Assessment of fertilisation regimes for specific situations

Defining the main representative Riau sites

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Contents

Acknowledgements

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The consultants acknowledge all the people for their warm welcome and their large involvement in the success of their mission in June 2007.

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WP1 "Assessment of fertilization regimes for specific situations"
Deliverable: "Defining the main representative Riau sites"
(Version 6th November 2007)

INTRODUCTION

The objectives of the Work package WP1 "Assessment of fertilization regimes for specific situations" were to develop a site specific silviculture for eucalypt stands in order to optimize the fertiliser inputs to 1) achieve a stand production as close as possible to the ecological potential, and 2) reduce the costs of fertilisation practices.

To attain these objectives, three tasks had been identified (i) Drawing a physiographic map by crossing geological map and landform (slope, topographic position) information, (ii) Defining the main representative sites by crossing the physical and chemical soil properties with the physiographic map and rainfall information, (iii) Establishing, monitoring and analyzing fertiliser trials on the different representative sites.

These three tasks had to be carried out in the Minas region - Rasau Kuning and Gelombang districts (AA - Riau), and in Jambi region - Districts 1 and 4 (WKS - Jambi). These districts had been chosen by AA and WKS as representatives of the dry land plantations.

The first task "Drawing a physiographic map" has been delivered in June 2007 (Bouillet et al. 2007).
This report finalized the second task "Defining the main representative sites" for Minas Region. The objectives of this report were (i) to provide a view of the properties of soils of Riau and an explanation of their variability, (ii) to define the main representative sites where fertilisation trials will be set.
We had not be able to finalize the second task "Defining the main representative sites" for Jambi region because we received too little data.

The work included in this report has been mainly carried out, firstly at the office in June 2007, secondly during a field mission in June 2007 (Annex 1) and finally at the office in September 2007.

A. CHARACTERISTICS OF SOILS OF RIAU

1. Classification

The mineral soils of provinces of Riau and Jambi are mainly red-yellow podzolic soils (Whitten et al. 1997). According to Fanning & Fanning (1989) and IUSS Working group WRB (2006), red-yellow podzolic soils correlate with *Ultisols* with low-activity clays of the Soil Taxonomy and with *Acrisols* of the international WRB classification. These soils have a higher clay content in the subsoil than in the topsoil leading to an argic subsoil horizon (i.e. clay accumulation). These soils are low in fertility with a low pH and a low base saturation.

The mineral soils of Arara Abadi (AA) concession in Riau are also mainly red-yellow podzolic soils (Soil survey staff). In attempt to produce a more suitable soil map for forestry, a local classification has been defined, based on soil texture and drainage classes of the upper 100 cm of the mineral layer (Soil survey staff). Initially, five texture classes had been defined in function of threshold values of sand content and clay content (**Table 1**). In this study, we met soils with clay content greater than 55%, a case not considered in the initial local classification. Consequently, we defined a sixth texture class in order to take into account clay content greater than 55% (**Table 1**). For the well drained acrisols, we named this class R01.
The correspondences between the local soil classification, the soil color classification, the USDA classification and the international WRB classification are given in Annex 2

Table 1: Criteria of particle size analysis for distinguishing texture class

Particle size analysis		Sand (%)	
		< 45 %	> 45%
Clay (%)	< 18%	**5. Loamy sand-sand**	**5. Loamy sand-sand**
	[18-34%]	**3. Clay loam-loam**	**4. Sandy clay loam-sandy loam**
	[35-55%]	**1. Clay-clay loam**	**2. Sand clay**
	> 55%	**0.**	

2. Mean characteristics

2.1. Material and Methods

Data

We used soil analyses that have been produced from the soil survey activity of Arara Abadi, RDD section. We gathered two data files sent by M. Rianto the 5th May 2007 and the 31st July 2007, respectively. These two data files contained 196 profiles.

Firstly, we detected and eliminated four profiles that had exactly the same values in the two data files. Secondly, we checked and sometimes modified the local soil classification affected for each profile using the soil particle size from the laboratory analysis. Third, we eliminated soil types where the number of sample per soil type was too low (below 10): R11, R12, R32, R52, W21, W22, W31, W51, and W52 (Annex 3).
Finally, 158 profiles have been studied, each of them for 5 depths: [0-10cm], [10-20cm], [20-30cm], [30-50cm], and [50-80cm]. These 158 profiles corresponded to 8 soil types: R01 (old name = R61), R21, R22, R41, R42, R51, W41, and W42 (Annex 3). These 158 profiles came from 10 districts, among of which the most representative are Dseb, Mgel (Gelombang), Dber, and Mras (Rasau Kuning) (Annex 4). The "Soil survey" data file contained 789 observations (i.e. rows)

The studied parameters were: bulk density, soil particle size (sand, silt, and clay), pH H_20 (1:2.5), C, N, C/N, P available (Bray 2 method) and exchangeable cations (NH_4OAc at pH7): Na, K, Ca, Mg, Total base, H, Fe, Al, Mn, Zn, Cu, Co, Mo, B, and Si.

There were too many missing data for Zn, Cu, Co, Mo, and B. Therefore, we did not take into account in the data analysis these five parameters.

In the initial "Soil survey, Riau" data file, there was too much inconsistency concerning the parameter Total base. Therefore, we calculated new values for this parameter using formula: Total base = Na + K + Ca + Mg.

In the initial "Soil survey, Riau" data file, the unit of the exchangeable cations was ppm. We converted this unit in the international unit, cmol+/kg, according to Baize (2000) for Na, K, Ca, Mg, and Al and calculating this conversion for H, Si, Mn, and Fe (Annex 5). In this report, we presented the results in the international unit, cmol+/kg.

Outlier data

A preliminary exploratory analysis (not presented in this report) allowed detecting 30 outlier values which corresponded to 24 observations (Annex 6). These outlier data can be due to (i) errors during laboratory measures (ii) errors during data capture (iii) or very specific soils. These outlier data had been checked with Rianto Marolop during our mission of June 2007. We replaced the value of these outlier data by a missing data.

Analysis

We carried out descriptive statistics (mean, median, standard deviation, minimum, maximum, number of observation) for each depth, confounding the soil types. Concerning pH H_20, (i) we converted pH in $[H^+]$ using the formula $[H^+] = 10^{-pH}$ (ii) we calculated mean and standard deviation of $[H^+]$, (iii) we converted mean and standard deviation of $[H^+]$ in pH using formula $pH = -\log_{10}[H^+]$ and gave the final result in pH. The descriptive statistics for each depth have been presented using boxplot.

2.2. Results

Mean characteristics of the soils of Riau …

Parameters of the "Soil survey, Riau" data file have been summarized in **Table 2** and illustrated for the physical parameters (bulk density, texture) and the chemical parameters in Figures 1 and 2, respectively.

On average, soils of Riau were sandy clay loam (sand > 45% and clay between 18 and 34%), very acid (pH <5), have a medium nitrogen content (<2.4‰) and a ratio C/N less than 14. On average, soils of Riau had very low available phosphorus content (P avail Bray2 < 3 ppm), very low potassium content (< 0.10 cmol+/kg) and exchangeable aluminium content less than 0.10 cmol+ kg^{-1}.

