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STUDY OF MINERAL NUTRIENT LOSSES FROM OIL PALM EMPTY FRUIT BUNCHES DURING TEMPORARY STORAGE

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ABSTRACT

Depending on the operational organization adopted by a plantation, empty fruit bunches (EFB) fresh from the mill are sometimes stored for a few days, either at the mill exit or on plot edges, before being spread in the field. Exposed to rainfall this way, the heaps are subject to substantial leaching of mineral nutrients. The trial conducted studied the dynamics of mineral nutrient release from a heap of fresh EFB stored in an open area and exposed to the elements. Watering was carried out to top up the rainfall and reach the rainfall levels defined by the protocol. Different storage times were studied over a period of two weeks.

Mineral nutrient release was rapid, especially for potassium, magnesium and boron. The release rates varied substantially depending on the nutrient and EFB position in the heap, with a wide range between the top and bottom of the heap, associated with the degree of mineralization. The released mineral nutrients accumulated in the EFB at the bottom of the heap. The most surprising result was the speed with which potassium, the main nutrient contained in EFB, was released: a fortnight into the trial, 73% of the potassium initially contained in the EFB in the upper part of the heap had been released (48% for magnesium and 60% for boron), as opposed to 16% for the EFB at the bottom of the heap.

A rapid estimation of financial losses cumulated over a year's production of EFB indicated the foregone earnings for the plantation and revealed the merits of returning EFB to the field immediately on leaving the mill. Any delay in application leads to a significant drop in the agricultural value of fresh EFB.

Keywords: EFB, storage, rainfall, mineralization, leaching.

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INTRODUCTION

Oil palm bunches processed in an oil mill generate between 20% and 25% EFB, the ligno-cellulose fibrous medium left after bunch stripping. A mill with a capacity of 60 t FFB hr^{-1} will thus produce almost 83 000 t EFB yr^{-1}. These considerable volumes of organic waste, which are produced on a continuous basis, require effective removal procedures adapted to the nature of the by-product.

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EFB is mostly used as a mineral fertilizer substitute by direct application in the field or, in some cases, after incineration and occasionally after composting. In fact, fresh EFB returns mineral nutrients and organic matter to the soil and helps to maintain soil fertility (Loong *et al*., 1987; Lim and Chan, 1989; Hornus and Nguimjen, 1992; Sadi *et al*., 1992).

In a context dominated by growing environmental concerns, oil mills are increasingly turning to agricultural utilization of oil mill by-products. The current low oil prices, combined with an increase in fertilizer prices, are also encouraging plantations to make better use of the fertilizing potential of such by-products (Caliman *et al*., 2001a).

In order to ensure that the agronomic value of EFB is put to the optimum and profitable use, farmers also need to ensure strict management of these available nutrient stocks, of their fertilizer equivalents and of spreading operations in the field.

When mineral fertilizers are directly replaced by EFB, it is necessary to determine the agronomic value of the latter, in order to adjust application rates. *Tables 1* and *2* give the mineral nutrient composition of fresh EFB on leaving the mill, along with the mineral fertilizer equivalents.

However, depending on the operational organization adopted by the plantation, EFB fresh from the mill are sometimes stored for a few days, either on a platform next to the mill, or on the edge of the plot, prior to spreading.

When exposed to rainfall this way, the heaps undergo substantial leaching, undoubtedly resulting in mineral nutrient losses likely to reduce the agricultural value of the product. Indeed, Caliman *et al*. (2001a) showed the rapidity of nutrient release once EFB is returned to the field: one week after field application, the N, P, K and Mg losses were 9%, 10%, 18% and 8% of original contents respectively, with 33 mm rainfall.

These observations led us to consider the nature and degree of such losses in mineral nutrients before EFB is returned to the field, during a rainy period representative of humid tropical conditions. A trial was therefore set up to study the mineral nutrient release dynamics in a heap of fresh EFB, also examining the vertical migration kinetics of the released nutrients.

MATERIALS AND METHODS

Principle

Observations were carried out during simulated storage of EFB in heaps on an open area exposed to the elements. Artificial watering was organized to top up natural rainfall to the levels defined in the protocol. Different storage times were studied over a maximum period of two weeks.

Empty Fruit Bunches (EFB) Heap Installation

The EFB used came fresh from the mill. They were first characterized (individual weight, average water and mineral nutrient contents) by sampling 10 EFB taken at random. The chemical analysis results are given in *Table 1*. Some EFB were also weighed and placed separately in wide-mesh plastic nets. They were to be used to monitor changes in their mineral nutrient contents over time.

