

Appendix

1 Grouping plantation fields in leaf sampling units

Objectives

To group individual fields together within each estate that are so similar in terms of land class (based on soil type and terrain), tree age group, and planting material that they can be considered a single unit for the purpose of nutrient and crop management, and yield forecasting.

Standards

Each field is assigned to a leaf sampling unit (LSU) group according to its land class (based on soil type and terrain), tree age group and planting material to give LSUs of 1,000–1,500 ha. A yield profile (t fruit bunch ha⁻¹ yr⁻¹) is established for each LSU. Fields nominated for field sampling should be 30–60 ha.

Procedures

Land class

Each soil type is assigned to a land class. Land classes distinguish between soil types and terrain classes that require different nutrient management strategies. Thus, several soil types, similar in terms of nutrient management requirements, may be included under a single land class. Each field in the plantation is then assigned to a land class.

Planting material

A distinction is made between planting materials that require different nutrient management strategies (e.g. clones versus D × P material). Thus, several planting materials may be grouped together under a single planting material category if their nutrient requirements are similar. Each field in the plantation is assigned to a planting material category.

Tree age

The concentration of nutrients in frond #17 changes with palm age and thus each age

group should comprise three to five planting years (e.g. 3–7; 8–12; 13–17; 18–22; and 22–26 years after planting). Each field in the plantation is assigned to a tree age category.

Allocation of the fields to LSUs

Each field is then assigned to an LSU group according to its planting material, tree age and land class.

Initially, leaf and soil sampling is carried out in each field. Once it can be verified that the variability of leaf and soil data is smaller within LSU groups than between fields grouped under administrative categories, it may be possible to reduce the requirement for leaf sampling to a single representative field for each LSU group without losing any precision.

Establish a written policy for nutrient management in each LSU (fertilizer types, generic fertilizer schedule, empty bunch and palm oil mill recycling plan, fertilizer placement and frequency policy, and soil conservation and ground cover management policies).

Notes

- ▶ An **LSU** is a leaf sampling unit and comprises several similar fields. An **LSU palm** is a palm selected and marked to be used for leaf sampling.
- ▶ An estate of 10,000 ha with three planting materials, two age groups (3–7 and 8–20 years after planting), and three land classes gives a maximum of 18 LSUs. In practice the number of LSU groups may be much smaller because there may not be any fields that fall under some of the possible LSUs.
- ▶ LSUs should be mapped to provide information on their geographic distribution and as a means to of informing management staff involved in the implementation of fertilizer recommendations and the recycling of crop residues.
- ▶ Plantation database software should be used to provide the means of comparing yield, soil and leaf data between fields grouped together according to LSU, tree age, soil type, planting material as well as administrative unit.
- ▶ LSU groups must be updated following replanting and in response to improved information on soil types and land classes.

2 Marking palms for leaf sampling in leaf sampling units

Objectives

To establish permanent sampling reference palm points within the plantation for leaf sampling, soil sampling, black bunch counts, environment, and pest and disease surveys.

Standards

The LSU system must follow a logical pattern within the plantation (and each field). It must provide a large enough number of sample palms (25–30 palms per field) to give representative information.

The standard method is to select every tenth tree in every tenth row, excluding all abnormal palms and the two palms closest to the roadside.

The standard method should be modified in terraced areas, where LSU palms are marked using a 'cluster' marking system to include 1% of planted palms. An isometric map is a very useful tool for this process.

Procedures

The following procedures have been used successfully in many estates and represent a practical method of obtaining representative leaf samples and a network of sample palms for other census operations:

- 1 Start from one corner of the field (e.g. always start on the southeast corner), count ten rows and place a blue patch on the roadside palm.
- 2 Count the palms in from the roadside and mark the third palm with a blue patch on a lower frond butt. The identification mark should be aligned similarly on all LSU palms (i.e. on the harvesting path side).
- 3 Move forward ten palms and mark the next LSU palm.

- 4 Continue this pattern until reaching the opposite side of the field. If the final palm is less than two palms from the field edge, move the last LSU into the field by 1–2 palms.
- 5 On reaching the far side, the palm marking team moves across by ten rows, and into the field by three palms to the first palm to be marked. The team then comes back across the field marking every tenth palm as described above until the field is completed.
- 6 The roadside palm of each row containing LSU reference palms should have a blue mark on a lower frond butt facing the road. This is to help workers to locate LSU palms quickly.
- 7 Blue marks on the LSU palms are then numbered, each with a unique number or code. Usually this consists of the field number and the row number (e.g. an LSU palm in field 35, row 20 would be coded 35/20).
- 8 The LSU palms are noted and marked on the isometric map of each field. Their location can be conveniently determined with a global positioning system (GPS) device which can then be used to relocate LSU palms at subsequent leaf sampling events.

The palms are marked once and these reference points remain constant until the palm dies or the field is replanted. LSU sites may be established when the field is declared ready for harvest.