There was a trend of an increase in bulk density from the topsoil to the deeper horizons, from 1 g/cm^3 at [0-10m] to 1.4 g/cm^3 at [50-80cm]. Such a trend was also observed for clay content, from 30% at [0-10cm] to 36% at [50-80cm], and for pH, from 4.3 at [0-10cm] to 4.7 at [50-80cm]. Most of the other parameters decreased from the top soil to the deeper horizon: sand content, carbon content, C/N, phosphorus available, Total base, Mg, Ca, K, H, Al. Other parameters, like Na and Si, had constant low values, whatever the depth.

Table 2: "Soil survey, Riau", main properties of soils, except outlier values
SD=standard deviation

Depth (cm)		Bulk density g/cm3	Sand (%)	Silt (%)	Clay (%)	pH H20 (1 : 2.5)	C (%)	N (%)	C/N	P_avail (ppm)
0-10	**Mean**	**1,0**	**60**	**10**	**30**	**4,3**	**2,4**	**0,23**	**14**	**2,6**
	Median	1,0	65	8	25	4,4	1,9	0,17	13	1,3
	SD	0,2	20	6	18	4,4	1,6	0,18	7	3,7
	Min	0,5	4	2	2	3,6	0,5	0,01	3	0,0
	Max	1,4	94	36	91	5,5	8,0	0,89	47	22,3
	N	157	156	156	156	149	155	156	154	147
10-20	**Mean**	**1,2**	**59**	**11**	**30**	**4,5**	**1,3**	**0,17**	**11,7**	**0,7**
	Median	1,2	64	9	26	4,6	1,0	0,12	9,8	0,3
	SD	0,2	20	6	19	4,7	0,9	0,15	9,2	0,9
	Min	0,8	4	0	1	4,1	0,1	0,01	1,3	0,0
	Max	1,6	93	29	89	5,4	4,6	0,79	57,0	4,8
	N	156	156	156	156	155	155	153	152	140
20-30	**Mean**	**1,3**	**59**	**10**	**32**	**4,6**	**0,9**	**0,13**	**10,2**	**0,5**
	Median	1,3	63	8	27	4,6	0,7	0,09	7,4	0,2
	SD	0,1	20	6	19	4,9	0,6	0,12	8,3	0,9
	Min	0,8	3	0	0	4,1	0,1	0,01	1,3	0,0
	Max	1,6	95	28	93	5,3	4,5	0,70	48,0	7,4
	N	158	157	158	158	155	154	153	153	135
30-50	**Mean**	**1,3**	**57**	**9**	**34**	**4,7**	**0,6**	**0,13**	**9**	**0,4**
	Median	1,3	61	7	29	4,8	0,4	0,07	6	0,1
	SD	0,1	20	5	20	4,9	0,5	0,15	10	1,1
	Min	0,8	3	1	0	4,1	0,1	0,01	1	0,0
	Max	1,7	97	29	95	5,4	4,7	0,97	59	11,7
	N	156	158	158	158	155	152	152	151	126
50-80	**Mean**	**1,4**	**56**	**8**	**36**	**4,7**	**0,6**	**0,14**	**8,0**	**0,4**
	Median	1,4	61	6	32	4,8	0,4	0,08	4,9	0,2
	SD	0,1	20	5	19	4,8	1,2	0,19	8,5	1,3
	Min	0,9	4	0	1	3,8	0,0	0,01	0,5	0,0
	Max	1,7	98	27	93	5,6	9,3	1,32	47,5	11,6
	N	157	158	158	158	155	151	153	147	130

Table 2 (continued): "Soil survey, Riau", main properties of soils, except outlier values
SD=standard deviation

Depth (cm)		Na	K	Ca	Mg	Total base	H	Fe	Al	Mn	Si
		Exchangeable cations (NH4OAc at pH7, cmol+/kg)									
0-10	**Mean**	**0,05**	**0,07**	**0,17**	**0,34**	**0,61**	**8,08**	**0,01**	**0,10**	**0,01**	**0,03**
	Median	0,03	0,06	0,08	0,19	0,45	7,47	0,01	0,08	0,00	0,02
	SD	0,07	0,06	0,22	0,39	0,54	4,09	0,02	0,09	0,01	0,04
	Min	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
	Max	0,51	0,42	1,33	2,35	3,54	27,88	0,12	0,82	0,07	0,32
	N	152	157	152	157	147	157	157	157	154	136
10-20	**Mean**	**0,04**	**0,04**	**0,05**	**0,12**	**0,26**	**5,22**	**0,01**	**0,09**	**0,00**	**0,03**
	Median	0,03	0,03	0,03	0,06	0,18	4,72	0,00	0,06	0,00	0,02
	SD	0,06	0,03	0,08	0,15	0,24	2,51	0,01	0,08	0,00	0,04
	Min	0,00	0,00	0,00	0,00	0,00	1,17	0,00	0,00	0,00	0,00
	Max	0,42	0,24	0,57	0,81	1,44	23,00	0,05	0,45	0,02	0,28
	N	147	156	151	157	143	158	153	156	154	132
20-30	**Mean**	**0,04**	**0,03**	**0,03**	**0,08**	**0,18**	**4,40**	**0,00**	**0,07**	**0,00**	**0,04**
	Median	0,03	0,02	0,02	0,04	0,14	3,87	0,00	0,05	0,00	0,02
	SD	0,07	0,03	0,03	0,09	0,15	2,24	0,00	0,08	0,00	0,05
	Min	0,00	0,00	0,00	0,00	0,00	0,78	0,00	0,00	0,00	0,00
	Max	0,53	0,16	0,19	0,52	1,02	19,16	0,03	0,56	0,06	0,39
	N	147	157	144	158	141	158	155	158	155	133
30-50	**Mean**	**0,04**	**0,02**	**0,03**	**0,06**	**0,15**	**3,99**	**0,00**	**0,05**	**0,00**	**0,03**
	Median	0,02	0,02	0,02	0,04	0,12	3,51	0,00	0,02	0,00	0,01
	SD	0,06	0,02	0,02	0,07	0,11	2,35	0,00	0,08	0,00	0,06
	Min	0,00	0,00	0,00	0,00	0,00	0,78	0,00	0,00	0,00	0,00
	Max	0,37	0,13	0,12	0,39	0,65	20,71	0,04	0,63	0,01	0,42
	N	134	157	139	158	126	158	155	157	155	127
50-80	**Mean**	**0,04**	**0,02**	**0,03**	**0,06**	**0,15**	**3,84**	**0,00**	**0,03**	**0,00**	**0,03**
	Median	0,02	0,01	0,02	0,03	0,11	3,12	0,00	0,01	0,00	0,01
	SD	0,05	0,02	0,02	0,10	0,12	2,85	0,00	0,06	0,00	0,06
	Min	0,00	0,00	0,00	0,00	0,00	0,39	0,00	0,00	0,00	0,00
	Max	0,31	0,19	0,14	0,85	0,89	22,99	0,03	0,48	0,04	0,56
	N	131	155	134	157	122	157	154	154	152	126