TABLE 1. CHEMICAL CHARACTERISTICS OF EMPTY FRUIT BUNCHES (EFB) (10 samples)*

Parameter	Composition	
	Range	Mean
Dry matter (%)	36-41	38
Total C (% DM)	49.2-50.6	49.6
N (% DM)	0.78-1.19	0.93
P_2O_5 (% DM)	0.188-0.346	0.27
K_2O (% DM)	3.08-3.65	3.42
MgO (% DM)	0.20-0.28	0.23
CaO (% DM)	0.29-0.66	0.36
Mn (ppm DM)	10-15	13
B (ppm DM)	11-14	13
Zn (ppm DM)	19-29	23
Cu (ppm DM)	6-17	8
Fe (ppm DM)	121-301	224
Na (ppm DM)	101-162	126

Note: DM = dry matter.
Source: * Caliman *et al.* (2001a).

TABLE 2. FERTILIZER EQUIVALENT (per tonne) OF EMPTY FRUIT BUNCHES (EFB) (kg)*

Urea	7.7
Tricalcium phosphate	2.3
KCl	21.7
Kieserite	3.3

Source: * Caliman *et al.* (2001a).

The EFB were then windrowed by hand on an open area, in heaps with trapezoidal cross-sections. Within each heap, EFB in separate nets were positioned at four levels, whose characteristics are indicated in *Table 3*. A system for recovery of the drainage water was also installed. It consisted of a plastic tarpaulin installed prior to the EFB windrowing. It was thus possible to determine the quantities of mineral nutrients leached by analysing the percolates.

Experimental Design

Two factors were studied: (a) EFB heap storage time (*Table 4*) and (b) EFB positioning within the heap (*Figure 1*). Five heaps were made, each associated with a storage time. Within each heap, four EFB were positioned at each of the four study levels, constituting four replicates. Each of the four levels characterized a uniform horizon, *i.e.* a slice of the heap corresponding to all the EFB located at the same distance from the surface, and was considered to undergo the same degree of exposure to rainfall.

Simulated Watering

The heaps were set up on an open area, in order to simulate actual field conditions as closely as possible. However, in order to ensure reproducibility of the results and carry out additional studies in the future on various rainfall patterns, a rainfall simulation system was installed in each heap (*Figure*

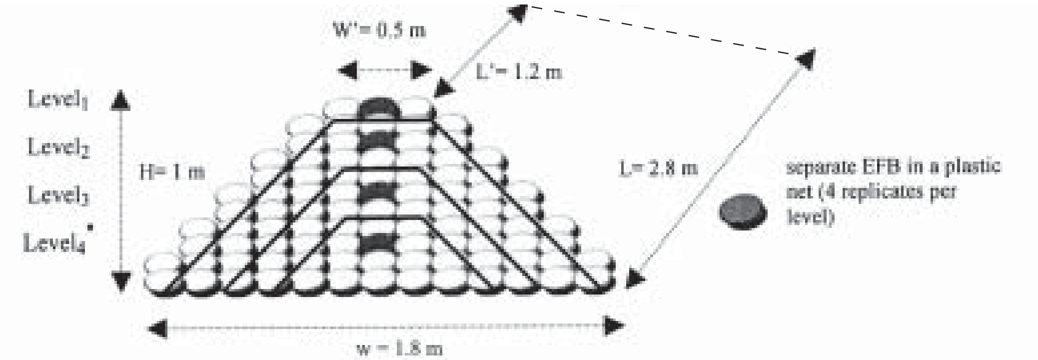
TABLE 3. DIMENSIONS OF EMPTY FRUIT BUNCHES (EFP) HEAPS

	Heap	Tarpaulin
L = length at base (m)	2.8	3.2
L' = length at top (m)	1.2	-
W = width at base (m)	1.8	2.2
W' = width at top (m)	0.5	-
H = height (m)	1.0	0.3
Ground area (m^2)	5.04	7.04
Volume[1] (m^3)	2.5	2
Density[2] ($t\ m^{-3}$)	0.26	-
Weight (t)	0.64	-

Notes: [1] Volume of a truncated pyramid = H/6[W(2L+L')+W'(2L'+L)] - the volumes of horizons I, II, III and IV were, respectively, 15%, 30%, 30% and 25% of the total volume (estimation from measurements of horizon limits theoretically determined from the EFB positioning set out in the protocol - *Figure 1*).
[2]Calculated from the total weight of EFB delivered to the trial site (double weighing of truck on weighbridge).

TABLE 4. STORAGE TIME (days)

T_1	2
T_2	4
T_3	6
T_4	9
T_5	15



Top of heap
Upper middle
Lower middle
Bottom of heap*

Note: * These EFB were placed around 20 cm above the bottom of the heap (second to last horizon) to prevent any contact and contamination with stagnated filtration water before recovery.

