Spatial-Temporal Yield Trend of Oil Palm as Influenced by Nitrogen Fertilizer Management

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Abstract: One of the major challenges in oil palm (*Elaeis guineensis* Jacq.) plantations today is proper interpretation of yield maps for site-specific management and identification and understanding of the causal factors influencing the variability of oil palm yields. A study was conducted to examine the structural yield variation in order to assess the spatial and temporal yield trends so as to interpret multi-year yield maps of oil palm as influenced by the long-term N fertilizer applications in the palm circle in fertilizer response trial in Sabah, Malaysia. Two clusters of palms were selected for the study; with and without N fertilizer applications for the past 10 years. Fresh fruit bunch (ffb) yields were recorded and summarized on an annual basis. Geostatistical analysis was used to characterize the spatial structure of the semivariogram while point kriging was used to interpolate the ffb yields at unsampled locations. A classified management zone map was developed based on the spatial and temporal stability yield maps from 1992-1999. Semivariance analysis revealed that the yield variations between plots and within plots could be distinguished from the structural semivariogram. The variability between plots was relatively higher compared with within plots. The maximum range of the semivariance of both fertilizer treatments was about 6-palm distance which corresponded well to the experimental plot size of 30 (5×6) palms. It was also observed that the structure of the semivariogram was governed by the sampling pattern and the experimental plot size. The annual yield maps suggested that the application of N could sustain ffb yields above 30 t ha^{-1} year^{-1} whereas its removal could result in a drastic decline in ffb yields after 1992. Long-term N fertilizer applications reduced the annual ffb yield fluctuations to between 35 and 45% based on the coefficient of variations between years obtained from individual palms. The results further demonstrate the potential of integrating spatial and temporal stability of ffb yields from multi-year yield data to classify management zones for site-specific oil palm management particularly for fertilizer application. However, the potential of misinterpretation of yield maps can be high if limited data are available. Further work is necessary to ascertain the minimum number of palms and years required for the generation of meaningful yield maps and management zones.

Key words: Spatial variability, nitrogen fertilizer, oil palm yield, Malaysia

INTRODUCTION

The large variation in the fresh fruit bunch (ffb) yields between individual oil palms has been recognized since their commercial cultivation in the 1920s. The average ffb yields in Malaysia ranged from 18-20 t but in efficient commercial estates it can exceed 30 t ha^{-1} year^{-1}. In fact, an average of 30 t ha^{-1} year^{-1} was reported by Tarmizi *et al.*[1] and Goh *et al.*[2] on a wide range of fertilizer response trials. This yield is very much below the theoretical yield potential of 44 t ha^{-1} year^{-1}[3,4].

Apart from the above, uniformity trials with oil palm have generally shown that the coefficient of variations (CV) of ffb yields could exceed 30.[5,6,7]. They also vary spatially and temporally[7,8,9], which

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suggest that some palms will consistently produce higher or lower yields than the field average while other palms may produce higher or lower yields in some years but not others.

However, the CV is non-spatial and does not distinguish between autocorrelated yield variation (which is manageable) and uncorrelated (nugget) variation (which is not manageable[10]). Goh *et al.*[9] used geostatistics to demonstrate that the yield variation of oil palm could be separated into spatial and random components. The spatial variability accounted for 75% of the total variation in the field, which is manageable if the causal factors can be identified. They further showed that distinct spatial patterns in ffb yields existed in their experimental field of 25 ha. Several portions of the field had consistently higher or lower ffb yields compared with the field average over the past 8 years. They postulated that soil nitrogen and water availability might be the main causes for the variation in ffb yields.

The high variation in ffb yields is probably best represented with yield maps for better visualization. This technique is now commonly used in developed countries to interpret and manage the yield variations of many crops for precision farming[11,12,13]. Also, it could be used to classify a large field into different management zones for site specific inputs to optimize productivity and profitability; two of the most important keys towards sustainability of oil palm plantations[14]. Management zoning is widely practiced in the oil palm plantations but its spatial scale at 30 to 60 ha is generally too large for site specific management[14]. Furthermore, the interpretation of trend from multiple yield maps of the same location and the development of a method to optimize management zoning for precision farming have not been well explored in the oil palm plantations. These will depend on the existence of manageable yield variations and a proper understanding of the yield variations.

Thus, the main objective of this study were to quantify and characterize the spatial and temporal variation of ffb yields so as to determine the optimum management zones for oil palm plantations, as well as to create possible management zones for site-specific inputs

MATERIALS AND METHODS

The experiment was located within a fertilizer response trial conducted by Applied Agricultural Research Sdn. Bhd. at Sri Kunak Estate, Tawau, Sabah, Malaysia. The oil palms were planted in 1982 in a triangular pattern with a planting distance of 9.1 m×9.1 m9.1 m. The experimental design comprised a 3×3×2

factorial combination of N, P and K arranged in a randomized complete block design (RCBD) with 3 replicates. The experiment consisted of 18 plots for each replicate with a plot size of 30 palms. Fresh fruit bunch yields were recorded from the 12 central palms at 10 day intervals. An initial assessment of ffb yields in the experimental site indicated that a thin layer of laterites in some of the plots was a major cause of yield variation. Apart from this, variation in soil nitrogen might affect the spatial yield variation of oil palm in the experiment.

Two clusters of palms were therefore selected for the study. The first cluster composed of oil palms that had been fertilized with N while the other had not been fertilized for the past 10 years. A total of 8 plots were selected, 4 plots with N and 4 plots without N respectively. Point map of the individual palms for both treatments, which showed their relative positions in the field, was geocoded using non-earth system in meter unit. The plot size for the N treatment was 160 m×90 m and for non-N treatment was 120 m×115 m as shown in Fig. 1. Each treatment had 48 measurement palms.

Fresh fruit bunch (ffb) yields were summarized on an annual basis. They were then adjusted using the difference method[15] in order to remove both P and K effects. The components of variation in ffb yields after the removal of all known sources of yield variation
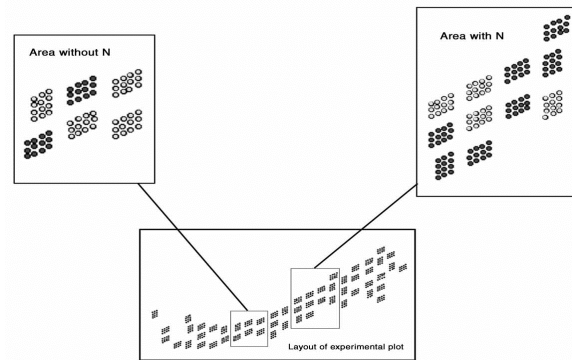

Fig. 1: Diagrammatic representation of experimental site

were calculated using the Statistical Analysis System (SAS) Package[16]. The F test was used to ascertain the differences in variations between and within plots.

Geostatistical analysis was performed on the data using semivariogram[17] and kriging[18] analyses. Semivariogram was fitted to the experimental model using Surfer Golden Software, Golden Co. (Demo version 7.0). The active lag distance for the grid in both treatments was limited to a maximum of 100 m. The lag

interval in the semivariogram was fixed at 9.1 m based on the planting distance of oil palm. Each lag distance class contained at least 60 pairs of points and most had more than 100 pairs of data points. Selection of the models for the semivariogram was made based on Akaike Information Criteria (AIC) following the procedures described by Webster and McBratney[19].

Interpolation of ffb yields at unsampled area was carried out by kriging using GS+™, Gamma Design Software (Version 3.1). The spatial yield maps of ffb were constructed by first using the point kriging method to estimate ffb yields at unsampled locations and then clustering them into ffb yield class of 5 t ha^{-1} year^{-1} at equal contour intervals. To avoid irregular field shape boundary and for comparing among plots with and without N, a rectangular field boundary was selected with extrapolated size of 165 m wide and 120 m long. The trend and stability of the yield maps were quantified by working out the corresponding mean and CV at each point of sampling over the past 8 years (1992-1999) as described by Blackmore[20]. Both maps were then combined into a classified management map with 9 different conditions of 3 yield classes and 3 temporal stability.

RESULTS AND DISCUSSION

Variation in FFB Yields: The ffb yields obtained from plots with and without N application from 1991 to 1999 are shown in Table 1. The annual ffb yields varied with CV ranging between 30 and 44% in plots with N and between 34 and 56% in plots without N. The high CVs of ffb yields were consistent with the findings of Webster[5], Chapas[6] (6) and Soh et al.[7] on a wide range of uniformity trials with oil palm. The mean CV in plot with N application was lower compared with plot without N, indicating that the applications of N fertilizer could reduce the yield fluctuation in oil palm. This was in agreement with the work of Lim et al.[21] and Tayeb et al.[22]. Goh et al.[2] attributed this phenomenon to the ability of well fertilized oil palms to use their nutrient reserve during the peak physiological yield cycle, which if not replenished quickly leads to a severe decline in yield as observed in unfertilized oil palms.

Table 1: Mean (kg palm^{-1}), coefficient of variation (%) and range of ffb yields from 1991 to 1999

	Without N			With N		
	Mean	CV	Range	Mean	CV	Range
1991	233	39.3	45-456	239	31.3	80-393
1992	169	52.4	30-464	277	34.2	87-494
1993	145	55.8	0-384	310	31.1	135-602
1994	141	53.1	9-388	308	29.3	137-546
1995	138	40.5	3-256	211	31.7	37-349
1996	146	37.0	41-255	207	44.0	0-406
1997	155	34.2	33-290	232	40.3	54-471
1998	112	41.8	17-244	207	37.4	36-377
1999	153	38.9	0-307	210	37.9	43-420
mean	155	43.7	20-338	245	35.2	68-451

Table 2: Components of yield variation in the trial site, 1992-1999

Source	DF	Mean Square	F Test
Plot	7	35341.75	23.66*
Palm	11	1683.78	1.15^{ns}
Plot x Palm	77	1466.75	
Total	95		

Note: ns denotes not significant at 0.05 probability level; *significant at 0.05 probability level

The average ffb yields over the past 8 years for each palm were used to examine palm to palm variability within the plot. The components of variation obtained from the ANOVA are shown in Table 2. No significant difference was detected between palm within plot although the results showed high coefficients of variation in annual ffb yields of individual palms. Thus, the main source of yield variation was between the plots. Also the classical statistical analysis could not distinguish the types of variability (spatial and random) between the palms within the plot.

Semivariance Analysis: Geostatistical analysis (semivariogram) was used to study the high variation in ffb yields of individual palms. The semivariograms for both treatments showed strong oscillations with lag distance following the sine wave model. Cressie[23] described this phenomenon as a hole (wave) effect. Further examination of the mean yield in each plot suggested that the sine wave pattern could be attributed to the yield distribution between and within the plots. As the variogram crossed the sampled palms within the plots the variance tended to decrease but it started to increase as it entered the transition zone between the plots. This pattern will repeat itself as it moved within and between the plots. This implies that the variance within plots was relatively smaller compared with the variance between plots as obtained from the classical statistical analysis presented earlier.

An important feature discernible from the semivariogram was the range between the maximum variance which is shown by the amplitude of the wave model. The amplitudes in both treatments generally lied between 25 m and 80 m, suggesting that the range of the semivariance was within 6-palm distance. This corresponded well to the experimental plot size of 30 palms (6×5 palms), which indicated that the spatial structure of the semivariogram was probably controlled by the sampling pattern and experimental plot size. This concurs with the findings of McBratney and Pringle[24] and show that the variograms and their parameters are functions of sampling interval and the area of the study.

Within the plots, the increase in semivariance generally reached a peak at a lag distance of 25 m. This

range was equivalent to about 2 to 3 palm distance. This confirms the results obtained by Goh *et al.*[9] who concluded that although the ability of the oil palm roots to exploit soil resources has been shown to be at least 2 palms away[25,26], the canopy structure of oil palm is such that it affects its immediate neighbors only (overlapping of fronds of oil palm). Thus, the main competition between the oil palms might be for light and immediate soil resources. It might also be construed that the efficiency of oil palm roots to absorb nutrients reduces substantially away from the palm due to limited feeder (tertiary and quaternary) roots[27]. This implies that poaching in oil palm is probably up to 3-palm distance at the furthest. Hence, trenching might be unnecessary in fertilizer response trials of oil palm if the experimental plots have guard rows of 2 to 3 palms. This result is consistent with the findings of Foster *et al.*[28] but contradicts those obtained by Ahmad and Chan[29].

The maximum range of 3-palm distance obtained from the semivariance analysis further suggested that with a triangular spacing in oil palm planting pattern, the optimum management zone for oil palm plantations is 37 palms; excluding field road. However, when field roads, which are normally spaced at 20 palm row intervals, are taken into consideration, the minimum size for practical management zone is 140 palms (7 palm rows×20 palms row^{-1}), which is approximately 1 hectare. The result is consistent with those obtained by Goh *et al.*[14].

Spatial Annual Yield Maps of Oil Palm: The spatial yield variation of oil palm was investigated by extrapolating ffb yield at unsampled locations using point kriging. Although the results from semivariogram analysis showed that the sine wave model was the best function for the ffb yield data, for practical management purposes, kriging interpolation was performed using the spherical model which was the next best. Observation showed that the removal of fertilizer resulted in a significant drop in ffb yields after 1992. A large proportion of the field without N had ffb yields lower than 15 t ha^{-1} year^{-1} particularly in the northern part. Fresh fruit bunch yields also declined to less than 30 t ha^{-1} year^{-1} in N treated plots after 1994. Apart from climatic effect and yield trend, the decline in ffb yields was associated with the severe leaf damage by *Darna trima,* which was reported in the trial in 1994. Comparing the yield maps of areas with and without N application indicated that the applications of N tend to sustain high ffb yields above 30 t ha^{-1} year^{-1}. Nitrogen is probably the major factor affecting the ffb yield

variation of oil palms in the experiment as obtained by Goh *et al.*[9].

The multi-year yield maps also showed distinct changes in the pattern of ffb yields from the same site. For example, in both treatments, high ffb yields were noted in 1997 followed by low yields in 1998. Similarly, high yielding area in one year might become low yielding in the next without any changes in the treatments. Such temporal yield variations are common in perennial crops[30] which increase the uncertainty in the interpretation of yield maps for site-specific crop management particularly for the following year(s).

Spatial and temporal stability yield maps of FFB: Blackmore *et al.*[20] suggested the incorporation of trend and temporal stability of ffb yields into the yield maps to overcome the problems of their interpretation. He divided the field into management zones based on the combination of discrete classifications of mean annual yield and temporal CV at each sampling point over the years of study. The management zone at each sampled point is then used to produce the management zone map by kriging for future decision making.

Following Blackmore et al.[20], the mean annual ffb yield and temporal CV of each oil palm were classified into 3 categories of high, moderate and low, each (Table 3). The classification was based on an approximate ½ standard deviation of the average ffb yield of oil palms in the trial site and the acceptable stability of ffb yields obtained in various uniformity studies as presented earlier. Results indicated that about 99% of the N treated palms had yields above 30 t ha^{-1} year^{-1} whereas only 22% achieved similar yield in the control palms. The latter was despite the withdrawal of N fertilizer for 8 years which suggested that the soil N status and conditions in part of the field were still favourable for high productivity. The control palms also showed a wider spread in the yield classes with the majority falling into the moderate yield category of between 20 and 30 t ha^{-1} year^{-1}.

In terms of temporal stability of ffb yields, the N treated palms were mainly classified under the stable to fairly stable categories while the converse was true for the control palms (Table 3). About 50% of the palms in the control plots had unstable ffb yields indicating large fluctuations which might be due to changing endogenous (physiological yield cycle) and exogenous (environmental) factors[31]. The results also showed that application of N tended to sustain high ffb yields and improve temporal stability of ffb yields; both highly favourable to the management of oil palm[32]. However, no spatial information was obtained from the yield

distribution classes as shown in the Table 3 and spatial analysis was required to ascertain them.

The yield class for each palm was used to produce the yield class map by kriging in order to illustrate its distribution as influenced by N applications (Fig. 2). As expected, the results for N treated palms showed a uniform distribution of high yield over the trial site. However, in the area without N application, low yield was observed in the northern part, stretching from east to west. Although it was tempting to separate the two areas for site-specific management, the stability of the ffb yields should be considered also to avoid pitfalls in the interpretation of the yield maps.

The temporal stability maps for both treatments produced by point kriging are presented in Fig. 3. These maps show the ffb yield fluctuations of oil palms with time irrespective of their productivity. Without N fertilizer application, there was a gradual change in the stability of ffb yields from the western to the eastern part of the field. The western portion of the field had unstable ffb yields compared with the eastern portion, suggesting that the interpretation of the yield map there

would have high uncertainty. Part of this uncertainty could be overcome with N manuring as discussed earlier. Figure 3 also shows that a portion of the N treated palms in the north had stable ffb yields while the

Table 3: Distribution of palms (%) in different categories of mean yield and temporal yield stability as influenced by N treatment

Treatment	FFB yields (t ha^{-1} year^{-1})	Coefficient of variation (%)			
		≤ 35[d]	35 < CV < 45[e]	≥ 45[f]	Total
With N	≥ 30[a]	21.8	74.1	3.5	99.4
	20 < yields <30[b]	0.6			
	Y ≤ 20[c]				0.6
	Total	22.4	74.1	3.5	
Without N	≥ 30[a]		16.0	5.9	21.9
	20 < yields <30[b]		24.3	30.2	54.4
	Y ≤ 20[c]		10.1	13.6	23.7
	Total		50.3	49.7	100.0

Note: a, b and c denote high, moderate and low ffb yields respectively
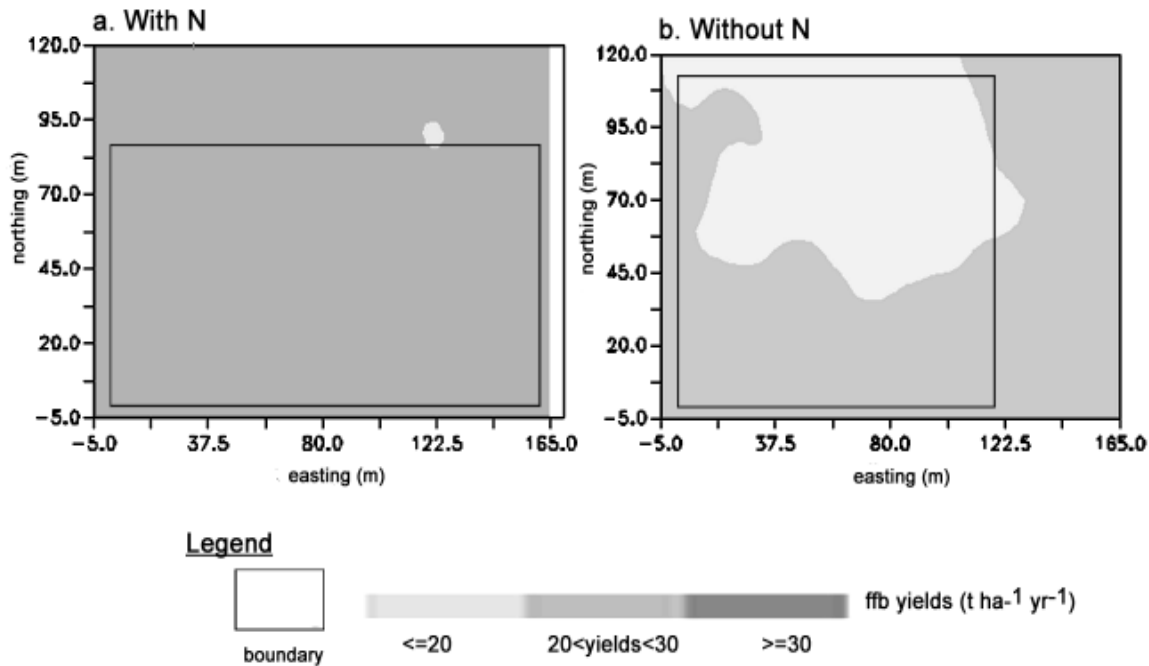d, e and f denote stable, fairly stable and unstable ffb yields respectively

Fig.2: Distribution of oil palm yield for with and without N application
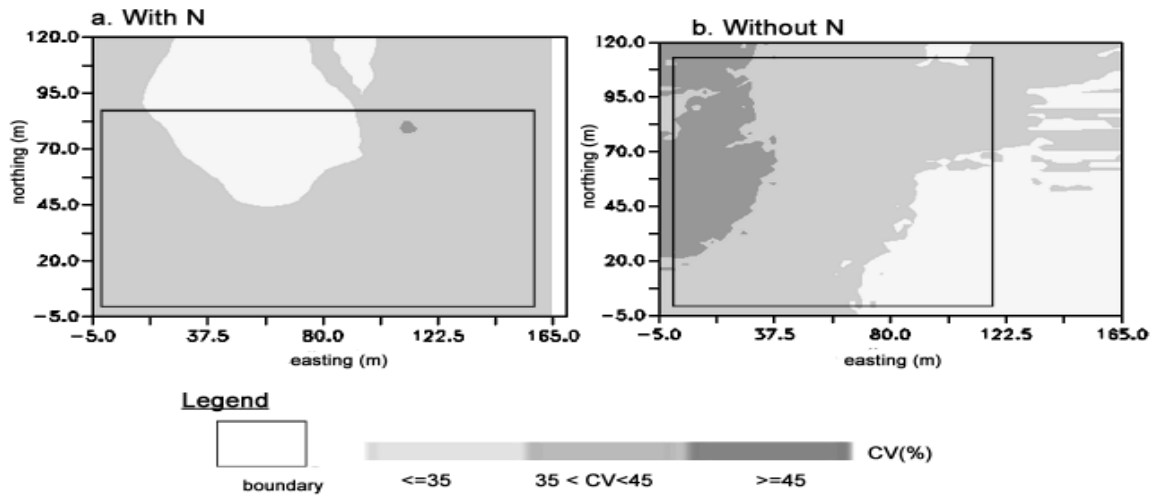
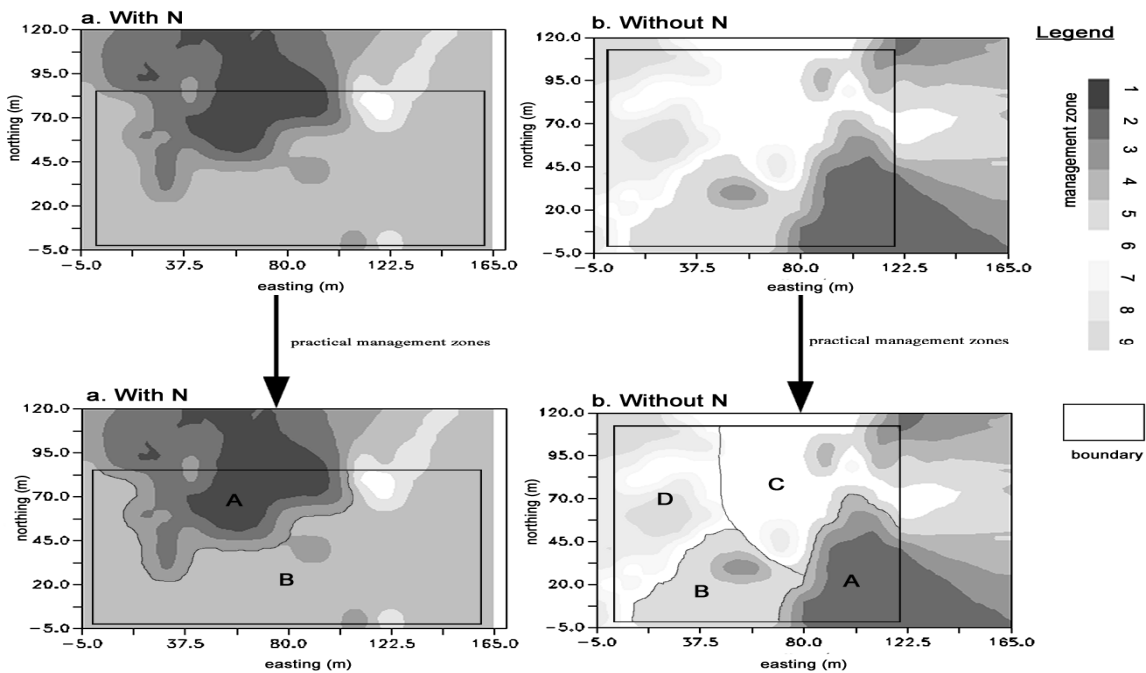Fig. 3: Temporal stability map for with and without N applications

Fig. 4: Management zone maps for with and without N applications

balance showed fair temporal stability. This implies that fertilizer application, which is an exogenous factor, could not overcome the temporal yield fluctuations of oil palms.

Classified Management Zone Maps: The 3 classes each of ffb yield and temporal stability were combined to produce 9 management zones (Table 4). Zone 1 represents the highly desirable oil palms of high, stable

yields while the worst scenario is Zone 9 with low, unstable ffb yields. Therefore, the management zones combined the important spatial and temporal features in the ffb yield variation for decision making. Based on this information, the management zone maps for both treatments were produced using point kriging (Fig. 4).

In the area with N fertilizer, a zone of high, stable yields was found in the northern portion with lower ffb yields as it radiated southward. It then changed to Zone

Table 4: Management classes based on the combined information of mean yield and temporal yield stability classes

Management class	ffb yields (t ha^{-1} yr^{-1})	CV (%)	Remark
1	y≥30	CV≤35	High, stable yield
2	20<y<30	CV≤35	Moderate, stable yield
3	y≤20	CV≤35	Low, stable yield
4	y≥30	35<CV<45	High, fairly stable yield
5	20<y<30	35<CV<45	Moderate, fairly stable yield
6	y≤20	35<CV<45	Low, fairly stable yield
7	y≥30	CV≥45	High, unstable yield
8	20<y<30	CV≥45	Moderate, unstable yield
9	y≤20	CV≥45	Low, unstable yield

4 with high, fairly stable yields. In unfertilized area, there were more management zones with a moderate, stable yield zone in the eastern corner. As it moved towards the northwestern direction, pockets of low, unstable yields were found.

For practical management purposes, it is probably difficult to provide site-specific inputs to the scattered, small areas or strips of different management zones particularly in the unfertilized field (Fig. 4). However, there is a possibility to re-group some of the management zones depending on the management resources[33] (33). For example, the fertilized area could be simply divided into 2 management zones of high, stable yields and high, fairly stable yields (Fig. 4). Similarly, the unfertilized area could be demarcated into 4 management zones of moderate, stable yields (Zone A), moderate, fairly stable yields (Zone B), moderate, unstable yields (Zone C) and low, unstable yields (Zone D). Different strategies could then be formulated to best manage the oil palms in each zone.

CONCLUSIONS

The spatial variations of ffb yields between and within plots were different and could be distinguished from semivariogram analysis. The semivariance was lower within plot and the lag distance (range) reached between 2 and 3-palm distance. With a triangular spacing in oil palm planting pattern, the optimum management zone for oil palm plantations was 37 palms. The large variation in ffb yields between the plots resulted in a sine wave model. Its maximum spatial range was about 6-palm distance which corresponded well to the experimental plot size of 30 (6×5) palms. Removal of N fertilizer resulted in a significant drop in ffb yields after 1992. High ffb yields above 30 t ha^{-1} year^{-1} with better temporal stability could be obtained with N applications to the palms. Long-term monitoring of ffb yields is needed to characterize their spatial and temporal pattern for the development of management zones for practical site-specific inputs. However, further work is required to ascertain the optimum spatial and temporal scales of ffb yields for reliable interpretation of yield maps.

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