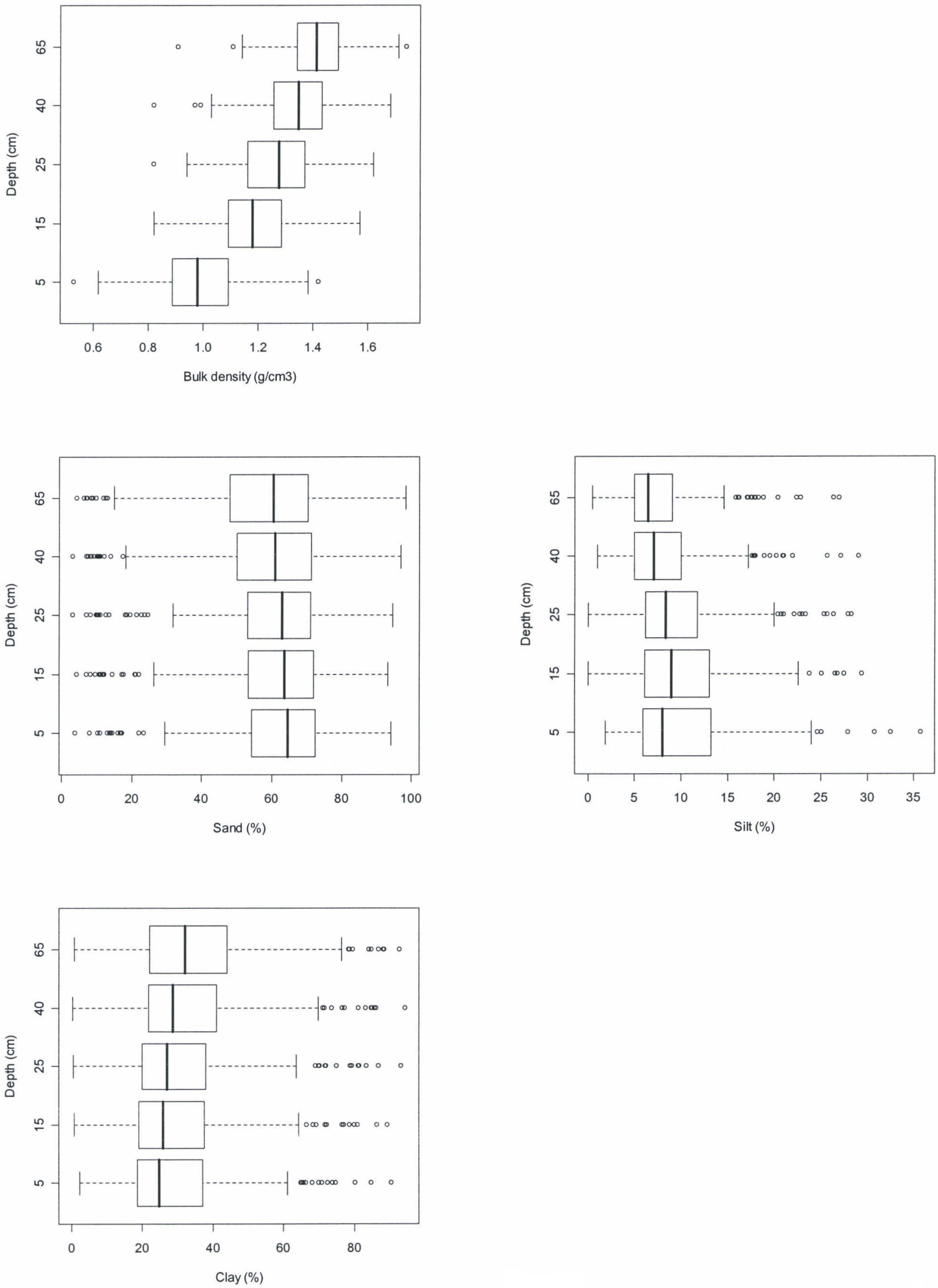


Figure 1: "Soil survey, Riau", relationship between physical parameters and depth of the soils

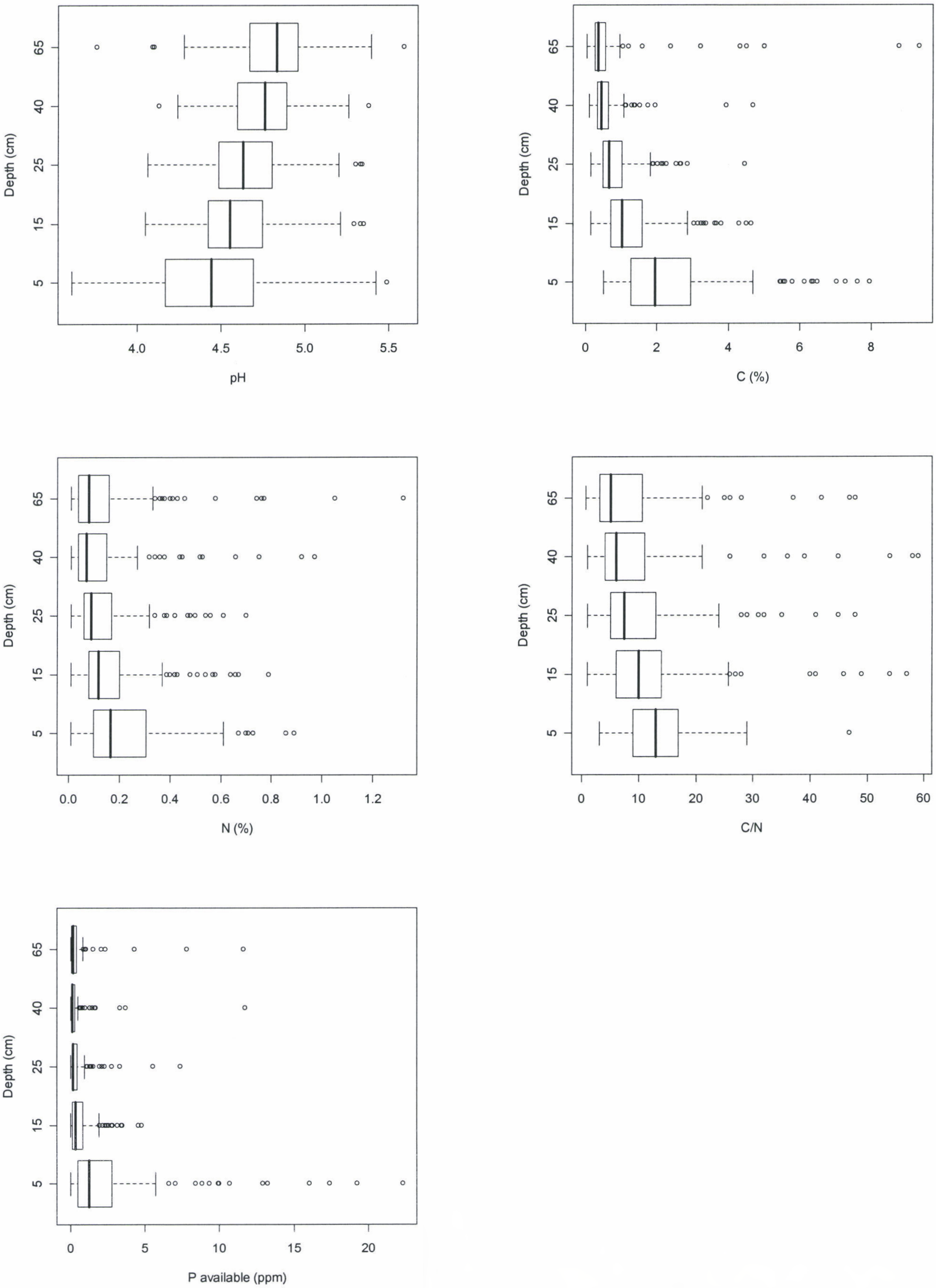


Figure 2: "Soil survey, Riau", relationship between chemical fertility and depth of the soils