Figure 1. Empty fruit bunches (EFB) positioning in the heap - (cross-section of the windrow).

2). It consisted of a perforated hosepipe calibrated beforehand to ensure rainfall of an intensity similar to average natural conditions.

The aim sought in this trial was to simulate the typical rainfall of a rainy season, *i.e.* a mean of 240 mm [mean of four reference years (1996-1999) at the trial site (Riau-Indonesia)] per month, with rainfall every two or three days. The intensity of rainfall applied was fixed to at least 20 mm/two or three days. Artificial watering was therefore used to top up natural rainfall when it was under 20 mm/two or three days (see the calendar on *Table 5*).

The aim in controlling rainfall was to reach at least the quantities fixed beforehand by the protocol, on the understanding that they might be exceeded in the event of heavy rain.

nutrients released. The results shown are the means of four replicates per level.

The leachates were covered after each watering operation and their volume determined for each heap. A composite sample, each corresponding to the storage times studied in the trial, was also sent to the laboratory for complete chemical analysis.

RESULTS

Rainfall

The rainfall recorded during the trial made it possible to precisely follow the protocol, except on

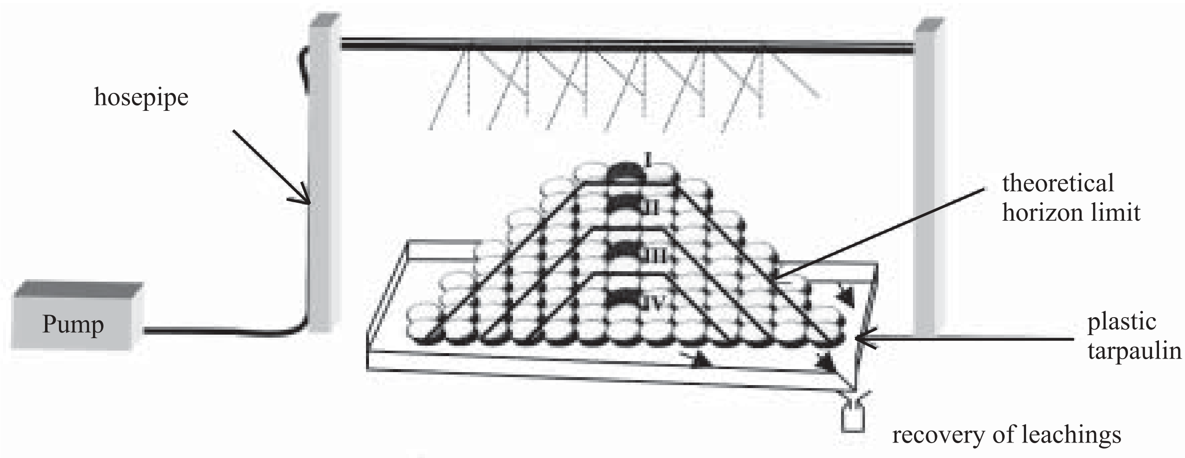


Figure 2. Simulation of rainfall on a heap of empty fruit bunches (EFB) during storage.

TABLE 5. ESTIMATED HEAP WATERING TIMETABLE

Days	Rainfall tested (mm)	
	Over the period	Cumulated
1-2	20	20
3-4	20	40
5-6	20	60
7-9	20	80
10-12	20	100
13-15	20	120

Observations

Rainfall was recorded with a rain gauge installed at the trial site. The top-up rainfall was then calculated to make up to the desired total. The five heaps were opened after two, four, six, nine and 15 days of storage, an hour after the final watering operation, to allow complete drainage. The EFB in separate nets were weighed again, then analysed in the laboratory to determine the quantities of mineral

the last day, where it exceeded the initially programmed total of 120 mm by 9 mm.

During the first four days of storage, water applications were totally artificial. However, on the 12th day, rainfall alone reached the programmed 20 mm level.

Figure 3 shows the natural rainfall and artificial watering distribution for the whole trial.

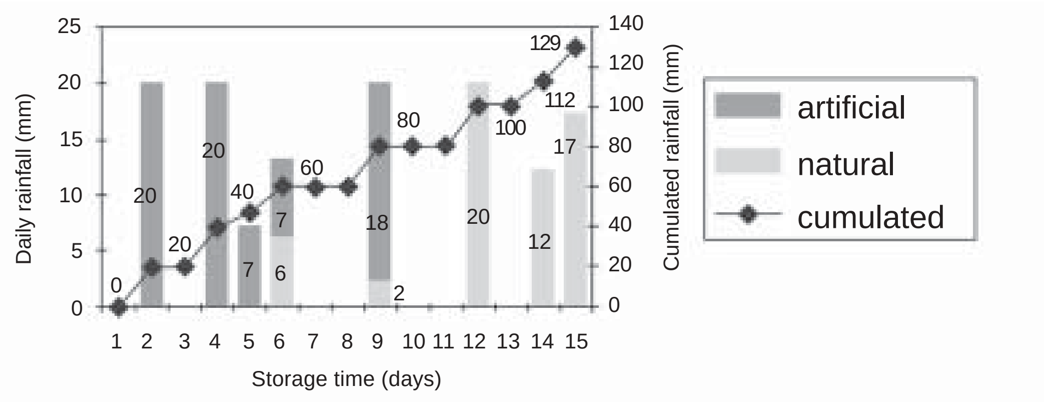


Figure 3. Rainfall recorded during the trial.

Analysis of Leachates

The cumulated quantities and chemical composition of leachates recovered from the bottom of the heaps are shown in *Table 6*. These data were used to calculate the total quantities of nutrients lost on an EFB heap scale, and an estimation of the cumulated relative losses during storage was made for each nutrient (*Table 7*).

The most surprising result was the speed with which potassium and magnesium were released: after only four days storage, 13% of these nutrients had been lost through leaching by 40 mm rainfall (two showers). Fifteen days into the trial, more than a third of the total potassium contained in the EFB had migrated, from the 129 mm rainfall recorded. Potassium ions are highly accessible and soluble in water, which explains its substantial losses.

The proportions of phosphorus and nitrogen lost through leaching were smaller, in conjunction with the slower release dynamics for these two nutrients. The values given above do not take into account the losses through volatilization of the ammonium fraction from the leachates and EFB.

TABLE 6. QUANTITIES AND CHEMICAL COMPOSITION[1] OF LEACHATES RECOVERED AFTER EACH STORAGE PERIOD

Parameter	2 days	4 days	6 days	9 days	15 days
Cumulated rainfall (mm)	20	40	60	80	129
Quantities of water recovered at base[2] (l) – in ( ), the % of water recovered compared to the amount applied[3]	119(84.6)	131(92.9)	133(94.3)	123(87.2)	293(84.9)
pH	5.27	6.23	6.52	7.76	6.46
NH_4^+ (mg litre^{-1})	35.7	95.9	-	54.7	17.5
NO_2^- (mg litre^{-1})	0.63	0.71	-	0.20	0.90
NO_3^- (mg litre^{-1})	204	213	-	74	88
Total N (mg litre^{-1})	509	527	297	287	324
P (mg litre^{-1})	-	-	-	76	67
K (mg litre^{-1})	3 345	3 765	3 470	3 075	2 255
Mg (mg litre^{-1})	222	128	102	63	54
Ca (mg litre^{-1})	94	30	12	59	38
Mn (mg litre^{-1})	1.07	0.52	0.80	0.71	0.67
Cu (mg litre^{-1})	0.18	0.18	0.06	0.25	0.21
B (mg litre^{-1})	-	-	-	0.84	1.67
Zn (mg litre^{-1})	2.57	1.91	1.66	2.19	1.18
Fe (mg litre^{-1})	2.39	2.44	5.08	7.32	10.04

Notes: [1] Results obtained by analysing a composite sample of leachates from all the heaps not yet opened up on the date indicated (mixture of five sub-samples for the 2nd day, four for the 4th day... 1 for the 15th day).
[2] Quantity corresponding to the mean of the leachate volumes measured for all the heaps not yet opened on the date indicated (five measurements for the 2nd day, four for the 4th day... 1 for the 15th day).
[3] The theoretical quantity of water reaching the tarpaulin was 7.04 l mm^{-1} of rainfall, *i.e.* 141 litres per 20 mm.
(-) Data unavailable. In later calculations, the missing data were replaced with the mean of the available results for the nutrient in question.

TABLE 7. CALCULATION OF CUMULATED RELATIVE LOSSES FOR EACH NUTRIENT [as a % of initial values from fresh empty fruit bunches (EFB)]

Nutrient	2 days	4 days	6 days	9 days	15 days
N	3	6	8	9	13
P	3	6	10	13	20
K	6	13	20	26	35
Mg	8	13	17	19	24
Ca	2	2	3	4	6
Mn	4	6	10	13	19
Cu	1	2	3	4	8
B	5	10	16	19	34
Zn	5	10	14	19	25
Fe	< 1	1	2	4	9

Note: *e.g.*: for N, there was 640 kg at 38% DM with 0.93% N/DM at the outset, hence a total of 2.273 kg of N in the fresh EFB; after four days, N in the drainage water was (0.509 g litre^{-1} x 119 litres)+(0.527 g litre^{-1} x 131 litres) = 0.129 g, *i.e.* a relative cumulated loss of 0.129/2.273 ≈ 6 %.

Vertical Migration Kinetics of the Nutrients

Humidity. *Figure 4* shows the changes in average humidity in the EFB for each of the levels studied. A moisture gradient clearly appeared within the heap: the bottom EFB remained slightly drier than those in the surface horizons, which received water directly in a well distributed manner.

Weight loss. *Figure 5* gives the EFB mineralization dynamics for each of the levels. The gradient found for humidity was also found here for dry weight losses, but the other way round. After two days storage (20 mm of rainfall), the difference between the EFB at the top of the heap and those towards the bottom had already reached over 14 points.

After 15 days (129 mm of water), the EFB in the upper layers and those at the bottom had lost 10% and 30% of their respective dry weights.

The EFB directly exposed to rainfall benefited from humidity that was highly favourable to microbial breakdown, hence much faster mineralization.

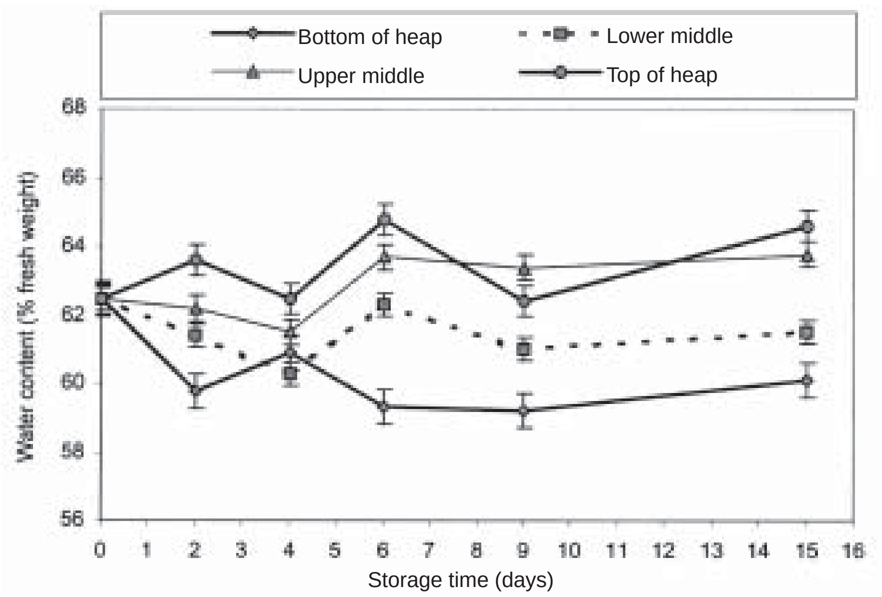


Figure 4. Empty fruit bunches (EFB) humidity.

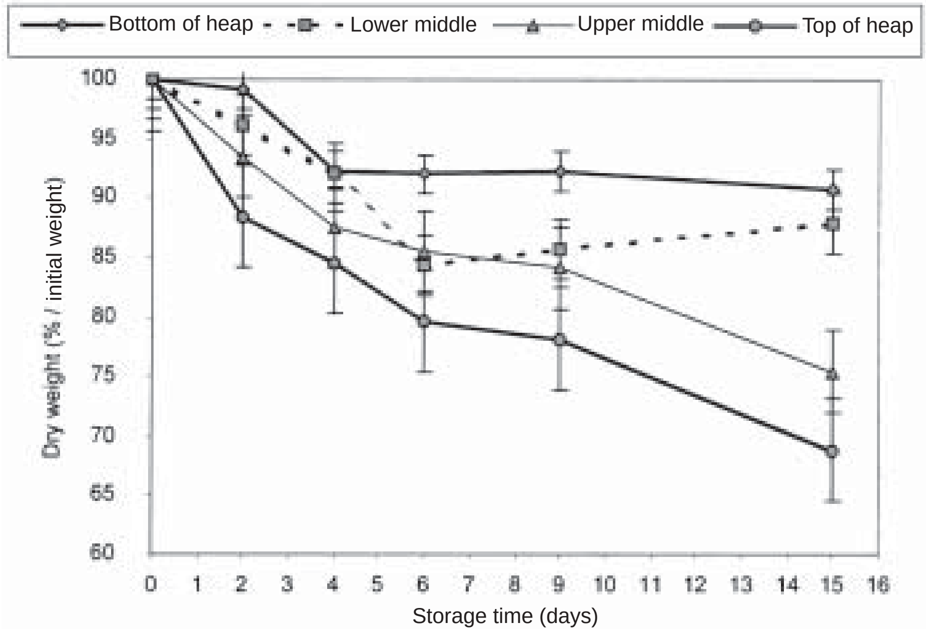


Figure 5. Empty fruit bunches (EFB) mineralization.

Dynamics of mineral nutrient release. The residual values for each mineral nutrient, expressed as a percentage of the initial contents, are given in *Figures 6* to *10*.

The release rate varied considerably depending on the nutrient involved and on the EFB position, with a wide range between the top and bottom of the heap, linked to the degree of mineralization.

The release rate for potassium, the main nutrient contained in EFB, was very high. Fifteen days into the trial, 73% of the potassium initially contained in the EFB in the upper position had been released, as opposed to only 16% for the EFB at the bottom of the heap.

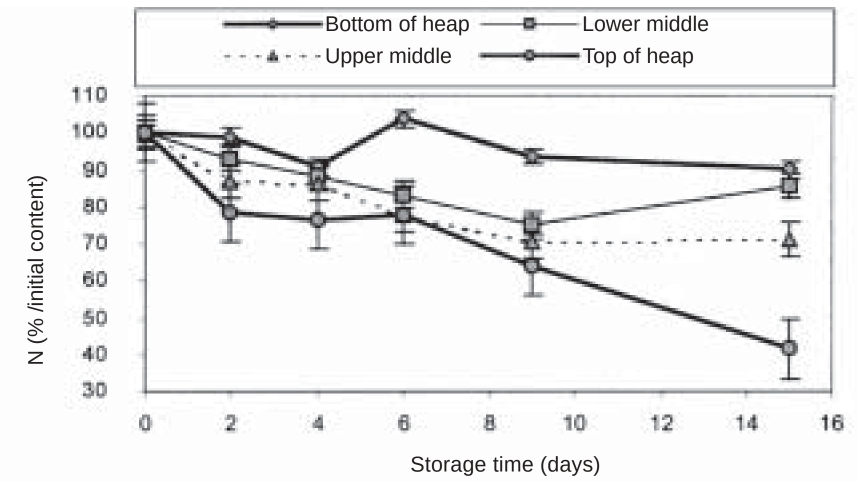


Figure 6. Empty fruit bunches (EFB) mineralization - residual nitrogen.

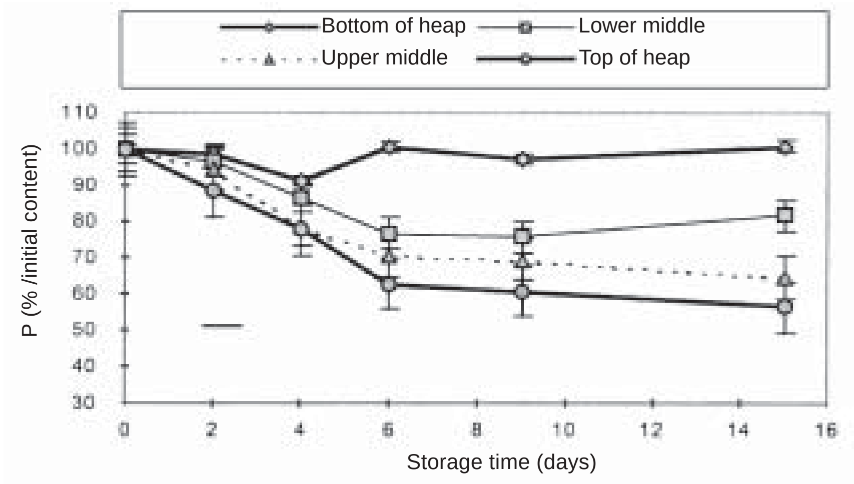


Figure 7. Empty fruit bunches (EFB) mineralization - residual phosphorus.

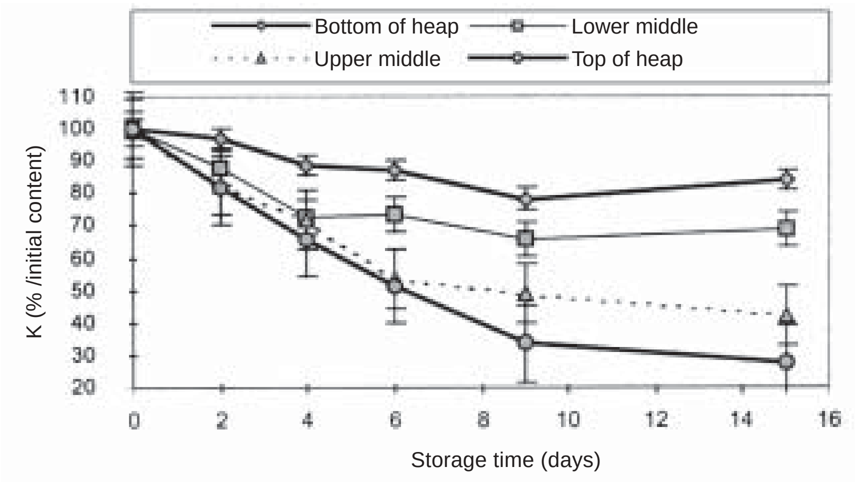


Figure 8. Empty fruit bunches (EFB) mineralization - residual potassium.

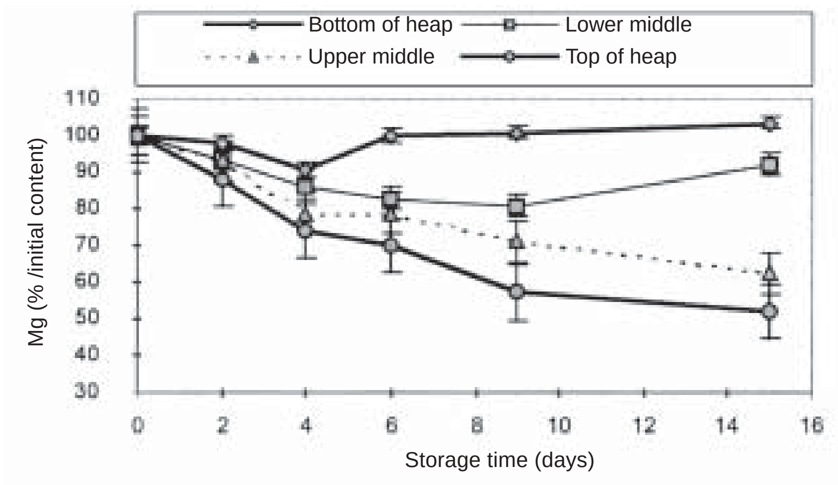


Figure 9. Empty fruit bunches (EFB) mineralization - residual magnesium.

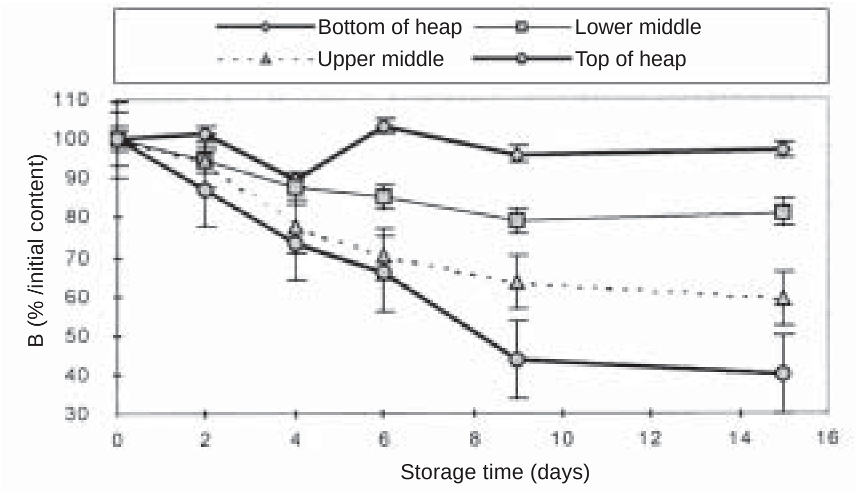


Figure 10. Empty fruit bunches (EFB) mineralization - residual boron.

Table 8 summarizes the losses found for several mineral nutrients over different storage times, for the two extreme levels studied in the trial. The *average* column quantifies the losses of a nutrient on a heap scale, weighting the proportions with the volume (or weight) of each of the four horizons defined (*Table 6*).

TABLE 8. CUMULATED NUTRIENT LOSSES FOR TWO LEVELS IN THE EMPTY FRUIT BUNCHES (EFB) HEAP

Storage time (days)	Rain (mm)	Dry weight loss (%)			Nitrogen loss (%)			Phosphorus loss (%)			Potassium loss (%)			Magnesium loss (%)			Boron loss (%)		
		Bot.	Top	Ave.	Bot.	Top	Ave.	Bot.	Top	Ave.	Bot.	Top	Ave.	Bot.	Top	Ave.	Bot.	Top	Ave.
0	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2	20	3	17	9	1	21	9	2	12	5	3	18	12	2	12	6	-1*	13	5
4	40	13	21	15	9	23	13	9	22	16	11	34	24	9	26	17	11	26	17
6	60	13	25	19	-4*	22	14	-1*	37	21	13	49	32	0	30	16	-3*	34	18
9	80	13	27	20	6	36	23	3	39	23	22	67	41	-1*	43	21	4	56	27
15	129	14	36	23	10	59	24	-1*	43	22	16	73	42	-3*	48	20	3	60	28

Note: * Contents over the initial value.

Table 7 and *Figures 6* to *10* reveal an accumulation of mineral nutrients released on the surface in the EFB located at the bottom of the heaps. This phenomenon, which is due to vertical migration, undoubtedly displays a gradient, but it is difficult to evaluate it with precision.

The losses found on a heap scale were slightly higher than those found from the calculations based on leachate (*Table 6*). The difference can be partly explained by experimental errors and especially by the approximation linked to the calculations of losses from the EFB, as each uniform horizon studied was only characterized by the mean of the measurements carried out on the four replicates.

However, it is also reasonable to assume that there is an accumulation of nutrients at the very bottom of the heap, with contents that are well above those measured in the experiment in the second to last horizon. The EFB at the bottom of the heap, in direct contact with the tarpaulin, were in fact left soaking in the leachates for an hour.

Thus, although the cumulated losses indicated above are undoubtedly slightly overestimated, the proportions found in the analyses of leachates for the different mineral nutrients were nonetheless found.

DISCUSSION

The limitations of the trial prevent any quantitative generalization of the results: indeed, the release dynamics obtained are only valid for the rainfall conditions defined in the protocol and for a heap height of around 1 m.

Nevertheless, the experiment provided an idea of the degree of nutrient loss occurring during EFB storage in a rainy period. Mineral nutrient release is very rapid, especially for potassium.

Table 9 indicates changes in the fertilizing value of substitute EFB, for the different storage times studied in the trial; the contents were calculated from the results of the leaching analysis given in *Tables 6* and *7*.

consideration could be given to installing a system to recover the leachates and send them back to the heap, or to the oil mill's effluent digestion lagoons, when the storage sites are adapted.

TABLE 9. RESIDUAL FERTILIZING VALUE OF EMPTY FRUIT BUNCHES (EFB) DURING STORAGE (kg fertilizer/t EFB)

Fertilizer equivalent	Storage time: Rainfall:	Start 0 mm	2 days 20 mm	4 days 40 mm	6 days 60 mm	9 days 80 mm	15 days 129 mm
Urea		7.7	7.5	7.4	7.1	7.0	6.7
Tricalcium phosphate		2.3	2.2	2.2	2.1	1.9	1.8
KCl		21.7	20.4	18.9	17.4	16.1	14.1
Kieserite		3.3	3.0	2.9	2.7	2.7	2.5

Note: Storage heap height = 1 m.

Based on these results, an estimation of the financial losses cumulated over an EFB production year was used to assess the foregone earnings for the plantation: for a mill processing 60 t of FFB hr^{-1} over 300 days per year, the losses amount to the equivalent of US$ 27 000 in fertilizer equivalent for four days of storage, and can reach US$ 73 000 for temporary storage of two weeks before application in the field.

Generally speaking, the trial showed the merits of returning EFB to the plantation as soon as possible after leaving the mill. Any delay in application results in significant nutrient losses, especially potassium. The agronomic value of the fresh EFB is proportionally decreased.

Temporary storage of EFB is often due to inappropriate organization of the spreading operations, or a lack of efficient equipment for continual removal. The level of losses that could be avoided by reducing the storage time should encourage plantations to invest accordingly, in order to improve the entire field application operation. For instance, merely switching from a storage time of two days on average to immediate application in the plantation would compensate in one year for the purchase of an EFB spreader with a capacity of 15 m^3. The savings made if only six days' storage is avoided would also pay for the purchase of an 85 HP tractor.

In addition, agronomic recommendations calculated from the average composition of fresh EFB should take into account the temporary storage time when defining the amounts to be applied in the field. This measure is obviously difficult to put into practice, given the eminently variable nature of the storage time.

When EFB spreading is not possible (wet ground too soft for mechanical spreaders to operate, technical problems with the spreaders, *etc*.),

A slightly sloping asphalted platform, with a network of channels to collect the leachates would be an affordable technical solution. It would then be possible to recover and use all the nutrients contained in the EFB. The merits of composting fresh EFB can also clearly be seen here, as transfer to the field would be more flexible and cheaper, given the much smaller volumes involved.

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