Notes

- ▶ Do not select the two palms adjacent to roads, rivers, unplantable areas, or areas affected by disease outbreaks (e.g. *Ganoderma* areas) as LSU reference palms.
- ▶ If there is a missing, diseased, abnormal or dead palm at the LSU point another healthy palm should be used as the reference palm. The selected healthy palm should be two palms away from an empty space.

Source: Rankine, I.R. and Fairhurst, T.H. (1999) *Field Handbook: Oil Palm Series Volume 3 – Mature*. (Oil Palm Series), 2nd ed. PPI/PPIC and 4T Consultants (4T), Singapore, 135p.

3 Leaf (frond) sampling

Objectives

To determine the nutritional status of leaflets from frond #9 on immature palms and frond #17 on mature palms to assist with the preparation of annual fertilizer programmes.

Standards

The appropriate frond is correctly sampled in each LSU palm in each field nominated for leaf sampling.

A composite sample, including leaf material from each LSU palm is provided for each field nominated for leaf sampling.

Leaf sampling must follow procedures very carefully to avoid sample contamination.

Frond #17 is used to allow year-on-year comparisons and to compare results with established critical nutrient levels (Tables A1 and A2).

Leaf samples are analyzed for N, P, K, Mg, Ca, B, Cu, Zn. Other nutrients may be included for palms planted on particular soil types.

Leaf sampling is carried out once each year but monthly sampling of a few LSU fields is required to determine seasonal fluctuations in leaf nutrient levels.

Procedures

Frond #17 is sampled from the labelled reference LSU palms in some or all fields in a leaf sampling unit (LSU) and prepared for analysis.

Cleanliness is essential at all stages to prevent sample contamination.

Collect samples between 6.30 am and 12.00 noon.

- 1 Locate the LSU palm and ensure that each is in a healthy condition. The LSU marking system (every tenth tree in every tenth row) will result in a 1% sample.
- 2 Abnormalities and deficiency symptoms (for N, P, K, Mg, B and Cu) identified on

LSU palms are recorded at sampling. Record the petiole cross-section (PCS) and frond production rate if required (Appendix 6).

- 3 Frond #17 is located by counting from the first fully open frond in the centre of the crown (frond #1) and removed with a sickle or chisel (see Ng *et al.*, this volume).
- 4 The frond is cut into three approximately equal sections. The tip and base sections are discarded and placed in the frond stack.
- 5 Twelve leaflets are selected and removed from each frond. Six leaflets are cut from each side at the mid-point of the frond section. Ensure that the 12 leaflets comprise three from the upper rank and three from the lower rank *from each side* of the rachis.
- 6 The leaflet samples from each field (or smaller area if required) are put together in a large labelled plastic bag. About 500 leaflets are collected for each field of 30 ha (e.g. 30 ha × 136 palms ha⁻¹ × 1% sampling points × 12 leaflets)
- 7 The samples are then sent to the estate laboratory or sample preparation room for further preparation.
- 8 The leaflets are bundled and trimmed to retain the 20–30 cm midsection.
- 9 It is not necessary to wash the leaves!
- 10 The mid-rib of each leaflet section is removed and discarded.
- 11 The remaining parts of the leaflets (lamina) are then cut into small pieces 2 cm long and placed on aluminum trays to be dried.
- 12 The samples must be clearly labelled at all stages of the process.
- 13 The leaflets are dried in a fan-assisted oven for 48 hours (65 °C) or 24 hours (105 °C). Leaf N concentration will be reduced if the temperature in the oven exceeds 105 °C!
- 14 After drying, the leaflets are placed in labelled plastic bags.
- 15 The sample is divided into two. Half is retained as a backup and for future reference (stored in a cool, dry place) and half is submitted for analysis.
- 16 It is recommended that leaf samples be ground at the estate before they are sent for analysis. This reduces processing time (and cost) for analysis and allows the

estate to carry out important cross-checking on laboratory analysis quality.

Leaf sampling is usually carried out once each year. More frequent sampling may be required to examine specific areas or to investigate particular nutritional problems.

Leaf sampling should be done at the same time each year and not during very wet or very dry periods. Complete the sampling procedure in the shortest possible time.

Tentative critical leaf nutrient levels are given in Table A1 and A2.

Notes

- ▶ Annual frond analyses should be interpreted in conjunction with soil analysis data, field inspections, and compared to results from previous years. Use of a suitable agronomic database will allow for more efficient data storage and the analysis of trends.
- ▶ Sample a few LSU fields at monthly intervals to determine magnitude of seasonal fluctuations in leaf nutrient levels.
- ▶ Frond #9 is used for leaf analysis in young palms, but results may be difficult to interpret. The usual practice is to delay sampling until frond #17 can be used (i.e. at least four years after planting).
- ▶ Samples should be taken at least three months after a fertilizer application so that leaf sampling results are not affected by

fertilizer applied recently. In the first three years after planting, application of fertilizer may be done at frequent intervals and there may not, therefore, be any three-month period during which no fertilizer has been applied.

- ▶ Since fertilizer costs are such a large part of total field costs it is essential to verify that the laboratory carrying out leaf analysis is reliable. The service laboratory must be checked each year by submitting cross-check samples. For this purpose, prepare a large homogenous bulk sample of dry ground leaf material from frond #17 and store in a cool, dry place. Submit five sub-samples with each estate consignment. These five samples are to be used to test the variability in analysis within a batch and over time. If laboratory analyses show unacceptable variation within a batch of samples or between years, the analysis must be repeated.
- ▶ A second cross-check is to include 5–10 identical paired samples with each sample consignment. Plot the results in a graph. The point plotted for each pair of samples should lie on or close to a 1:1 straight line in the graph.

Source: (1) Rankine, I.R. and Fairhurst, T.H. (1999) *Field Handbook: Oil Palm Series Volume 3 – Mature. (Oil Palm Series)*, 2nd. ed. PPI/ PPIC and 4T Consultants (4T), Singapore, 135p. (2) Fairhurst, T. (1998) *Nutrient Deficiency Symptoms and Disorders in Oil Palm (Elaeis guineensis Jacq.). Pocket Guide*. PPI, Singapore, 31p.

Table A1. Critical nutrient concentration ranges of frond #17 in young palms (≤ 6 years).

Element	Deficiency	Optimum	Excess
N (%)	<2.50	2.6 - 2.9	>3.1
P (%)	<0.15	0.16 - 0.19	>0.25
K (%)	<1.00	1.1 - 1.3	>1.8
Mg (%)	<0.20	0.3 - 0.45	>0.7
Ca (%)	<0.30	0.5 - 0.7	>0.7
S (%)	<0.20	0.25 - 0.40	>0.6
Cl (%)	<0.25	0.5 - 0.7	>1.0
B (mg kg ⁻¹)	<8	15 - 25	>40
Cu (mg kg ⁻¹)	<3	5 - 8	>15
Zn (mg kg ⁻¹)	<10	12 - 18	>80

Table A2. Critical nutrient concentration ranges of frond #17 in older palms (≥ 6 years).

Element	Deficiency	Optimum	Excess
N (%)	<2.30	2.4 - 2.8	>3.0
P (%)	<0.14	0.15 - 0.18	>0.25
K (%)	<0.75	0.9 - 1.2	>1.6
Mg (%)	<0.20	0.25 - 0.40	>0.7
Ca (%)	<0.25	0.50 - 0.75	>1.0
S (%)	<0.20	0.25 - 0.35	>0.6
Cl (%)	<0.25	0.5 - 0.7	>1.0
B (mg kg ⁻¹)	<8	15 - 25	>40
Cu (mg kg ⁻¹)	<3	5 - 8	>15
Zn (mg kg ⁻¹)	<10	12 - 18	>80

4 Soil sampling for analysis and soil fertility appraisal

Objectives

To sample and analyze the physical and chemical soil properties in each field for use when determining management procedures and fertilizer requirements.

To provide the basis for grouping fields according to soil types, land class and soil fertility status.

Standards

A land class (based on soil type) is attributed to each field.

Data for soil pH, organic C, total N, available P, exchangeable K, Mg and Ca for the soil beneath the weeded circle and beneath the frond stack in the 0–20 cm depth must be available for each field.

Soil analysis is carried out at five-year intervals.

Procedures

- 1 Auger samples are taken using an Edelman ('Dutch') auger or equivalent at each LSU point.
- 2 Two samples (200 g) are taken at each LSU palm at the 0–20 cm depth, from soil beneath the circle and beneath the closest frond stack. These two samples are kept separate so that the nutritional status of each zone can be compared.
- 3 When sampling has been completed, the 0–20 cm samples from each zone are then bulked to produce two samples for each field (circle, 0–20 cm; frond stack, 0–20 cm). Soil samples are air-dried and two representative 200 g sub-samples are taken from each bulk sample. One sample is sent for analysis and the other is stored in a cool, dry place as a backup and for future reference.

- 4 The sub-samples should be sealed in plastic bags which are clearly marked, packaged and dispatched promptly to a reputable laboratory.
- 5 Soil samples are usually packed in plastic sample bags with a waterproof label showing the estate name, field name and crop grown on the site. The label can be sealed inside the bag so that each bag always has a label attached.

Soil test results should be used as a guide only, and should be used together with the results of leaf analysis to prepare fertilizer recommendations. The results should also be related to soil types and boundaries, and visual field inspections.

Soil sampling should be carried out once during the immature phase and every five years thereafter.

Soil samples should not be taken during very dry or very wet periods.

Collect soil samples at least two months after the most recent fertilizer application.

Critical values for soil chemical properties are given in Table A3.

Notes

- ▶ Database software is recommended for the analysis of soil data.
- ▶ It is essential to monitor trends in soil fertility to prevent long-term depletion of nutrients.
- ▶ Since fertilizer costs are such a large part of total field costs it is essential to verify that the laboratory carrying out soil analysis is reliable. The service laboratory must be checked each year by submitting cross-check samples. For this purpose, prepare a large homogenous bulk sample of dry soil and store in a cool, dry place. Submit five sub-samples with each estate consignment to determine variability within the analysis of the standard sample and between years. If laboratory analyses show unacceptable variation, the laboratory must be requested to repeat the entire analysis.

Table A3. Soil fertility evaluation for oil palm.

Property	Units	Very low	Low	Moderate	High	Very high
pH	-	<3.5	4.0	4.2	5.5	>5.5
Organic C	%	<0.8	1.2	1.5	2.5	>2.5
Total N	%	0.08	0.12	0.15	0.25	>0.25
Total P	mg kg ⁻¹	<120	200	250	400	>400
Available P	mg kg ⁻¹	<8	15	20	25	>25
Exchangeable K	cmol _c kg ⁻¹	<0.08	0.2	0.25	0.3	>0.3
Exchangeable M	cmol _c kg ⁻¹	<0.08	0.2	0.25	0.3	>0.3
ECEC	cmol _c kg ⁻¹	<6	12	15	18	>18
Deficiency	-	Likely	Possible	-	-	Induced
Hidden hunger	-	-	-	Likely	-	Possible
Response to fertilizer	-	Definite	Likely	Possible	-	Possible

Source: after Goh et al., 1997.

- ▶ A second cross-check is to include 5–10 identical paired samples with each sample consignment. Plot the results in a graph. The point plotted for each pair of samples should lie on or close to a 1:1 straight line in the graph.

Source:(1) Rankine, I.R. and Fairhurst, T.H. (1999) *Field Handbook: Oil Palm Series Volume 3 – Mature. (Oil Palm Series)*, 2nd. ed. PPI/ PPIC and 4T Consultants (4T), Singapore, 135p. (2) Goh, K.J., Chew, P.S., Heng, Y.C., Tey, S.H. and Gan, H.H. (1997) *Developing decision support systems for plantations: A new role for agronomists*. The Planter, **73**, 687–693.

5 Isometric palm point mapping

Objectives

To create a permanent pictorial record of the palm stand after planting.

To provide a base map to display the results of future census operations.

To help determine whether the field is ready for harvesting.

Standards

An isometric map shows mature, immature, supply, dead, unplantable and abnormal palm points. Roads, bridges, rivers and creeks, and noteworthy topographic features (e.g. swamps, hills) are also displayed (Figure A1).

Digital base maps are now preferred and many plantations record the location of each palm point at planting using a global positioning system (GPS) device.

Geographic information systems (GIS) can be used to plot isometric survey data collected with a GPS. Such maps are much easier to update and can be printed to show different levels of detail.

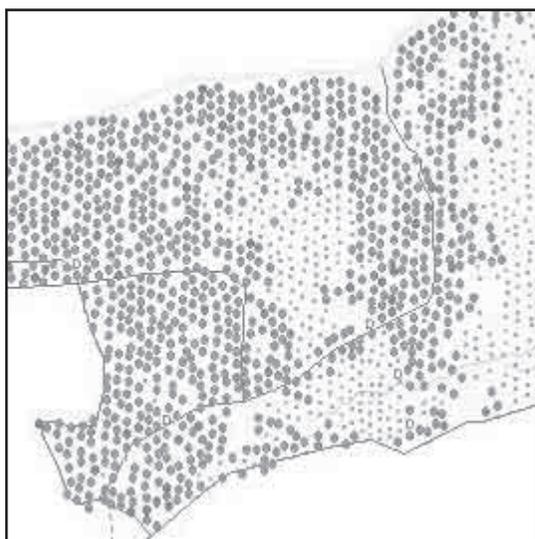


Figure A1. Isometric map showing the location of roads, bridges, rivers, planting points and LSU palms.

Procedures

The field is surveyed after planting, and each palm is classified as either mature, immature, supply, dead, unplantable or abnormal.

The survey is repeated immediately before harvest commences and thereafter at five-year intervals (if possible to coincide with soil sampling).

Palms are marked on the map as a dot (immature and supply palms) and a dot within a circle (mature palms). Symbols may be used to identify other palm types, but it should be possible to update paper maps.

The field area is calculated (total number of plantable points divided by the palm density). This may be different from the physical area of the field when there are a large number of unplantable points due to the presence of rivers, creeks and unplantable areas.

The field hectareage based on planted points (not the physical hectareage) is always used to calculate yield and is entered in the agronomy database.

Notes

- ▶ Store isometric maps in a proper map drawer.
- ▶ Keep a stock of two photocopies of each map for use during periodic surveys and census operations.
- ▶ Consider preparing reduced, laminated isometric maps for field use during leaf sampling, patrols, etc. Noteworthy areas can be marked on the map using a chinagraph pencil.
- ▶ A rough estimate of leaf area index (L) can be calculated from data for leaf area, the number of green fronds production rate and the number of healthy productive palms per hectare. This may be useful to compare canopy development in each field or LSU group.

Source: Rankine, I.R. and Fairhurst, T.H. (1999) *Field Handbook: Oil Palm Series Volume 3 – Mature. (Oil Palm Series)*, 2nd. ed. PPI/ PPIC and 4T Consultants (4T), Singapore, 135p.

6 Measurement of vegetative and generative growth in mature palms

Objectives

To monitor the vegetative growth of oil palms in terms of leaf production, leaf area, petiole cross-section, trunk growth and total dry matter production.

Standards

Standard vegetative growth measurements are taken in all treatments in fertilizer experiments and selected commercial fields.

Procedures



Rate of leaf production

1. Mark frond #1 (i.e. the youngest fully open frond) at the start of the recording period. The most conspicuous colour to use is light blue, but identification is easier when a different color is used at each round of marking.
2. At each survey, note position of the previously marked frond #1 in relation to new frond #1. Left-handed palms should be counted right from frond #1, and right-handed palms to the left.
3. Estimate the number of new leaves produced during the period using Table A4. For example, if the previously marked frond #1 is now the third frond from the top in parastichy 4 (i.e. next to parastichy 1), 19 new leaves have been produced. If the recording period was 12 months, frond production rate = $19/12 = 1.6$ fronds month⁻¹.
4. Mark a new frond #1 at least once per year or at every survey to provide a new reference point before the old frond #1 is pruned off.

Depending on palm age and environment, the rate of leaf production should be 18–40 leaves yr⁻¹ or 1.5–3.3 fronds month⁻¹.

It should be noted that the order of the columns in Table A4 follows the order of the parastichies (spirals) around the tree, and not the order of production of leaves. The latter is given by the parastichy numbers at the head of each column.



Total number of green leaves

Where data for individual palms are required, the number of leaves in each spiral must be counted.

To estimate the total number of green leaves (*g*) for a plot of palms, count the number of leaves in spiral 4 on five palms and calculate the mean.



Trunk height

1. Identify frond #41 (the sixth frond in spiral 1), or the leaf base if it has been pruned off. (Any other convenient standard leaf can also be used, since increments in height from year to year are of more interest than actual height, for most purposes).
2. Alternatively, if frond #1 is being marked regularly for leaf production studies, measurements can be made to the base of the oldest of these marked leaves.
3. If necessary, remove adjacent leaf bases to expose the lower edge of the selected leaf (i.e. where the leaf joins the trunk). With experience, however, the position of this point can be estimated without removing adjacent leaves.
4. Measure height from ground level to base of the leaf. If very precise height increment data are required, it may be better to mark a reference point near the base of the trunk with blue paint, rather than measuring to ground level.

Height increments vary between 0.3–0.9 m yr⁻¹ (or more at very high planting densities and on volcanic soils).

Table A4. Diagram for determining number of leaves produced in a given period, from the present position of leaf #1 marked at the beginning of the period.

Fronde number	Parastichy number								Number of fronds produced since marking
	1	4	7	2	5	8	3	6	
	Present position of previously marked Fronde 1								
1	1								0
2				1					1
3							1		2
4		1							3
5									4
6								1	5
7									6
8						1			7
9	2								8
10				2					9
11							2		10
12		2							11
13					2				12
14								2	13
15			2						14
16						2			15
17	3								16
18				3					17
19							3		18
20		3							19
21					3				20
22								3	21
23			3						22
24						3			23
25	4								24
26				4					25
27							4		26
28		4							27
29					4				28
30								4	29
31			4						30
32						4			31
33	5								32
34				5					33
35							5		34
36		5							35
37					5				36
38								5	37
39			5						38
40						5			39
41	6								40
42				6					41
43							6		42
44		6							43
45					6				44
46								6	45
47			6						46
48						6			47



Leaf area

1. Select either a standard leaf (e.g. frond #17) or measure those leaves marked as frond #1 for leaf production records. The time of opening for these leaves is known, thus giving good standardization.
2. Count number of leaflets (n) on one side of the rachis, including rudimentary leaflets at the base and fused leaflets at the tip of the leaf.
3. Measure rachis length (rl) and mark a point at $rl \times 0.6$ from the base of the rachis (marking is done easily by tying two opposite leaflets together). Alternatively, this point can be estimated visually.
4. Cut about ten leaflets from each side, in the region with the longest leaflets about $rl \times 0.4$ from the leaf tip.
5. Select the six longest undamaged leaflets from the total of 20, and measure the length and mid-width of each leaflet (the mid-point can easily be determined by folding the leaflet in half). If the length is measured after folding, a shorter ruler can be used.
6. Calculate length \times mid-width for each leaflet, and then the mean product for all six leaflets measured (b):

$$\text{Relative leaf area (rla)} = 2n \times b$$

where b is the mean length \times width and n is the leaflet number on one side of rachis.

True area (a) is fairly constant at about $rla \times 0.55$ with some variation with palm age and progeny.

The value for true area (a) ranges from $<1\text{m}^2$ per leaf at field planting to $\leq 12\text{m}^2$ per leaf in fully grown palms.



Petiole cross-section

1. Select either a standard leaf (e.g. frond #17) or measure those leaves marked as frond #1 for leaf production records.
2. Measure width (in cm) of petiole at point of insertion of the lowest rudimentary leaflet (this is normally lower on one side than on the other; the lower side should be taken).
3. Either measure depth at the same point with callipers, or cut through the petiole at the same point, and measure the depth across the cut end with a ruler.
4. Calculate the petiole cross-section (PCS):

$$P = \text{width} \times \text{depth}$$

The PCS value increases with palm age, up to about 60 cm^2 .

Half width \times depth is sometimes calculated and this more closely approximates the actual triangular cross-section area. Care must be taken to specify which calculation method is being used.

Petiole cross-section is highly correlated with leaf dry weight, total palm dry weight and vegetative dry matter production.



Trunk diameter

1. Remove sufficient old leaf bases, at about 1.5 m above ground level (i.e. above the basal bulge), to expose about 5 cm^2 of trunk at two points on opposite sides of the trunk.
2. Measure trunk diameter with a large pair of calipers.

Trunk diameter ranges from 0.30 to 0.50 m (but is greater at basal bulge).



Rachis length

1. Select either a standard leaf (e.g. frond #17) or measure those leaves marked as frond #1 for leaf production records.
2. Measure length from the point of insertion of lowest rudimentary leaflet to the tip of the rachis (not the tip of terminal leaflets).



Dry matter in vegetative growth

Dry weight of trunk

The weight of dry matter per unit trunk volume (S) has been shown to depend on palm age (y , in years):

$$S = 0.0076 y + 0.083 \quad (\text{A1})$$

where S is trunk density (kg dm^{-3}).

1. Measure trunk height increment (h).
2. Calculate volume increase, u (dm^3):

$$u = \pi d \times h/4 \quad (\text{A2})$$

3. Calculate dry weight increase, T (kg):

$$T = u \times S \text{ (kg yr}^{-1}\text{)} \quad (\text{A3})$$

Note that if d and h are expressed in dm, u is then in dm^3 , and T in kg.

Dry weight of leaves

1. For palms >2 years after planting, calculate the mean leaf dry weight, W (kg):

$$W = 0.102 P + 0.206 \quad (\text{A4})$$

where P is the petiole cross-section.

2. Calculate the total dry weight of new leaves:

$$\text{Total dry weight} = g \times W \text{ (kg yr}^{-1}\text{)} \quad (\text{A5})$$

Note that the relationship given in equation (A4) does not hold in palms younger than about two years after planting. Petiole cross-section can still be used as a growth index in younger palms, however.

Total vegetative dry matter increment

Calculate vegetative dry matter increment, V ($\text{kg palm}^{-1} \text{ yr}^{-1}$):

$$V = T + g \times W \quad (\text{A6})$$

The total vegetative dry matter increment ranges between $< 50 \text{ kg palm}^{-1} \text{ yr}^{-1}$ in palms two years after planting, and up to $130 \text{ kg palm}^{-1} \text{ yr}^{-1}$ in vigorous older palms.



Bunch dry weight

1. Dry weight of bunches is approximately 53% of fresh weight, provided the fruit:bunch ratio is 60–65%. Where large differences in fruit:bunch are found, dry matter content of the bunch (B), can be estimated:

$$B = 0.37 X + 29 \quad (\text{A7})$$

where X is fruit:bunch ratio (X and B are both percentages)

2. Calculate total dry weight of bunches (Y , in $\text{kg palm}^{-1} \text{ yr}^{-1}$) from B and fruit bunch yield.

The total dry weight of bunches is directly related to fruit bunch yield.



Leaf area index

Leaf area index (L) is the ratio of total leaf area to ground area. It is dimensionless as it is a ratio.

1. Calculate total leaf area per palm, A (m^2):

$$A = rla \times g \quad (\text{A8})$$

where rla is the mean area per leaf, and g is the number of green leaves per palm.

2. Calculate total leaf area per hectare, LA :

$$LA = A \times D \quad (\text{A9})$$

where A is the total leaf area per palm, and D is the planting density (palms ha^{-1})

3. Calculate the leaf area index, L :

$$L = A \times D / 10,000 \quad (\text{A10})$$

The normal range for L in mature plantings is between 4–7 and ≤ 10 in very high planting densities.

Adapted from: Corley, R.H.V. and Breure, C.J. (1981) Measurements in oil palm experiments. Internal report. Unilever Plantations Group. London. 33p.

7 Measurement of nutrient use efficiency

Objectives

To estimate the indigenous nutrient supply and the recovery and physiological efficiency of fertilizer nutrient use in oil palm fertilizer experiments and commercial fields by measuring annual nutrient uptake without destructive sampling (Appendix 6).

Standards

Annual incremental biomass contained in trunk, leaves and bunches is measured in experiments and commercial fields using the methods described in Appendix 6.

Procedures

Nutrient concentration is measured in rachis, leaflets, trunk and bunches in each treatment of each fertilizer experiment using the same sampling method used for other measurements in fertilizer experiments.

Annual nutrient uptake in leaves, bunches and trunk can be estimated provided the following data are available:

- ▶ Fruit bunch yield (t ha⁻¹)
- ▶ Petiole cross-section (PCS) (cm²)
- ▶ Leaf production rate (leaf yr⁻¹)
- ▶ Trunk incremental growth (m yr⁻¹)
- ▶ Trunk diameter (m)
- ▶ Nutrient concentration (N, P, K, Mg) in bunches by measurement or from standard values from the literature (% on dry matter)
- ▶ Nutrient concentration (N, P, K, Mg) of rachis, leaflets and trunk (% on dry matter)

Annual nutrient uptake in each fertilizer treatment is calculated by multiplying the amount of biomass produced in each compartment of biomass production by the nutrient concentration in the respective tissue.

Most agronomists analyze rachis as well as leaflet tissue and PCS as part of routine annual fertilizer experiment monitoring. Trunk incremental growth can be included in the program for annual monitoring of fertilizer experiments. Trunk diameter need only be measured once.

Recent work suggests that there are large differences between progenies and planting materials in the nutrient concentration in bunches. The nutrient concentration in bunches should therefore be assessed for the main planting materials used.

Recovery efficiency (*RE*) and physiological efficiency (*PE*) of fertilizer nutrients can only be calculated if there are data for nutrient uptake for omission plots for each nutrient located on representative soils. The following plots are required:

- ▶ **-N** plot receives no N fertilizer, but all other nutrients (P, K, Mg, B, Cu) are supplied in optimal amounts.
- ▶ **-P** plot receives no P fertilizer, but all other nutrients (N, K, Mg, B, Cu) are supplied in optimal amounts.
- ▶ **-K** plot receives no K fertilizer, but all other nutrients (N, P, Mg, B, Cu) are supplied in optimal amounts.
- ▶ **-Mg** plot receives no Mg fertilizer, but all other nutrients (N, P, K, B, Cu) are supplied in optimal amounts.

Each omission plot comprises 64 palms (~0.5 ha) to provide two guard rows around the central plot of 16 palms used for recording. Provided the topography is not too hilly, a set of omission plots (four nutrients × three replicates = 12 plots) can be installed in a single field.

Recovery efficiency (*RE*) provides an indication of the amount of fertilizer nutrients applied that have been taken up by the crop:

$$RE_{FN} = (UN_{+FN} - UN_{0, FN}) / FN \quad (A11)$$

where UN_{+FN} is the total palm uptake of fertilizer nutrient measured in aboveground biomass in plots that receive fertilizer nutrients at the rate of FN (kg ha⁻¹); and $UN_{0, FN}$ is the total nutrient uptake in a nutrient omission plot (i.e. without the addition of a particular fertilizer nutrient).

Recovery efficiency is affected by factors such as:

- ▶ Quantity of fertilizer applied;
- ▶ Nutrient availability in fertilizer;
- ▶ Effect of soil properties on nutrient availability (e.g. soil P sorption, N-immobilization, K-fixation);
- ▶ Frequency and timing of application;
- ▶ Competition from weeds; and
- ▶ Effect of rainfall on leaching and surface runoff losses.

Physiological efficiency (*PE*) provides an indication of the increase in yield for each additional unit of nutrient uptake.

$$PE_{FN} = (BY_{+FN} - BY_{0FN}) / (UN_{+FN} - UN_{0FN}) \quad (A12)$$

where BY_{+FN} is the bunch yield in a treatment with fertilizer nutrient application (kg ha^{-1}); BY_{0FN} is the bunch yield in a treatment without fertilizer nutrient (*FN*) application; UN_{+FN} is the total uptake of the particular nutrient in a fertilized plot and UN_{0FN} is the uptake of the particular nutrient in an omission plot.

Physiological efficiency is affected by factors such as:

- ▶ Progeny or planting material response to fertilizer nutrients;
- ▶ Canopy management (over and/or under-pruning);
- ▶ Inter-palm competition;

- ▶ Supply of other nutrients (e.g. effect of K supply on *PE* of N use and *vice versa*); and
- ▶ Effect of pests and disease on canopy efficiency.

Notes

It should be remembered that these methods are used to estimate nutrient uptake in each treatment in oil palm experiments for the purpose of improving the interpretation of fertilizer experiment results *on a comparative basis* and not as absolute values for nutrient uptake.

The *RE* and *PE* can also be measured in commercial areas provided nutrient omission plot data are available. Since workers must visit each leaf sampling unit (LSU) palm to collect leaf samples, it is argued that frond production rate (based on recording the position of frond #1 marked the previous year), trunk incremental growth and petiole cross-section (PCS, a useful indicator of vegetative growth) can be measured at the same time. Trunk diameter need only be measured once. For commercial areas, standard values for nutrient concentration in trunk and bunches may be used but nutrient concentration in rachis as well as leaflets should be measured.

Source: (1) Goh and Härdter, this volume. (2) Prabowo, N.E., Lubis, T., Fairhurst, T., Foster, H.L. and Nafisah, E.N. (2002) Efficiency of fertiliser recovery by oil palm in Sumatra. In: *International Oil Palm Conference and Exhibition*. IOPRI, Bali, Indonesia, 8–12 July 2002, 9p.

8 Sampling fertilizer materials for analysis

Objectives

To ensure that purchased fertilizer inputs meet the standards specified by the supplier and stipulated in contract tender documents.

Standards

Fertilizers used in the plantation meet specified standards.

Procedures

I Sampling of fertilizers in packages

All bags in a single consignment of the material of the same grade and type, drawn from a single batch of manufacture constitute one lot. Selected bags should be intact and in good external condition.

- ▶ If a consignment is declared to consist of different batches of manufacture, the batches should be marked separately. The

groups of bags in each batch constitute separate lots.

- ▶ If a consignment is drawn from a continuous process, 2,000 bags (or 100 t) of the material constitute one lot. The number of bags to be sampled depends on lot size (Table A5).
1. Lay each bag to be sampled horizontally and take a full-length diagonal core from bottom corner to top corner or from two opposite corners using the non-corrosive probe.
 2. Mix the cores thoroughly to form a representative sample and store in an airtight container. The slot must be inserted face down when the probe is pushed into the bag and turned 180° once it has penetrated fully so that the slot faces upward. The probe is then removed from the bag.

II Sampling of bulk fertilizers

1. From each lot or batch, take 20 samples (cores) at random from different parts and at different depths using a non-corrosive 130–155 cm long grain probe (Figure A2).
2. Mix the samples thoroughly and store in an airtight container.

Table A5. Scale of sampling and method of selection.

Lot size	Sample size	Method of selection
	bags	
1 - 3	all	At random
4 - 15	3	
16 - 50	10	
51 - 50	15	
151 - 500	25	
501 - 2000	35	

If the lot size exceeds 2000 packages, the sampling cycle is repeated.

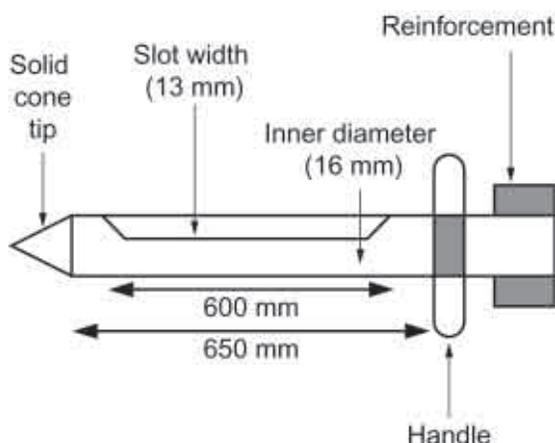


Figure A2. Fertilizer sampling probe.

III Preparation of sample for analysis

1. Transfer the collected sample to a suitable sample riffle. Set the riffle in operation until the sample is reduced to about 250 g.
2. Grind the sample as rapidly as possible to a fine homogeneous powder so that particles pass through the appropriate sieve size (Table A6). Avoid unnecessary exposure to the atmosphere (e.g. urea is hygroscopic, and grinding should be conducted immediately after sampling).
3. Transfer the sample to a non-corrodible and airtight container. The ground sample is then sub-sampled for laboratory analysis.

Adapted from: Tiong, S. (1999) Sampling of Fertilizer: To Confirm Nutrient & Quality Specifications. In: Fertilizer Management for Oil Palm Plantations. The Incorporated Society of Planters, Sabah North East Branch, Sandakan.

Table A6. Size requirement of fertilizers for analysis.

Type of fertilizer	Example	Sieve size (mm ²)
Ground mineral phosphate	Phosphate rock	0.25
Granular fertilizer	Compound and mixture	0.25
Dry powdered fertilizer	Ground magnesium limestone	0.50
Crystalline fertilizer	Ammonium sulfate; ammonium nitrate; magnesium sulfate (kieserite)	1.00