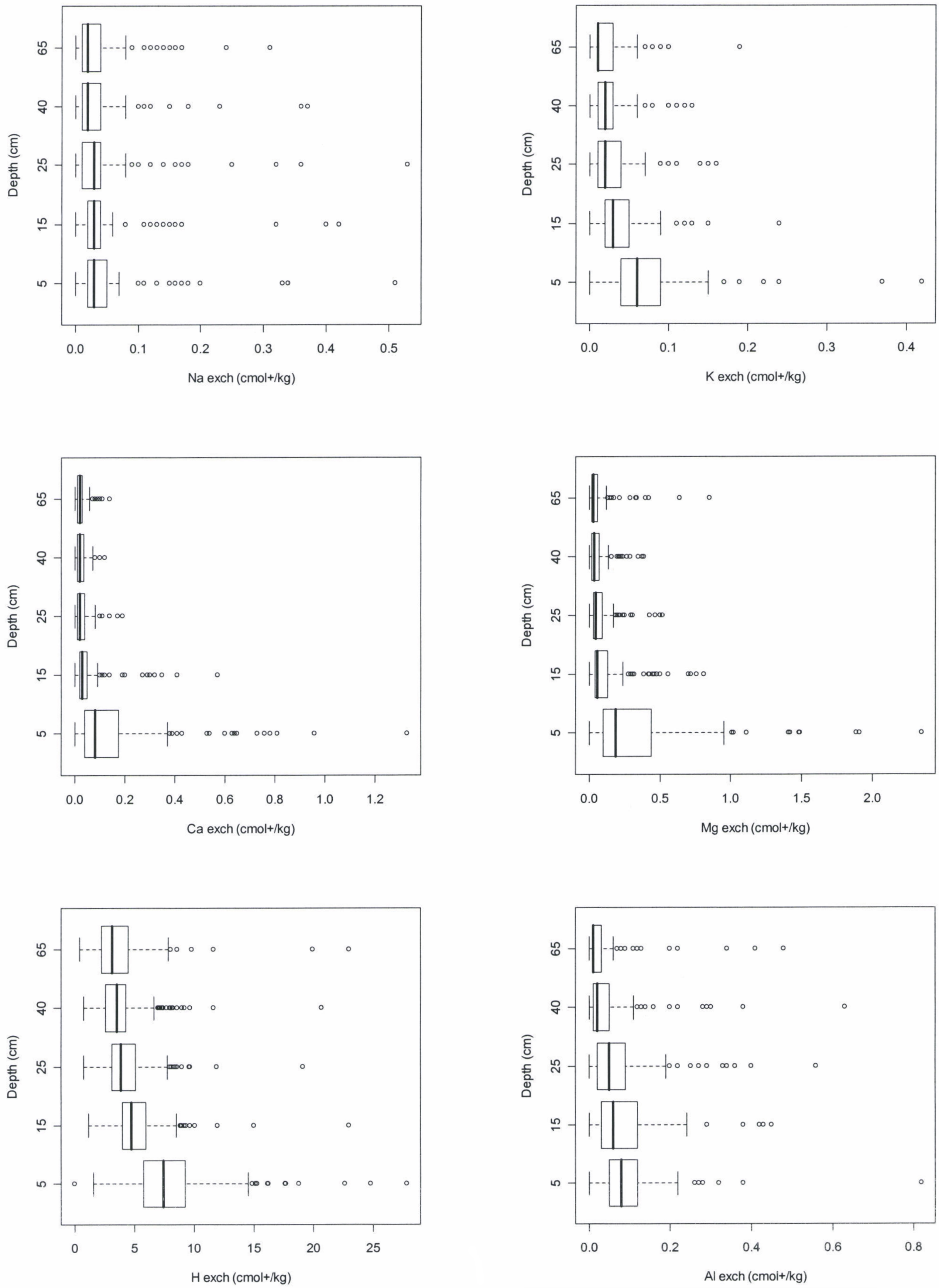


Figure 2 (continued): "Soil survey, Riau", relationship between chemical fertility and depth of the soils

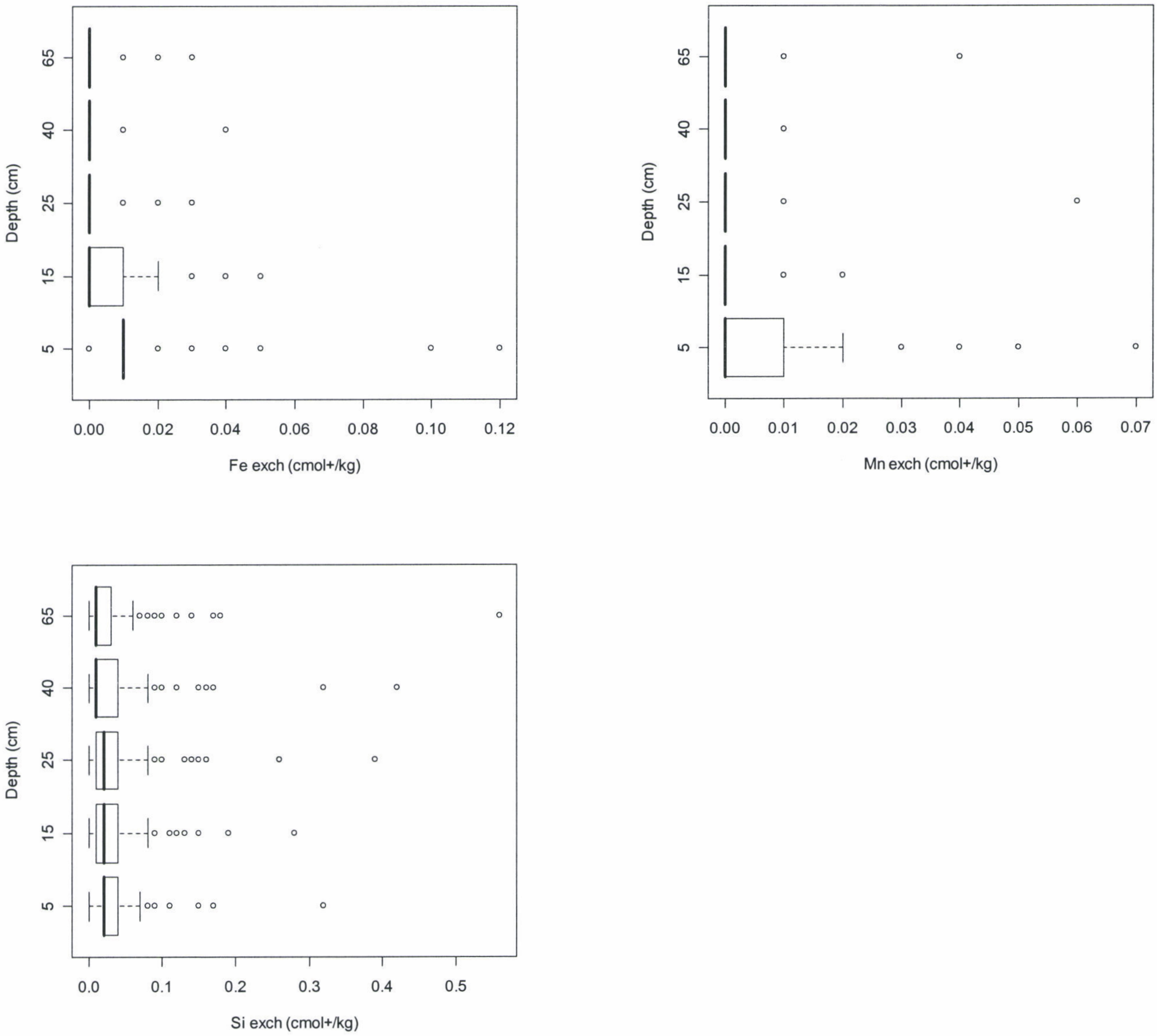


Figure 2 (continued): "Soil survey, Riau", relationship between chemical fertility and depth of the soils

3. Variability of the soil particle size

3.1. Material & Methods

Data

We used "Soil survey, Riau" data file that has been described in §2.

Analysis

For three representative profiles of each soil type R01, R21, R41, R42, and R51, we realized a graphic, which illustrated the change in soil particle size with depth.

3.2. Results: A high variability of the soil particle size

Soils of Riau presented a high variability of soil particle size. At [0-10cm] depth, sand content varied from 4 to 94%, silt content from 2 to 36% and clay content from 2 to 91% (**Table 2**). Typic profiles of soil particle size in function of the depth were presented in Figure 3a, Figure 4a, Figure 5a, Figure 6a, and Figure 7a, for each soil type R01, R21, R41, R42, and R51, respectively. These typical profiles had an argic subsoil horizon.

We observed also a variability of the soil particle size within each soil type. Some profiles had no argic subsoil horizon (Figure 3b, Figure 4b, Figure 5b, Figure 6b, and Figure 7b). Other profiles had medium silt content (Figure 3c, Figure 4c, Figure 5c, Figure 6c, and Figure 7c).

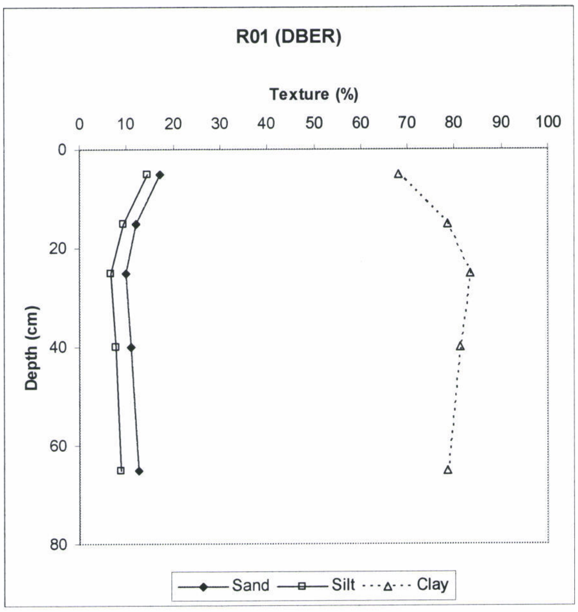
It may be also underlined that some profiles did not match easily soil type classification. For example, a profile could have the characteristics of R41 at topsoil and the characteristics of R11 at deeper horizon (Figure 4c).

3.3. Discussion

The high variability of soil particle size of Riau soils has been well taken into account by the local soil classification. Indeed, soil particle size is one of the two criteria on which the local classification of soils of Riau was based. This classification allows distinguishing a range of soils within *Acrisols* (i.e. *Ultisols* or *red-yellow podzolic* soils) from clayed soils (e.g. R01) to sandy soils (e.g. R51).

This high variability of soil particle size was certainly due to subsoil characteristics. According to the geological map of Pakanbaru, mineral soils of Riau were mainly located on Minas Anticline formation (Pleistocene, quaternary era). Subsoil was constituted of *"unconsolidated to semi-consolidated mud, sands and gravels. Extensive pebble beds in mountain front area"* (Clarke et al. 1982). Consequently, we suppose that the alteration of sandstone led to sandy soils (e.g. R51), while the alteration of mudstone led to clayed soils (e.g. R01).

The high variability of soil particle size should lead to different fertilization practices. Clayed soils (e.g. R01) should have a buffer capacity higher than sandy soils (e.g. R51). Consequently, on clayed soils, fertilization could be applied in one pass. On the opposite, on sandy soils, fertilization should be split.



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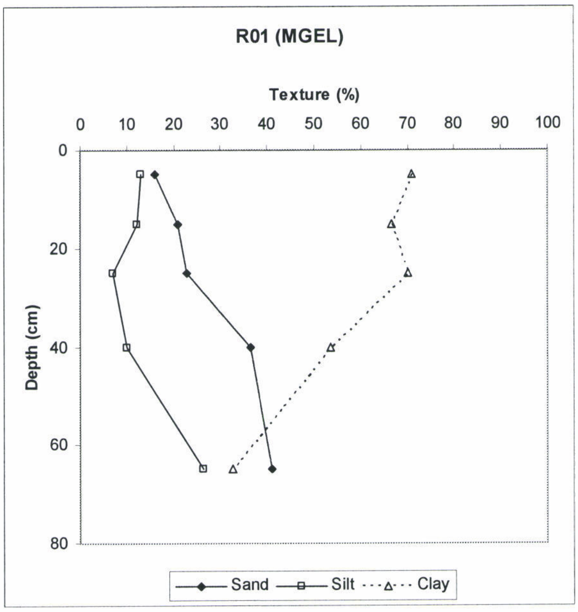

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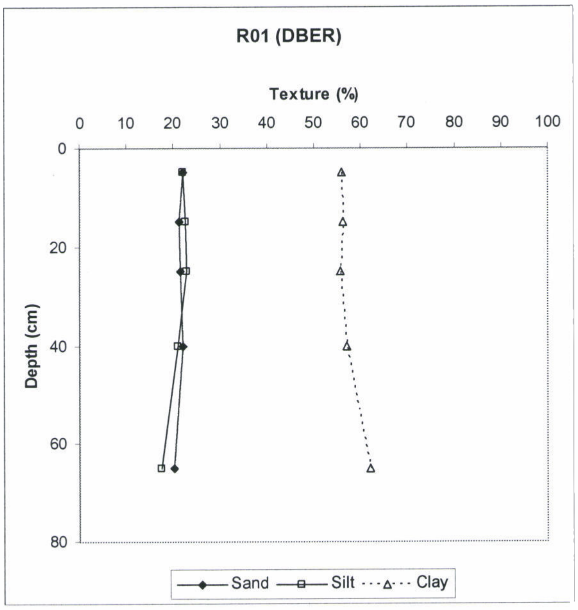


(c)

Figure 3: Profiles of soil particle size in function of depth for the soil type R01

(a) Typic soil type R01 with an argic subsoil horizon (i.e. clay accumulation)
(b) Soil type R01 without an argic subsoil horizon
(c) Soil type R01 with medium silt content

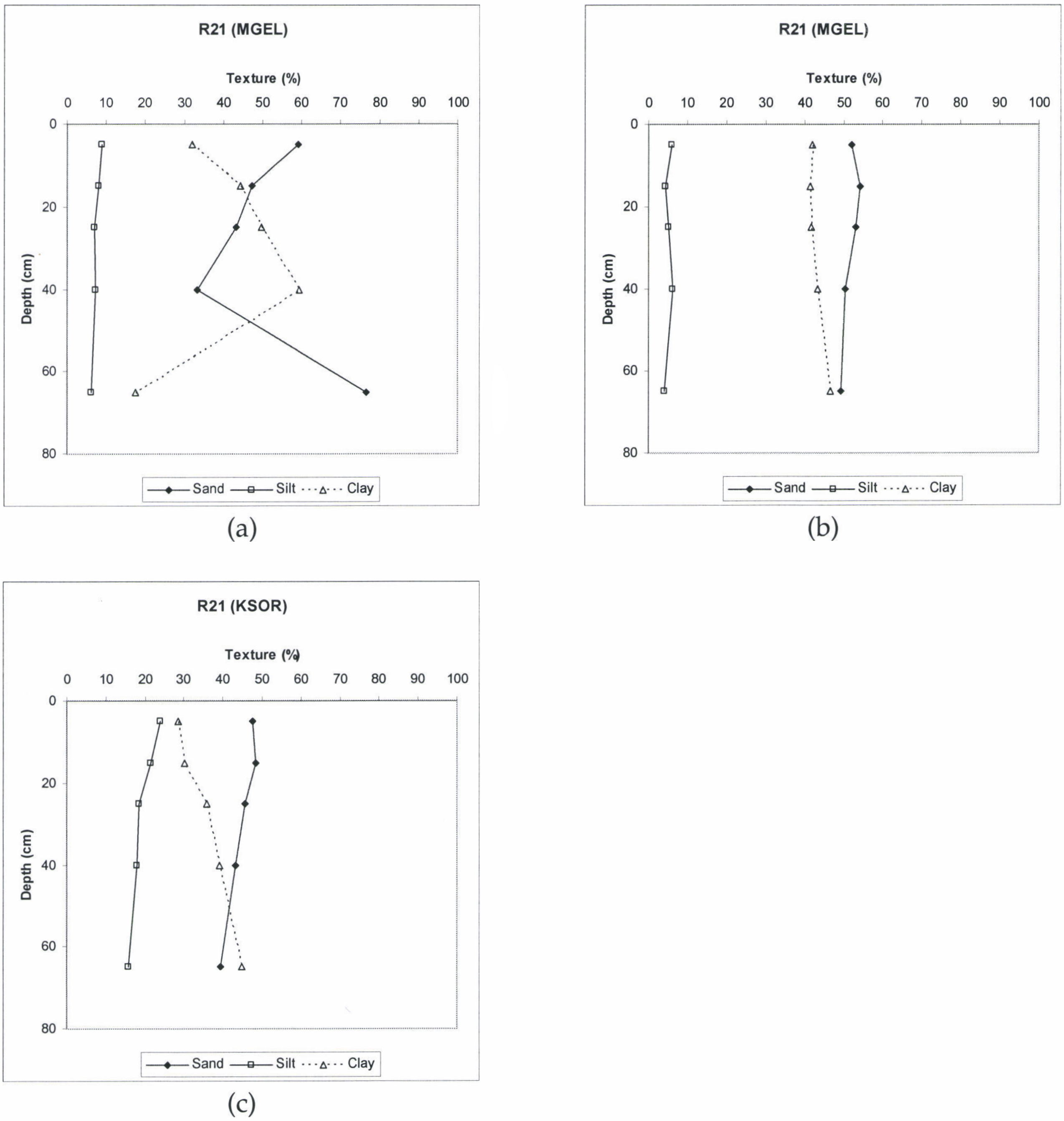
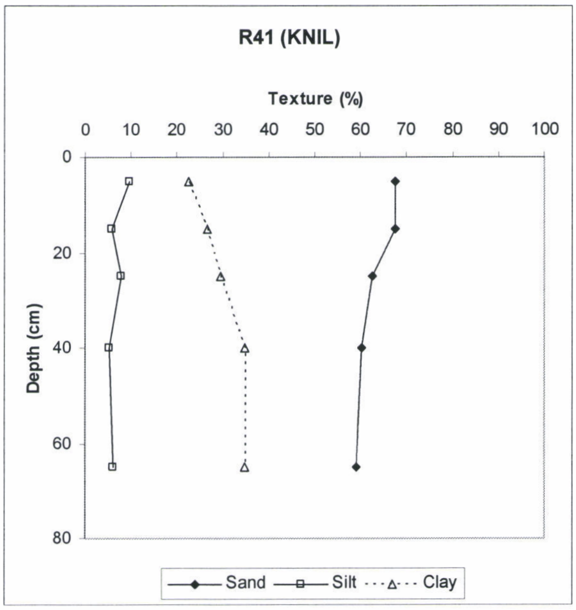
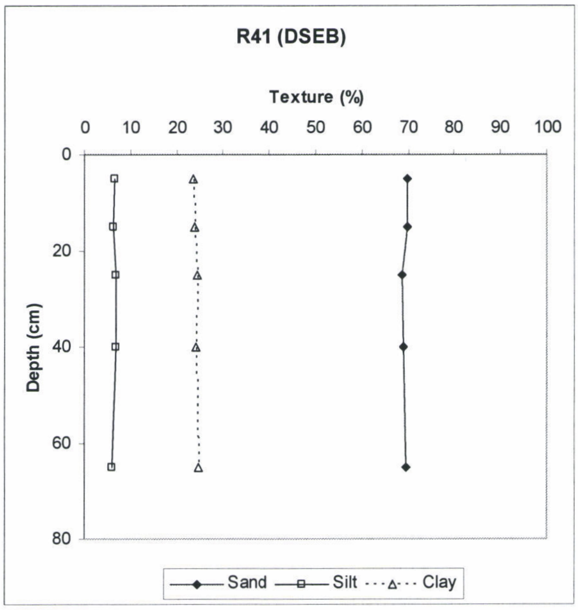


Figure 4: Profiles of soil particle size in function of depth for the soil type R21
(a) Typic soil type R21 with an argic subsoil horizon (i.e. clay accumulation)
(b) Soil type R21 without an argic subsoil horizon
(c) Soil type R21 with medium silt content



(a)



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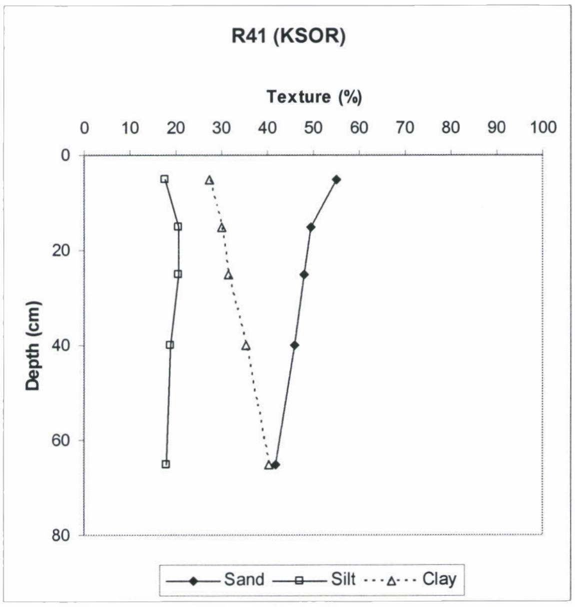
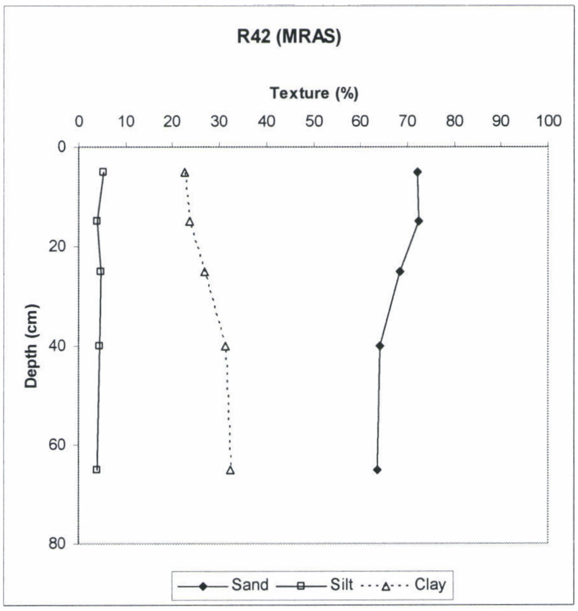


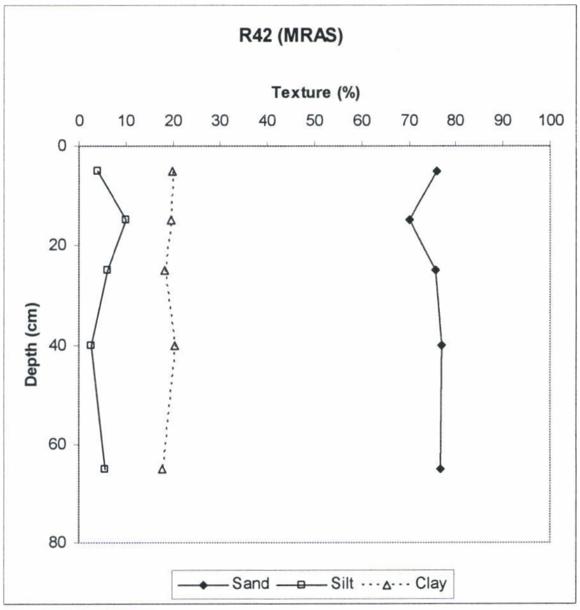
(c)

Figure 5: Profiles of soil particle size in function of depth for the soil type R41

(a) Typic soil type R41 with an argic subsoil horizon (i.e. clay accumulation)
(b) Soil type R41 without an argic subsoil horizon
(c) Soil type R41 with medium silt content



(a)



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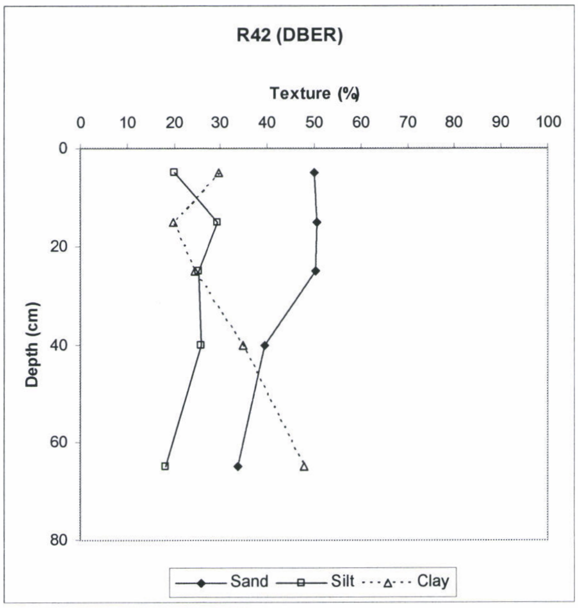
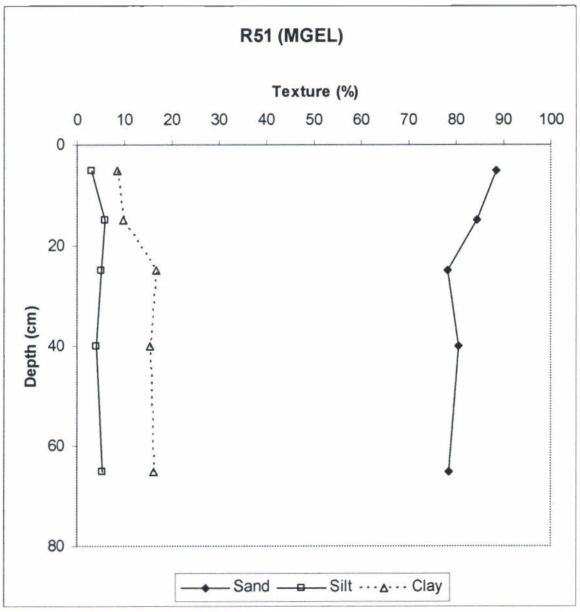


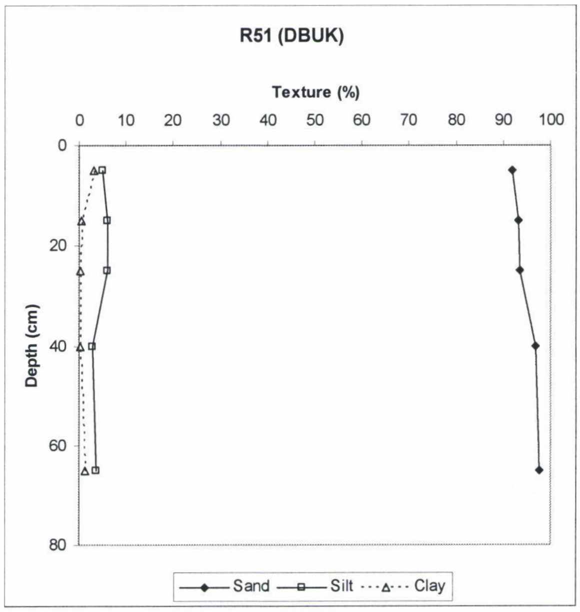
(c)

Figure 6: Profiles of soil particle size in function of depth for the soil type R42

(a) Typic soil type R42 with an argic subsoil horizon (i.e. clay accumulation)
(b) Soil type R42 without an argic subsoil horizon
(c) Soil type R42 with medium silt content



(a)



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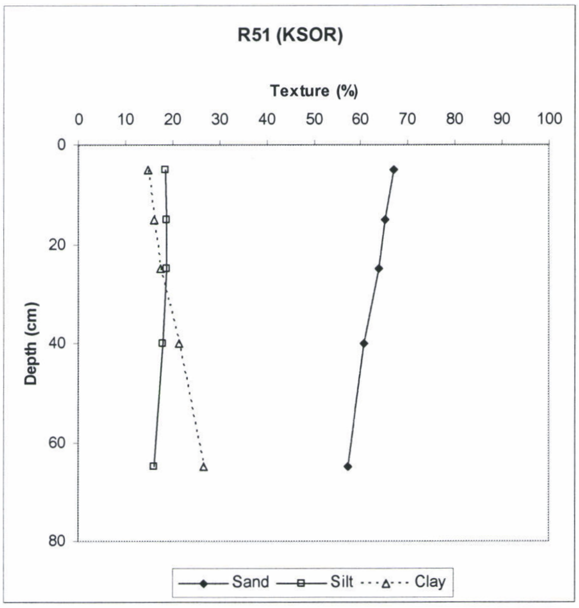


(c)

Figure 7: Profiles of soil particle size in function of depth for the soil type R51

(a) Typic soil type R51 with an argic subsoil horizon (i.e. clay accumulation)
(b) Soil type R51 without an argic subsoil horizon
(c) Soil type R51 with medium silt content

4. Variability of the chemical variability and the relationship between chemical fertility and local soil classification

The objectives were the following:

Was the chemical fertility homogeneous or variable?

Was the local soil classification relevant to explain the variability of chemical fertility of soils of Riau?

4.1. Material & Methods

Data

We used "Soil survey, Riau" data file that has been described in §2.

Threshold values

We used a threshold value of fertility (deficiency, cultural limitation ...) for ammonium and pH (Annex 7), available phosphorus, exchangeable potassium and magnesium, balance between magnesium and potassium (Annex 8), and exchangeable aluminum, using Kamprath indice in order to evaluate cultural limitation due to aluminum toxicity (Annex 9). In some cases, the threshold was a range and not a single value. In the other cases, the threshold of fertility of a parameter is function of another soil parameter. For example, the threshold of exchangeable potassium content depends on soil particle size. For available phosphorus, we used a range that varied between 3 and 5 ppm, from threshold value specifically defined for Eucalypt stands (Attiwill & Adams 1996, Gonçalves & Benedetti 2004). For the other parameters, we used threshold values defined by Boyer (1982) reviewing many fertilization trials that had been carried out on different tropical crops.

Analysis

The statistical analysis was carried out for [0-10cm] layer.

For each chemical parameter (i) firstly, we compared the frequency of soils of Riau, whatever the soil type, with the threshold value of the chemical parameter (ii) secondly, we compared the data of each soil type (boxplot) with the threshold value of the chemical parameter (iii) thirdly, we realized an analysis of variance (Anova) at one factor to test if soil type had a significant effect on the chemical parameter. If Fisher's test was significant, we used Bonferroni's test to compare the means between the soil type (iv) finally, we summarized the results of Anova creating a table of ranks from Bonferroni's test (a=2, ab=1.5, b=1, etc.) and carried out a principal component analysis (PCA) on this table.

4.2. Results: A global low fertility for phosphorus and potassium ... and a variable fertility for ammonium and magnesium. A chemical fertility partially explained by the soil type.

At [0-10cm] of depth:

- The potential of fertility of soils of Riau in function of N and pH was variable: bad or very bad (31%), mean (38%), and good or very good (31%) (Figure 8). We found this range of potential of fertility for most of soil types (Figure 9).
- Most of soils of Riau were phosphorus deficient. The percentage of these soils varied between 78% and 88% in function of the value of the threshold we considered, from 3 ppm to 5 ppm, respectively (Figure 10a). This deficiency in phosphorus concerned all the soils of R01, R21, R22, R41, R42, R51, but only about 50% of the soils of W41 and W42 (Figure 10b). We observed a high variability of phosphorus content within W42.
- Most of soils of Riau presented a deficiency in potassium, whatever the soil particle size. This deficiency concerned 83% of the sandy soils (Figure 11a), 86% of the sandy-clayed soils (Figure 12a) and 95% of the clayed soils (Figure 13a). This deficiency in potassium concerned all (or most of) the soils of R01, R21, R41, R42, R51, and W41 (Figure 11b, 12b, and 13b). But, some soils of R22 and W42 had no deficiency in potassium (Figure 12b).
- Some soils of Riau had a deficiency in magnesium. The percentage of these soils varied between 27% and 43% in function of the value of the threshold we considered, from 0.10 cmol+/kg to 0.17 cmol+/kg (Figure 14a). This deficiency in magnesium concerned most of soils of R51, and about half of soils of R21, R22, and R41. On the contrary, all the soils of R01, and most of soils of R42, W42, and W41 had no deficiency in magnesium (Figure 14b).

- Most of soils of Riau that had a low magnesium content (Mg < 0.3 cmol+/kg) also exhibited an unbalance between magnesium and potassium, whatever the soil type (Figure 15a, and 15b). These soils concerned about 50% of soils of Riau. On the contrary, soils of Riau that had a mean magnesium content (0.3 < Mg < 1 cmol+/kg) or a good magnesium content (Mg > 1 cmol+/kg) were balanced between magnesium and potassium whatever the soil type (Figure 16a, 16b, 17a, 17b).
- The cultural limitation of soils of Riau due to aluminum toxicity was variable: very high or high (20%), mean (46%), and low or null (34%) (Figure 18a). This cultural limitation was null to low for R01, low for W42, low to mean for R21, R22, R41, R42 and W41, and mean to very high for R51. We observed a high variability of this cultural limitation within R51.

Anova showed that, at [0-10cm] of depth, soil type had a significant effect on P, Total (exchangeable bases), K, Ca, Mg, Mg/K, Al, Kamprath indice, and Mn (**Table 3**).
Soil types with highest available P were W42 and W41 (mean= 6.9 and 4.8 ppm). Soil type with the highest exchangeable base (Total, K, Ca, Mg) was R01 (mean= 1.1, 0.11, 0.33 and 0.72 cmol+/kg, respectively). Soil types with the highest Mg/K were W41, R01, R42 and W42 (mean from 6.9 to 5.3). Soil type with the highest exchangeable aluminium and Kamprath indice was R51 (mean= 0.18cmol+/kg and 37%, respectively).

Results of Anova and PCA on rank table allowed us to easily compare soil types (**Table 3**, Figure 19, Figure 20) and finally to distinguish:
- