, better synchronization is required between nutrient release and plant growth requirements (Swift, 1984). In the case of oil palm ecosystem, this spatial integration can only be achieved by planting new palms onto the rows of trunk and fronds residues following felling of the old stands.

Experiments were set up to study whether planting the young palms directly into the residue piles would improve their growth and nutrient uptake without inorganic fertilizer applications. The objectives of the study were to investigate nutrient transfer from residues to the palms and to compare changes in soil properties and nutrient dynamics after a mature oil palm plantation had been cleared and the land subjected to different management of crop residue practices. The hypothesis is that different residue treatments will vary in their effects on the properties and processes in soils and hence on the growth performance of palms. The four residue treatments, as management option, adopted and evaluated using standard growth assessments in relation to the carry over of nutrients and availability to the young palms were complete removal (C/R), chipping and shredding (C/S), chipping and pulverization (C/P) and partial burning (P/B). This paper describes the relationships between soil properties, standard growth assessments and four residue management options used for replanting under zero burning practices.

MATERIALS AND METHODS

The trial was established in June 1994 at the PORIM Research Station, Kluang, Johor (latitude 1° 57' N, longitude 103° 22' E) situated in a region of fairly typical agroecological conditions in inland West Malaysia. The soil was a reddish-yellow sandy clay developed from granite and classified as an Ultisol of the Rengam series (Typic Paleudult). The experimental plots described in this study were set up following felling of a 23-year-old oil palm plantation of first rotation with the palms planted at a density of 136 ha^{-1}. Normal fertilizer applications had ceased one year before felling. The old stand was felled using an excavator fitted with a chipping bucket. The treatments were established immediately after felling and clearing, in line with standard practices.

Treatments and Experimental Design

Four experimental treatments of residue management, namely, C/R, C/S, C/P and P/B were established. The treatments replicated four times consisted a total of 16 plots laid out in a randomized complete block design (RCBD). Each plot consisted of 4 x 5 palms of 0.15 ha.

The treatments established were as follows:

- C/R: the trunks of palms were cut into several pieces 1-2 m in length without chipping. The cut trunks together with fronds and other palm components were loaded onto a lorry and removed from the plot. This treatment was to study the residual effect of fertilizer inputs received by the previous crop one year before felling and nutrient release from the decomposed root biomass and legume ground covers. Also the treatment served as standard control zero burning plots in which no residues were placed close to the newly planted palms.

- C/S: the palm trunks with fronds were chipped and shredded to pieces of about 10 cm thick across at 45°-60° angle. For this treatment, during C/S, the operator needed to clear or vacate an area of about 1.5 m^2 in between old stand points for the new planting points where the chipped and shredded materials were spread evenly at about 3-4 m wide to avoid thick pile formation.

- C/P: the palm trunks with fronds were chipped and shredded and spread out as in the C/S treatment. However, after one week, these residues were pulverized into smaller pieces using a pulverizer machine mounted on a 120 hp tractor.

- P/B: P/B of chipped and shredded materials was conducted early August 1994 one month after felling. The unburnt materials, which mainly consisted of about 50% of the chipped trunks, were left to decompose in the field.

Legume covers were sown after all the residue treatments had been completed and about one week after the partial burning. At the same time, lining for the new planting points were surveyed. The base line of felled old stands was used for reference and new planting points were marked in old planting rows between felled old stands. Commercial DxP 12-month-old seedlings were planted out in late August 1994 using 8.8 x 8.8 x 8.8 m triangular spacing. No fertilizers were applied during the experimental period except for an initial treatment of 250 g of phosphate rock in each planting hole at the time of transplanting. In normal estate practice, inorganic fertilizers are applied at six months and 12 months after field planting but were omitted in this study in order to enable nutrient transfers from residues to palms to be studied.

Soil Analyses

Soil samples were collected, using a screw auger, for two depths of 0-15 cm and 15-30 cm at two-monthly intervals. For each plot, 10 to 15 cores were taken at random inside the planting rows, the old avenue (O/A) and old frond piles (O/FP) and each set of subsamples bulked into a composite sample for each plot (weighing approximately 2 kg). The soil samples were air dried, sieved and the 2 mm fraction retained for analysis. In addition to soil samples, the surface organic matter in the mulched areas was also sampled for analysis at 12- and 18-month intervals after the treatments were established. The samples were sieved and the 2 mm fraction air dried.

Total soil N, total soil P, available P and exchangeable K, Ca and Mg were determined on the air dried soil samples.

Soil pH was determined [1:2.5 soil:water (w/v)] using an Orion combination pH electrode with the soil suspensions left overnight before the readings were made.

The cation exchange capacity (CEC) was determined by leaching with ammonium acetate.

Soil moisture was determined gravimetrically at two-monthly intervals during the experimental period. Soil samples were collected using a screw auger to the depths of 0 to 15 cm and 15 to 30 cm. The samples were weighed to obtain the fresh weight and then oven dried at 105°C for 24 hr. Soil moisture content was calculated as a percentage of soil dry weight.

Leaf Assays and Growth Measurements

Leaf sampling of frond 3 at 12 months and frond 9 at 18 months of age of the young palms following standard procedure were carried out after field planting in all treatment plots. Concentrations of leaf N, P, K, Ca and Mg were determined at each sampling.

Standard methods to estimate various growth parameters by non-destructive measurements, developed by Hardon *et al.* (1969) and Corley *et al.* (1971), were used for growth measurements. Measurements made on the young palms at 12 and 18 months after field planting were frond length, frond dry weight, leaf area of frond 3 at 12 months and frond 9 at 18 months respectively. The height of frond 1 from ground level was also determined. Trunk diameter was only measured at 18 months after field planting. Flower census was conducted at 12 and 18 months after field planting.

RESULTS AND DISCUSSION

Soil Nutrient Dynamics

The changes in soil chemical properties and nutrient dynamics over 18 months for the treatments, plot locations and soil depths are presented in this paper. The total N, total P, available P, exchangeable K, Ca, and Mg in the 0 to 15 cm and 15 to 30 cm soil depths are compared among treatments and locations over time. The characteristics of soils in the experimental plots were compared with those of other Rengam series soils and other inland soils in Malaysia commonly used for planting oil palm ut still under natural vegetation.

Soil nutrient concentrations in the plots with-ut residues treatment (C/R, O/A and O/FP) ere within the range of most common inland oils for total N, total P, available P, and exchang-able K but higher for Ca. The high concentra-on of Ca was probably a consequence of accu-ulation of residual Ca from applications the ck phosphate over 23 years in a mature plan-tion. For the plots with residue treatments /S, P/B and C/P), the concentrations of all nut-nts were higher indicating that significant ntribution of nutrients from the crop residue.

Data for all nutrients analyses taken at two monthly intervals showed that data in month 12 were much higher than the values for the other sampling periods up to month 18. This result can be explained in terms of the nutrient dynamics which may have been associated with rapid mineralization under moist conditions. At that time, the soils were exceptionally wet. On this sampling occasion which was carried out during wet period, surface organic matter, with high nutrient concentrations, tended to adhere to the screw auger and may have contributed nutrients to the small mass of the mineral soil samples. However over the 18 months, the trends in nutrient availability were picked out without much difficulty.

Total Nitrogen

The initial levels of total N in the soil were higher (0.19%) in the old frond piles than in the O/A (0.15%) at 0-15 cm soil depth as shown in *Table 1*. The initial levels of total N at 15-30 cm soil depth were only slightly lower than the top 0-15 cm and were similar for all treatments and locations (0.14%-0.15%). Total N in the soil at 0-15 cm soil depth gradually increased in all treatments after six months but with the lowest values in the O/A location and C/R treatment where there were no organic inputs to soils. The levels of total N in the C/S, C/P, P/B treatments and O/FP location (0.18%, 0.19%, 0.20% and 0.20% respectively) were significantly higher ($P < 0.05$) than the O/A location (0.15%) but not the C/R treatment (0.17%). The trend was observed to be quite similar at 15-30 cm soil depth except that no appreciable increase was observed in the C/R treatment and O/A location. The peak values for total N at 0-15 cm soil depth were recorded at 12 months in all treatments with the highest values of 0.28% in the C/S and C/P treatments compared with 0.18% in the O/A location. Similarly, at 15-30 cm soil depth, the C/S and C/P treatments had values of 0.24% and 0.25% respectively compared with 0.15% in the O/A location. The levels of total N in the C/S and C/P treatments at both soil depths were significantly higher ($P < 0.05$) than other treatments and locations. The peak values for total N at 12 months coincided with the highest mineralization rates measured for that

TABLE 1. CHANGES IN TOTAL NITROGEN (%) IN SOIL AT 0-15 cm AND 15-30 cm DEPTHS WITH TIME IN RELATION TO DIFFERENT TREATMENTS AND LOCATIONS

Treatment		C/R	C/S	P/B	C/P	O/A	O/FP	LSD (0.05)
Month	Depth (cm)			Total soil nitrogen (%)				
0	0-15	0.15	0.15	0.15	0.15	0.15	0.19	-
	15-30	0.14	0.14	0.14	0.14	0.14	0.15	-
2	0-15	0.18	0.18	0.18	0.17	0.13	0.18	0.0247
	15-30	0.15	0.14	0.15	0.15	0.12	0.16	0.0211
4	0-15	0.16	0.18	0.21	0.18	0.14	0.22	0.0303
	15-30	0.15	0.15	0.18	0.15	0.13	0.17	0.0281
6	0-15	0.17	0.18	0.20	0.19	0.15	0.20	0.0333
	15-30	0.13	0.17	0.18	0.16	0.14	0.17	0.0283
8	0-15	0.18	0.20	0.18	0.17	0.15	0.19	0.0164
	15-30	0.14	0.16	0.15	0.14	0.14	0.17	0.0223
10	0-15	0.18	0.20	0.20	0.20	0.15	0.20	0.0295
	15-30	0.17	0.19	0.17	0.17	0.14	0.17	0.0209
12	0-15	0.20	0.28	0.22	0.28	0.18	0.21	0.0413
	15-30	0.19	0.24	0.19	0.25	0.15	0.19	0.0378
14	0-15	0.18	0.20	0.19	0.22	0.18	0.20	0.0139
	15-30	0.17	0.19	0.18	0.19	0.17	0.18	ns
16	0-15	0.17	0.22	0.19	0.20	0.17	0.21	0.0204
	15-30	0.15	0.19	0.18	0.18	0.14	0.17	0.0245
18	0-15	0.18	0.22	0.20	0.21	0.18	0.20	0.0226
	15-30	0.17	0.19	0.18	0.19	0.17	0.18	0.0198

Note: Figures are means of four replicates.

month (which has been studied separately). Even at 18 months, the C/S and C/P treatments still give the highest value among other treatments although the levels were decreased significantly. The levels of soil N in the C/S and C/P treatments at 0-15 cm soil depth were significantly higher ($P < 0.05$) than the C/R treatment and O/A location but there were no significant differences at 15-30 cm.

Over the period of 18 months, the total soil N concentration increased by about 30% in the C/S, C/P, P/B treatments and O/FP. Only a slightly smaller increase (c.20%) was observed in the C/R treatment and O/A which received no above-ground organic matter inputs. This suggests that most of the changes observed in total N were derived from decomposing root material which would initially have been excluded from the 2 mm sieve fraction. Hence, it would appear that the surface residues had little effect on organic N pools in mineral soil during the study period. The increase in total N over 18 months was paralleled by an increase in N mineralization rates for all treatments and locations. The differences in N mineralization between treatments did not, however, reflect the magnitude of residue inputs above-ground. This is probably because these materials largely decomposed on the soil surface and relatively small amounts of soluble and particulate organic matter leached into the mineral soil. Transfers of mineral N to the soil from above-ground, conversely, would not be detected by the mineralization assays. The supply of mineral N to plants may well include ammonium (and possibly nitrate) released from the mineralization of above-ground residues and leached into soil. This would not be enough to affect the total soil N pool but could be important for the mineral N supply to plants.

Total Phosphorus

The phosphorus status of major soil groups in Malaysia has been extensively surveyed by Ng and Law (1971) and Goh *et al.* (1993) using measurements of total P and available P. Total P in some Malaysian soils from orders such as Oxisols, Ultisols and Alfisols may vary between 224-427 mg kg^{-1} in the A-horizon to less than 200 mg kg^{-1} in the B-horizon (Goh *et al.,* 1993). These results are also typical for the soil orders in other tropical regions (Sanchez, 1976).

At the initial sampling, the levels of total P in the soil were lower in the old frond piles than other treatments and locations at both soil depths (*Table 2*). Significant increases in total P were observed in the P/B treatment at both soil depths four months after treatments establishment. At four months, total P in the P/B treatment increased to maximum levels with a value of 526 µg g^{-1} at 0-15 cm depth and 371 µg g^{-1} at 15-30 cm depth. Total P value in the P/B treatment was significantly higher ($P < 0.05$) than

TABLE 2. CHANGES IN TOTAL PHOSPHORUS IN SOIL AT 0-15 cm AND 15-30 cm DEPTHS WITH TIME IN RELATION TO DIFFERENT TREATMENTS AND LOCATIONS

Treatment		C/R	C/S	P/B	C/P	O/A	O/FP	LSD (0.05)
Month	Depth (cm)	Total P (µg g^{-1})						
0	0-15	263	263	263	263	263	150	-
	15-30	168	168	168	168	168	115	-
2	0-15	131	142	134	103	64	68	66.78
	15-30	99	80	94	75	54	60	ns
4	0-15	99	102	526	199	90	96	130.26
	15-30	77	75	371	140	75	64	74.89
6	0-15	171	206	506	306	145	136	122.87
	15-30	137	159	346	197	125	105	100.25
8	0-15	128	203	395	202	156	134	110.98
	15-30	104	138	252	124	137	116	77.07
10	0-15	151	233	283	200	132	119	106.49
	15-30	116	154	182	154	104	102	65.22
12	0-15	243	777	485	488	151	121	229.04
	15-30	197	329	246	302	132	108	103.48
14	0-15	139	191	223	230	109	116	77.17
	15-30	117	130	150	150	96	101	ns
16	0-15	205	350	295	274	166	147	80.52
	15-30	155	255	234	216	133	136	50.51
18	0-15	210	285	332	281	133	177	60.69
	15-30	165	230	214	218	112	126	61.20

Note: Figures are means of four replicates.

other treatments and locations at both soil depths and the levels were maintained until the eighth month. It was clear that burning increased the total P during the early stages as a consequence of ash inputs. Total P in the C/S treatment at 0-15 cm soil depth showed an increase and reached its peak at 12 months with a value of 777 µg g^{-1}. The total P in the C/S treatment at 0-15 cm soil depth was significantly higher ($P < 0.05$) compared with the other treatments and locations. The P/B and C/P treatments showed no significant differences in total P concentrations, however they were significantly higher ($P < 0.05$) than those in the C/R treatment and O/A and O/FP locations.

In contrast, the levels of total P in the C/R treatment, at the O/A and O/FP locations were low compared with the other treatments during the course of the study. This may reflect the lack of organic matter inputs except root material in the C/R treatment and O/A location. Also the release of P from frond inputs in the O/FP location was small and not significant. This was consistent with the low P content of the pruned fronds. The total P concentrations after 12 months in all treatments decreased significantly and at 18 months the total P in the C/S, P/B and C/P treatments at 0-15 cm depth were significantly higher ($P < 0.05$) compared with the C/R treatment, O/A and O/FP locations. However, there was no significant difference in total P for C/S, P/B and C/P treatments. The C/R treatment, O/A and O/FP locations showed no increase in total P throughout the experiment.

Avalaible Phosphorus

Available P concentrations in the soil of the experimental plots (*Table 3*) were higher than

TABLE 3. CHANGES IN AVAILABLE PHOSPHORUS IN SOIL AT 0-15 cm AND 15-30 cm DEPTHS WITH TIME IN RELATION TO DIFFERENT TREATMENTS AND LOCATIONS

Treatment		C/R	C/S	P/B	C/P	O/A	O/FP	LSD (0.05)
Month	Depth (cm)	Available: P (µg g^{-1})						
0	0-15	56.6	56.6	56.6	56.6	56.6	6.5	-
	15-30	38.5	38.5	38.5	38.5	38.5	4.4	-
2	0-15	88.6	105.1	75.1	43.5	14.4	11.6	ns
	15-30	51.1	53.3	43.3	26.9	11.4	7.9	39.3
4	0-15	31.3	31.3	280.0	94.0	21.4	11.5	60.5
	15-30	16.9	12.6	197.8	50.9	14.5	7.4	60.9
6	0-15	36.1	90.6	229.1	135.4	31.5	16.0	71.3
	15-30	31.8	58.4	146.5	54.0	20.4	6.5	67.5
8	0-15	17.3	57.6	141.4	35.8	24.1	8.6	70.3
	15-30	7.6	26.1	88.1	19.5	17.9	6.1	33.9
10	0-15	23.4	89.3	95.5	84.3	21.6	14.0	61.0
	15-30	12.6	49.6	55.3	52.1	10.0	5.9	24.0
12	0-15	90.8	354.6	263.8	233.3	40.6	16.0	78.4
	15-30	51.9	154.8	130.6	128.9	28.6	8.3	60.4
14	0-15	39.5	59.8	88.5	65.9	24.1	13.3	36.6
	15-30	23.0	29.3	40.9	36.6	12.8	9.8	21.9
16	0-15	39.9	119.0	101.3	89.1	21.4	10.4	31.7
	15-30	23.3	79.8	67.8	45.0	15.5	6.8	25.6
18	0-15	54.4	69.3	90.1	67.1	14.5	20.3	22.1
	15-30	40.8	45.9	40.8	42.9	8.5	8.8	19.7

Note: Figures are means of four replicates.

might be expected for soils under natural vegetation or low-input agriculture. Sivanadyan and Norhayati (1992) showed that with the conversion of natural forest to commercial oil palm plantations, the available P increased from 3 mg kg^{-1} for 0-15 cm depth under forest to 36 mg kg^{-1} after six years under oil palm. This increase in available P is a consequence of standard fertilizer practices involving applications of rock phosphate: amounting to 400 kg ha^{-1} yr^{-1} over 23 years in the mature plantation which was cleared for the present study. In addition, the standard Bray-2 method used by the oil palm industry to estimate P availability in Malaysian soils also reacts with residual rock phosphate. Hence, the acid extract not only extracts soil P but also apatite and calcium phosphate resulting in over estimation of plant avalaible P (Chien, 1978; Zulkifli *et al.,* 1996).

As shown in *Table 3,* significant increases in soil available P were observed in the P/B treatment at both soil depths after six months. The increase in soil available P in the P/B treatment was probably a consequence of ash increasing the soil pH and inorganic P in the ash itself. Similar effects were reported by Jordan (1985) for the effects of slash and burn practices where the ash reduced the solubility of iron and aluminum and complexed phosphates became soluble and available to crops. Similar findings were also obtained by Norhayati and Lau (1990) in forest clearing for rubber in which available P levels in the top soil increased to almost double after burning, then gradually decreased. Significantly higher levels ($P < 0.05$) of available P were also observed in the C/P and C/S treatments at both soil depths compared to the C/R treatment and for the O/A and O/FP locations. Available P in the C/S treatment at both soil depths were increased to maximum levels at 12 months (154.75 to 354.63 µg g^{-1}) and the concentrations were significantly higher ($P < 0.05$) than those in the other treatments. The P/B and C/P treatments showed no significant difference in available P concentrations. However the levels of available P in the C/R treatment, and at the O/A and O/FP locations were low compared with the other treatments throughout the 18-month period. This was paralleled by the low levels of total P in these plots. The available P at 18 months for the C/S, P/B and C/P treatments were decreased and the trends were quite similar to those for total P. The data also showed that the P/B treatment was significantly higher ($P < 0.05$) in available P compared with the other treatments and locations. However, there was no significant difference in available P between the C/S and C/P treatments. The available P concentrations for the C/R treatment and in all the O/A and frond pile locations were the lowest and did not increase during the course of the study. The available P was found to be on average 60% of total P and it was assumed most of the available P was from residual soil P with only a fraction released from the oil palm residues by mineralization. Lau *et al.* (1981) showed palm frond mulching had a significant effect on the humic colloids content in soil and found the available P under palm frond mulch to be 77 mg kg^{-1} and contributing about 34% to the total P (230 mg kg^{-1}). Other workers like Sivanadyan and Norhayati (1992) observed that the available P (36 mg kg^{-1}) was about 12% of total P (303 mg kg^{-1}) after six years under oil palm. This means the available P increased with the increase of residual P and with total P from the decomposed residues.

Exchangeable Potassium

The data in *Table 4* showed that exchangeable K concentrations at both soil depths were less than 0.3 meq.100 g^{-1} of soil at initial sampling in all treatments and locations. The immediate release of K as a result of the burning increased the soil available pool substantially within six months in the P/B treatment with values in the range 1.03-1.32 meq.100 g^{-1} soil at both depths. Significantly higher ($P < 0.05$) concentrations of exchangeable K were also observed in the C/P treatment at both depths after six months. At six months, concentrations of exchangeable K at both soil depths in the P/B treatment were comparable with the C/P treatment and significantly higher ($P < 0.05$) compared with the other treatments and locations. The C/S treatment also showed significantly higher ($P < 0.05$) exchangeable K compared with the C/R treatment and at the O/A and O/FP locations. At 12 months, exchangeable K concentrations in the C/S treatment at both

TABLE 4. CHANGES IN EXCHANGEABLE POTASSIUM IN SOIL AT 0-15 cm AND 15-30 cm DEPTHS WITH TIME IN RELATION TO DIFFERENT TREATMENTS AND LOCATIONS

Treatment		C/R	C/S	P/B	C/P	O/A	O/FP	LSD (0.05)
Month	Depth (cm)	Exch.K (meq.100 g^{-1} soil)						
0	0-15	0.15	0.15	0.15	0.15	0.15	0.23	-
	15-30	0.13	0.13	0.13	0.13	0.13	0.20	-
2	0-15	0.34	0.69	1.30	1.16	0.24	0.46	0.305
	15-30	0.25	0.54	0.88	0.80	0.18	0.38	0.244
4	0-15	0.21	0.64	2.12	1.03	0.18	0.29	0.430
	15-30	0.15	0.53	1.63	0.86	0.13	0.21	0.389
6	0-15	0.26	0.88	1.32	1.37	0.22	0.30	0.277
	15-30	0.22	0.70	1.03	1.09	0.19	0.22	0.198
8	0-15	0.20	1.20	1.26	1.08	0.24	0.30	0.268
	15-30	0.15	1.00	1.07	0.85	0.22	0.31	0.254
10	0-15	0.31	1.41	0.64	0.82	0.21	0.33	0.259
	15-30	0.23	1.15	0.54	0.76	0.17	0.29	0.256
12	0-15	0.50	2.62	1.29	1.37	0.54	0.64	0.880
	15-30	0.31	2.01	1.07	1.14	0.39	0.47	0.464
14	0-15	0.44	1.87	1.12	1.26	0.38	0.61	0.467
	15-30	0.34	1.51	0.94	1.02	0.30	0.46	0.406
16	0-15	0.41	1.49	0.97	1.09	0.43	0.63	0.147
	15-30	0.36	1.23	0.85	0.98	0.33	0.51	0.140
18	0-15	0.64	2.16	1.74	1.81	0.86	0.91	0.258
	15-30	0.55	1.88	1.44	1.47	0.67	0.65	0.226

Note: Figures are means of four replicates.

depths reached a peak with values ranging from 2.01-2.62 meq.100 g^{-1} soil and were significantly higher ($P < 0.05$) than the other treatments and locations in all plots. This was paralleled by the results of a decomposition study that showed maximum release of K at 12 months from decomposing palm residues. Lim *et al.* (1993) showed similar increases in exchangeable K concentrations in soils of the Rengam series from 0.43 to 1.46 meq. 100 g^{-1} soil after 12 months in plots mulched with 30 t ha^{-1} chipped oil palm trunks. Rosenani *et al.* (1996) observed that mulching with empty fruit bunches (EFB) also increased exchangeable K in a Typic Hapludox (an inland soil of the Gajah Mati series) from 0.05 to 6.53 meq. 100 g^{-1} soil over 15 weeks. The peak concentration of K at 12 months in the C/S treatment suggested a limit to K retention by the soil which was largely determined by the CEC. The lower values of exchangeable K at 15-30 cm were also reflected by low values of CEC. These relative patterns were maintained over 18 months although the exchangeable K concentrations decreased. In contrast, exchangeable K at both soil depths in the C/R treatment and at the O/A and O/FP locations were extremely low compared with other treatments and slightly increased over time.

Exchangeable Calcium

Table 5 shows the exchangeable Ca concentrations at 0-15 cm and 15-30 cm soil depths. The concentrations of exchangeable Ca in the P/B treatment at both soil depths increased within four to six months after treatment and were significantly higher ($P < 0.05$) compared with other treatments and both the O/A and O/FP locations. The release of Ca in the C/S and C/P treatments was observed after six to eight months and the concentrations of exchangeable Ca gradually increased in these treatments. At 10 months, the concentrations of exchangeable Ca were comparable among P/B, C/S and C/P treatments and were maintained up to 12 months. At this period, concentrations of exchangeable Ca in all treatments at 0-15 cm soil depth ranged from 0.60-1.79 meq.100g^{-1} soil. In contrast, there was no significant increase in the level of exchangeable Ca in the C/R treatment and at O/A and O/FP locations over time. Similarly, the levels of exchangeable Ca at 18 months in the C/R treatment and O/A location at 0-15 cm depth were significantly lower than

TABLE 5. CHANGES IN EXCHANGEABLE CALCIUM IN SOIL AT 0-15 cm AND 15-30 cm DEPTHS WITH TIME IN RELATION TO DIFFERENT TREATMENTS AND LOCATIONS

Treatment		C/R	C/S	P/B	C/P	O/A	O/FP	LSD (0.05)
Month	Depth (cm)	Exch. Ca (meq. 100 g^{-1} soil)						
0	0-15	0.69	0.69	0.69	0.69	0.69	1.35	-
	15-30	0.63	0.63	0.63	0.63	0.63	0.92	-
2	0-15	0.72	0.70	0.93	0.59	0.44	0.97	0.249
	15-30	0.55	0.59	0.76	0.50	0.40	0.79	0.215
4	0-15	0.50	0.64	2.72	0.79	0.51	1.41	0.765
	15-30	0.43	0.42	2.02	0.60	0.42	0.90	0.893
6	0-15	0.56	0.55	1.66	1.08	0.57	1.17	0.392
	15-30	0.44	0.49	1.44	0.79	0.36	1.09	0.279
8	0-15	0.64	0.69	0.86	0.68	0.52	0.91	0.262
	15-30	0.34	0.50	0.75	0.47	0.45	0.80	0.210
10	0-15	0.47	0.84	1.07	0.80	0.44	1.00	0.290
	15-30	0.39	0.74	0.73	0.73	0.36	0.87	0.154
12	0-15	0.81	1.79	1.51	1.75	0.60	1.07	0.632
	15-30	0.65	1.42	0.82	1.08	0.54	0.73	0.448
14	0-15	1.25	1.87	1.67	1.81	1.14	1.73	0.385
	15-30	1.12	1.60	1.36	1.64	1.01	1.33	0.204
16	0-15	0.68	1.55	1.20	1.50	0.59	1.06	0.267
	15-30	0.53	1.32	1.00	1.30	0.55	0.89	0.280
18	0-15	0.76	1.41	1.24	1.53	0.63	1.13	0.345
	15-30	0.74	1.18	0.99	1.17	0.48	0.85	0.302

Note: Figures are means of four replicates.

those in the other treatments and a O/FP location.

Exchangeable Magnesium

Exchangeable Mg concentrations at both soil depths in the P/B treatment increased within six months after treatment and were significantly higher ($P < 0.05$) compared with the other treatments and both the O/A and O/FP locations except the C/P treatment (*Table 6*). At 12 months, exchangeable Mg concentrations at 0-15 cm soil depth in all treatments ranged between 0.24 to 1.1 meq. 100 g^{-1} soil. Exchangeable Mg in the C/R treatment was significantly lower than that in the P/B, C/S and C/P treatments and significantly higher ($P < 0.05$) in the C/S treatment as compared with the other treatments and locations. Small decreases of exchangeable Mg in the C/S, C/P and P/B treatments were observed after 18 months. In contrast, exchangeable Mg concentrations in the C/R treatment and at the O/A and O/FP locations were approximately constant over time except that there was a slight increase at 12 months, possibly due to the release of nutrient from decomposed roots.

TABLE 6. CHANGES IN EXCHANGEABLE MAGNESIUM IN SOIL AT 0-15 cm AND 15-30 cm DEPTHS WITH TIME IN RELATION TO DIFFERENT TREATMENTS AND LOCATIONS

Treatment		C/R	C/S	P/B	C/P	O/A	O/FP	LSD (0.05)
Month	Depth (cm)	Exch. Mg (meq. 100 g^{-1} soil)						
0	0-15	0.26	0.26	0.26	0.26	0.26	0.38	-
	15-30	0.20	0.20	0.20	0.20	0.20	0.26	-
2	0-15	0.20	0.20	0.41	0.26	0.15	0.36	0.102
	15-30	0.18	0.15	0.31	0.23	0.14	0.29	0.084
4	0-15	0.15	0.21	1.81	0.40	0.14	0.43	0.312
	15-30	0.12	0.15	1.22	0.32	0.13	0.28	0.391
6	0-15	0.18	0.24	0.69	0.55	0.14	0.29	0.149
	15-30	0.16	0.20	0.55	0.42	0.11	0.26	0.111
8	0-15	0.16	0.31	0.50	0.41	0.14	0.28	0.140
	15-30	0.12	0.27	0.40	0.26	0.12	0.27	0.130
10	0-15	0.16	0.43	0.45	0.46	0.15	0.31	0.175
	15-30	0.13	0.39	0.29	0.36	0.12	0.25	0.090
12	0-15	0.32	1.11	0.66	0.94	0.24	0.36	0.347
	15-30	0.27	0.84	0.39	0.61	0.17	0.25	0.391
14	0-15	0.28	0.81	0.56	0.73	0.29	0.43	0.160
	15-30	0.24	0.64	0.43	0.60	0.22	0.34	0.118
16	0-15	0.24	0.70	0.75	0.71	0.15	0.35	0.106
	15-30	0.18	0.60	0.53	0.65	0.14	0.30	0.134
18	0-15	0.24	0.62	0.56	0.71	0.19	0.32	0.176
	15-30	0.21	0.53	0.41	0.57	0.17	0.23	0.110

Note: Figures are means of four replicates.

Soil Organic Carbon

Table 7 shows the changes in soil organic carbon at 0-15 cm and 15-30 cm soil depths. The initial levels of soil organic C in the soil showed that the O/FP location had higher concentration of total soil organic C. The data showed that at 0-15 cm depth, the total organic C at the O/FP location was 3.06% and 2.33% at the O/A location. The total organic C at 15-30 cm depth was slightly lower than in the top soil layer in which at the O/FP and O/A location was 2.61% and 2.08% respectively. In the early part of the first 12 months, total organic C generally increased, especially in the C/S, P/B and C/P treatments. However, the increases in the C/R treatment and at the O/FP location were small and no increase was observed at the O/A location. This might have been caused by the occurrence of more decomposed root materials in the O/FP location and also under the C/R treatment which still had the large root biomass from the old oil palm rows. In contrast, the O/A location was at a distance away from the old palm rows and had the lowest roots biomass or density.

TABLE 7. CHANGES IN ORGANIC CARBON (%) IN SOIL AT 0-15 cm AND 15-30 cm DEPTHS WITH TIME IN RELATION TO DIFFERENT TREATMENTS AND LOCATIONS

Treatment		C/R	C/S	P/B	C/P	O/A	O/FP	LSD (0.05)
Month	Depth (cm)	Soil organic carbon (%)						
0	0-15	2.33	2.33	2.33	2.33	2.33	3.06	-
	15-30	2.08	2.08	2.08	2.08	2.08	2.61	-
2	0-15	2.36	2.51	2.59	2.72	2.23	2.93	0.197
	15-30	2.07	2.10	2.44	2.41	2.03	2.46	0.279
4	0-15	2.30	2.42	2.93	2.68	2.14	3.13	0.170
	15-30	2.01	2.12	2.36	2.20	2.03	2.59	0.162
6	0-15	2.42	2.60	2.83	2.90	2.21	3.13	0.217
	15-30	2.17	2.35	2.46	2.49	2.12	2.69	0.198
8	0-15	2.42	2.71	2.92	2.83	2.31	3.04	0.201
	15-30	2.19	2.38	2.61	2.45	2.18	2.57	0.207
10	0-15	2.49	3.07	2.66	2.77	2.34	2.96	0.222
	15-30	2.31	2.62	2.47	2.44	2.22	2.61	0.177
12	0-15	2.78	4.64	3.04	3.90	2.54	3.30	0.424
	15-30	2.58	3.57	2.80	3.22	2.28	2.92	0.348
14	0-15	2.51	3.70	2.76	3.37	2.38	3.06	0.308
	15-30	2.20	2.92	2.46	2.75	2.21	2.76	0.290
16	0-15	2.67	3.23	3.01	3.41	2.47	3.11	0.204
	15-30	2.38	2.93	2.68	2.85	2.30	2.55	0.222
18	0-15	2.81	3.33	2.94	3.65	2.66	3.17	0.237
	15-30	2.57	2.74	2.67	3.02	2.42	2.87	0.264

Note: Figures are means of four replicates.

At six months measurement, O/FP still had significantly higher ($P < 0.05$) organic C than other treatments and O/A location. The levels of organic C in the C/P and P/B treatments at 0-15 cm soil depth were significantly higher ($P < 0.05$) compared to the C/S and C/R treatments and at the O/A location. This was attributed to faster decomposition of pulverized materials in the C/P treatment and accumulation of organic C from burnt materials in the P/B treatment. The peak values for total organic C were recorded at 12 months in all treatments with the highest value of 4.64% in the C/S treatment compared to the lowest 2.54% in the O/A location at 0-15 cm soil depth. The total organic C concentrations at 0-15 cm soil depth in the C/S and C/P treatments were significantly higher ($P < 0.05$) than the other treatments and locations. This was paralleled with the residue inputs in these plots and more than 50% of the residues decomposed within 12 months.

Even at 18 months, the C/S and C/P treatments still maintained higher values than other treatments and locations. It seems that mulching crop residues can increase the organic matter or the total soil organic C in the soil. In contrast, the C/R treatment and O/A location showed only slight increases in total organic C from the receipt of organic input from decomposed root materials and covers during the course of the study.

The mean C:N ratio of the soil during the study period for all treatments at both soil depths was between 14:1 to 16:1. The ratio increased only slightly even at the O/FP location with organic matter accumulation over a longer period of time. As reported by Wild (1988), a C:N ratio greater than 14:1 or so is a strong indication that a soil contains much partially decomposed plant material. This implies that much of the soil organic matter was derived from roots which can be seen in the C/R treatment and O/A location besides additional organic materials from above-ground residues inputs in the C/S and C/P treatments and O/FP location.

The increase in total soil organic C at both soil depths in the plots which received crop residues (C/S and C/P treatments) did not reflect the amounts of inputs due to the localization or placement of crop residues at the soil surface. A similar result was observed at the O/FP location which had received organic inputs at the soil surface over a longer period of time.

Organic Matter Accumulation on the Soil Surface

The light fraction carbon (C) on the top soil surface under the debris was collected in the C/S and C/P treatments at 12 and 18 months after the experiment was initiated. Light fraction C is defined as the C that is not bound to the mineral soil and that falls in the less than 2 mm size category. This is considered to be an unstabilized component of soil organic matter and its turnover rate is dependent on the quality of the organic inputs. The chemical properties for the light fraction C are presented in *Table 8*. The light fraction C contained higher concentrations of plant nutrients compared with the

TABLE 8. CHEMICAL PROPERTIES OF LIGHT FRACTION ORGANIC CARBON (<2 mm) ON TOP SOIL SURFACE

Treatment	Months after treatment	Total N (%)	Total P (ppm)	Available P (ppm)	Exch. K	Exch. Ca meq.100 g^{-1}	Exch. Mg	C (%)	C:N
C/S	12	1.55	888	190	4.33	9.21	5.45	29.80	19.23
	18	1.27	640	134	3.36	9.43	5.12	23.75	18.70
C/P	12	1.34	1 238	269	2.63	9.32	5.06	22.90	17.09
	18	1.16	477	103	2.44	8.19	4.60	21.57	18.59

Note: Figures are means of four replicates.

mineral soil. For example, the concentrations of N and K were about five and two times higher than in the mineral soil respectively. It was observed the C:N ratio of the light fraction C ranged from 17:1 to 19:1 which mostly contained in the partially decomposed plant material.

The accumulation of light fraction C in the P/B treatment due to burning was not found to be significant because burning destroyed much of the small litter material. Similarly, in the C/R treatment, light fraction C was negligible because the only residue inputs above-ground were from the leguminous and other ground covers.

Overall Trends in Soil Nutrients

As shown in *Tables 1* to *6*, there was a large early build-up of plant nutrients in soil, especially K in the P/B treatment after burning. Burning results in the loss of most of the organic N capital in the palm residues but the ash has high concentrations of P and base nutrients. To what extent these nutrients are taken up or leached out will depend mainly on the intensity of rainfall events before ground covers and the rooting systems of the succeeding palms are developed. It was observed that the legumes established full ground cover after six months from the start of the experiment. During the first six months before the covers became fully established and when the soil was bare, it was assumed that most of the plant nutrients released in the burnt plots were lost through surface run off or losses through leaching. These losses, however, would depend on the topography of the area and soil infiltration rates. In contrast, nutrients in the decomposing plant materials were released over a relatively longer period through leaching and mineralization processes with a gradual increase in the soil pools over six to 12 months. Differences in the nutrient status of the locations within the plantations also show the importance of organic matter inputs for maintaining nutrient reserves in soils. There was a negligible increase of plant nutrients in the C/R treatment and at the O/A and O/FP locations over time. However, a slight increase was observed at 12 and 18 months possibly due to the decomposed roots and leguminous covers. A slight increase in nutrient levels at the early stage was observed in the C/P treatment where the pulverized palm residues decomposed faster, and K was more readily leached, than from the shredded materials. It was also observed that the patterns of N and P released from decomposing materials were quite similar because both elements are mobilized by microbial activity through mineralization, whereas releases of Ca and Mg are largely determined by biotic and abiotic processes affected by the mass of the resources. The release of K was mainly in ionic form through leaching from decomposed materials.

Overall the changes in nutrient dynamics over 18 months seem to indicate that the nutrients released from the previous oil palm residues were returned to the soil pools and can supply nutrients to the succeeding palms.

Monitoring of Other Experimental Variables

Soil moisture. Soil moisture content for the top 0-15 cm during the study period (*Appendix 1*) ranged between 24.4% (O/A location at 10 months measurement) and 32.1% (O/FP locations at four months sampling) with an overall mean of 28.2%. The soil moisture content at 15-30 cm depth ranged between 24.5% (O/A location and at 10 months measurement) and 31.0% (O/FP location at four months sampling) with an overall mean of 28.2%. The fluctuation of soil moisture was minimal (about 2%) throughout the experimental period and was related to rainfall distribution. Application of crop residues can alter the soil moisture content especially during dry weather or periods of low precipitation. For example, at 10 months, the soil moisture at 0-15 cm soil depth in the C/S treatment, which involved surface applications of chopped residues was 28%, significantly higher than that in the C/R (25.5%) or P/B (24.8%) treatments. However, the C/P treatment, which had chipped and pulverized residues, had almost similar soil moisture (25.3%) to the C/R treatment indicating that the pulverized materials decomposed faster than the chopped residues which shortens the effect of mulching on soil moisture.

Soil pH. The pH of plant materials is normally acidic. Addition of crop residues or green manuring effects change in soil pH in two ways (Singh *et al.,* 1992). Organic acids and CO_2 produced during decomposition of green manure can protonate the soil decreasing the pH. The oxidation of ammonium to nitrate is also an acidifying process through release of protons. However, organic reducing substances formed during decomposition of green manure can alter the change of Fe and Mn oxides causing soil pH to rise because protons are consumed in the course of the reduction of oxides. Increased soil pH may also result through mineralization of organic anions to CO_2 and H_2O, thereby removing H^+. Release of base nutrients during decomposition of crop residues will also increase the soil pH.

Changes in soil pH during the study period in relation to different treatments were observed (*Appendix 2*). The soil pH at 0-15 cm recorded during the study period ranged between 3.85-5.32 with an overall mean of 4.46. At 15-30 cm soil depth, pH ranged between 3.80-4.90 with an overall mean of 4.33.

During the early stages of the experiment, the P/B treatment showed higher soil pH compared to other treatments and location because of the basic effects of ash. At four months measurement, the soil pH in the P/B treatment at both soil depths were significantly higher ($P < 0.05$) at pH 5.30 at 0-15 cm depth and pH 4.90 at 15-30 cm depth respectively than in other treatments and locations.

The increase in soil pH due to addition of crop residues was only observed after 10 months treatment as base cations, particularly Ca, were released by decomposition. At 12 months, the soil pH at 0-15 cm soil depth ranged from a minimum 4.67 in the C/R treatment to a maximum of 5.32 in the C/S treatment. The soil pH in the C/S treatment was significantly higher ($P < 0.05$) compared to other treatments and locations. Lim *et al.* (1993) and Rosenani *et al.* (1996) have similarly observed significant increases in soil pH through application of oil palm residues.

Soil CEC. Measurements of CEC at 18 months (*Table 9*) showed the effects of residue applications at both soil depths. The CEC at 0-15 cm was lowest in the O/A at 8.10 meq. 100 g^{-1} soil and highest at 9.72 meq.100 g^{-1} soil in the C/S treatment reflecting the differences in residue inputs. The C/S and C/P treatments and O/FP location all had significantly higher ($P < 0.05$) CEC (>8.50 meq.100 g^{-1} soil) compared to the C/R and P/B treatments and O/A location (<8.50 meq. 100 g^{-1} soil) at both soil depths. These effects are a consequence of the increase in exchange sites contributed by the formation of humic materials. Humic substances have a CEC in the order of 400 meq. 100 g^{-1} soil (Wild, 1988) and are particularly important in weathered tropical soils where the CEC of the mineral soil is low and usually saturated with protons and aluminium ions.

TABLE 9. EFFECT OF DIFFERENT TREATMENTS AND LOCATIONS ON CEC AT 0-15 cm AND 15-30 cm SOIL DEPTHS MEASURED 18 MONTHS AFTER TREATMENTS

Treatment	CEC (meq. 100 g^{-1} soil)	
	0-15 cm	15-30 cm
C/R	8.21	7.50
C/S	9.72	9.03
P/B	8.47	7.79
C/P	9.53	8.96
O/A	8.10	7.12
O/FP	9.69	8.58
LSD (0.05)	0.713	0.608

Note: Figures are means of four replications.

Leaf nutrient concentrations and palm growth. Data for leaf nutrient and vegetative measurements are summarized in *Tables 10* and *11* respectively. Significantly higher N and K were recorded in the C/S and C/P treatments compared with the P/B and C/R treatments (*Table 10*). These effects were reflected by the release of nutrients from the decomposed palm residues as indicated in the results from soil analysis. The concentrations of N and K in the C/S and C/P treatments were not significantly different.

Leaf P concentrations ranged from 0.15% to 0.16% and at 12 months sampling showed little significant difference between treatments. However, leaf P at 18 months were significantly higher ($P < 0.05$) in the C/S, C/P and P/B treatments compared with the C/R treatment.

TABLE 10. LEAF NUTRIENT CONCENTRATIONS (% of dry matter) IN FROND SAMPLES OF YOUNG PALMS FROM DIFFERENT TREATMENTS

Treatment	Months after treatment	% Nutrient concentrations⁺				
		N	P	K	Ca	Mg
C/R	12	2.47	0.145	1.20	0.37	0.31
	18	2.50	0.134	1.12	0.41	0.30
C/S	12	2.77	0.156	1.46	0.38	0.33
	18	2.75	0.144	1.34	0.49	0.35
P/B	12	2.50	0.150	1.32	0.48	0.35
	18	2.54	0.144	1.23	0.50	0.35
C/P	12	2.65	0.150	1.39	0.40	0.33
	18	2.61	0.143	1.26	0.45	0.35
LSD (0.05)*	12	0.22	0.01	0.08	0.06	ns
	18	0.17	0.003	0.09	0.03	0.02

Notes: ⁺ Frond 3 sampled at 12 months and frond 9 sampled at 18 months.
Figures are means of four replicates.
* Significant at P = 0.05.

TABLE 11. VEGETATIVE GROWTH⁺ OF YOUNG PALMS IN RESPONSE TO REPLANTING TECHNIQUES

Treatment	Months after treatment	Frond length (cm)	Frond dry wt. (kg)	Leaf area (m^2)	Palm height (cm)	Trunk diameter (cm)
C/R	12	134	0.57	0.89	195	-
	18	165	0.80	1.37	237	16.83
C/S	12	157	0.74	1.28	236	-
	18	196	0.97	1.77	289	27.48
P/B	12	142	0.61	1.01	214	-
	18	185	0.89	1.62	268	20.54
C/P	12	154	0.71	1.21	229	-
	18	190	0.94	1.62	280	24.63
LSD (0.05)*	12	6.80	0.05	0.13	11.39	-
	18	9.79	0.09	0.20	13.34	2.58

Notes: ⁺ Frond 3 sampled at 12 months and frond 9 sampled at 18 months.
Figures are means of four replicates.
* Significant at P = 0.05.

This suggests that even with application of rock phosphate in the planting hole and the residual P in the soil, there were benefits to be gained from the addition of organic residues, either in increasing the P supply or by enhancing P uptake. Significantly higher ($P<0.05$) concentrations of Ca were recorded in the P/B treatment than in the other treatments at 12 months. At 18 months, leaf Ca in the C/R treatment was significantly lower ($P<0.05$) than in the other treatments. Leaf Mg showed no significant difference between treatments at 12 months' sampling. However at 18 months, leaf Mg in the C/R treatment was significantly lower ($P<0.05$) than in the other treatments. Slight increases or decreases in the leaf nutrient concentrations of the young palms at 18 months were probably due to a 'dilution effect' resulting from the increases in palm biomass. This was supported by the increases in vegetative growth in all the parameters measured (*Table 11*). Overall, it was observed that the leaf nutrient levels in the C/S and C/P treatments were satisfactory for optimum palm growth compared with the P/B and C/R treatments.

Data on the vegetative growth of the palms (*Table 11*) show that the C/S and C/P treatments had similar responses with significantly larger palms than those in the C/R and P/B treatments. The growth of palms in the P/B treatment however was better than that in the C/R treatment with significant differences in the vegetative parameters measured except for leaf area at 12 months and frond dry weight at 12 and 18 months.

The palms in the C/R treatment were significantly smaller with lower leaf nutrients. This suggests that removal of palm biomass at replanting affected growth of the succeeding palms as little plant nutrients were recycled in the system except from decomposed root biomass, legume covers and from residual fertilizers received from the previous crop.

Effect on flowering. The results of flower censuses at 12 and 18 months after field planting are shown in *Table 12*. It is interesting to note that palms in the C/S and C/P treatments produced a higher percentage of flowering at the 12 months period of 41% and 53% respectively. The P/B treatment only showed 15% flowering while the C/R treatment showed very low percentage of flowering of only 4%. At 18th months, the C/S, C/P, P/B and C/R treatments showed 64%, 60%, 44% and 34% flowering respectively. The high percentage of flowering in the C/S and C/P treatments at an early age indicates that soil fertility in the plots is favourable for oil palm growth. In addition, the C/R treatment produced more male flowers, probably due to the low soil fertility and stress effect.

TABLE 12. PERCENTAGE FLOWERING OF YOUNG PALMS IN RESPONSE TO REPLANTING TECHNIQUES

Treatment	Months after treatment	Flowering* (%)
C/R	12	4
	18	34
C/S	12	41
	18	64
P/B	12	15
	18	44
C/P	12	53
	18	60

Note: * Flowering as a percentage of the 80 palms in each treatment.

CONCLUSION

Changes in soil nutrient dynamics under different crop residue management practices were observed throughout the 18-month study period. The importance of crop residue inputs for maintaining nutrient reserves in soils was observed in the C/S and C/P treatments which showed differences in the nutrient status when compared with the plots without crop residues inputs. This difference was attributed to the significant increase in organic matter in these plots even though the effects were minimal due to crop residue placement. Placement of the crop residues on the soil surface affected the soil organic matter and nutrient dynamics in all treatments and locations. The fast decomposition of palm residues and rapid release of nutrients, particularly K, indicated only a small proportion of the nutrient capital was carried over to the young palms. The excess nutrients were probably lost from the top soil.

Placement of organic materials or organic mulch on the soil surface or their incorporation into the soil has long been recognized as beneficial to crop production. Apart from their direct nutrient contribution, mulch or crop residues are known to affect soil physical properties either directly or indirectly through microbial and soil fauna activities (Hulugalle *et al.*, 1986), and availability of soil nutrients (Wade and Sanchez, 1983). Hence, mulches influence crop production through two types of effects on the soil - the direct effect as a nutrient source and the indirect effects of soil protection, reduction of surface evaporation and maintenance of soil organic matter content which affects a wide range of soil properties and processes. An increase in CEC, which was primarily attributed to the increase in organic matter content in the mulched plots and the O/FP location, was observed 18 months after treatments. The plots with residue inputs (C/S and C/P treatments) and O/FP location had significantly higher CECs compared to plots without residues inputs (C/R treatment and O/A location) and the P/B treatment. One of the most significantly chemical properties of soil organic matter is its high exchange capacity, both for cations and anions.

The results obtained from the study showed that palm responses to the C/S and C/P treatments were impressive as a consequence of improving the transfer efficiency of nutrients in these plots. The nutrient concentrations and palm biomass showed that greater synchrony between nutrient release and plant uptake was achieved compared with the C/R treatment which had no residues or the standard replanting practice in which the residues are placed some distance away from the newly planted palms. Overall, the vigorous vegetative growth of the succeeding palms in the C/S and C/P treatments relative to the C/R treatment was attributed to their near optimal uptake of nutrients released in the residue treatments. In the P/B treatment, the large amounts of plant nutrients released in the early stages of growth were not in spatial or temporal synchrony with plant uptake and nutrients were probably lost from the topsoil by leaching or run off. Some of the nutrients were retained in the lower soil profile where they may be accessible to palms as the stand matures and its rooting system develops. This practice of biomass recycling not only saves on fertilizer cost or reduces the cost of production but, more importantly, goes a long way towards environmental conservation by, firstly, reducing dependence on fossil fuel required for the manufacture of inorganic fertilizer and secondly, the slow mineralization of residue provide a sink for CO_2 unlike the P/B treatment which releases CO_2 much faster. Further studies are in progress to monitor the effects of different residues management and in preparing fertilizer recommendations to ensure the optimum levels in the replanting of oil palm.

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APPENDIX 1

GRAVIMETRIC SOIL MOISTURE CONTENT AT 0-15 cm AND 15-30 cm DEPTHS IN RELATION TO DIFFERENT TREATMENTS AND LOCATIONS

Treatment		C/R	C/S	P/B	C/P	O/A	O/FP	LSD (0.05)
Month	Depth (cm)	Soil moisture content (%)						
2	0-15	26.30	29.89	25.94	30.47	25.40	29.76	1.671
	15-30	26.73	28.96	26.81	30.02	25.64	29.19	1.502
4	0-15	28.29	30.92	30.44	31.16	27.23	32.11	2.005
	15-30	28.61	30.77	29.54	30.55	27.91	31.02	2.199
6	0-15	27.16	29.27	27.08	30.79	25.71	29.35	1.400
	15-30	27.05	29.34	27.19	30.30	25.78	28.38	1.025
8	0-15	28.13	27.79	27.00	28.51	26.36	29.95	1.215
	15-30	28.10	28.61	27.22	28.77	26.35	29.42	1.059
10	0-15	25.51	27.95	24.79	25.33	24.41	26.74	1.366
	15-30	25.83	28.19	25.14	25.83	24.48	26.39	1.013
12	0-15	28.52	31.24	28.26	30.96	27.07	30.68	2.922
	15-30	28.86	30.63	27.89	30.30	26.90	30.62	2.683
14	0-15	28.89	31.19	28.12	30.74	27.80	30.18	1.651
	15-30	28.94	30.52	28.58	29.43	27.79	29.82	1.671
16	0-15	27.86	28.58	26.70	28.34	26.54	29.42	1.537
	15-30	28.34	29.04	26.56	28.58	27.08	29.31	1.644
18	0-15	26.43	27.39	26.21	27.37	25.98	27.85	1.278
	15-30	26.77	28.22	26.78	28.43	26.29	28.08	1.336

Note: Figures are means of our replicates.

APPENDIX 2

CHANGES IN SOIL pH AT 0-15 cm AND 15-30 cm DEPTHS WITH TIME IN RELATION TO DIFFERENT TREATMENTS AND LOCATIONS

Treatment		C/R	C/S	P/B	C/P	O/A	O/FP	LSD (0.05)
Month	Depth (cm)	Soil pH						
2	0-15	4.31	4.06	4.54	4.25	4.16	4.47	0.279
	15-30	4.27	4.02	4.42	4.12	4.14	4.39	0.225
4	0-15	4.05	4.15	5.30	4.28	4.13	4.32	0.311
	15-30	4.00	3.99	4.90	4.15	4.07	4.23	0.421
6	0-15	4.30	4.59	4.74	4.59	4.34	4.49	0.244
	15-30	4.22	4.37	4.44	4.43	4.25	4.34	0.235
8	0-15	4.21	4.38	4.52	4.46	4.20	4.50	0.243
	15-30	4.12	4.30	4.28	4.13	4.10	4.33	0.121
10	0-15	3.85	4.11	4.12	4.03	3.87	3.96	0.185
	15-30	3.82	4.03	4.01	4.00	3.80	3.93	0.155
12	0-15	4.67	5.32	4.90	4.94	4.75	4.79	0.283
	15-30	4.58	4.84	4.73	4.75	4.66	4.67	0.247
14	0-15	4.42	4.83	4.72	4.69	4.51	4.70	0.150
	15-30	4.36	4.57	4.53	4.53	4.44	4.52	0.097
16	0-15	4.18	4.52	4.54	4.47	4.32	4.44	0.139
	15-30	4.12	4.39	4.42	4.33	4.26	4.38	0.079
18	0-15	4.42	4.71	4.63	4.82	4.56	4.69	0.151
	15-30	4.38	4.68	4.57	4.69	4.51	4.55	0.137

Note: Figures are means of four replicates.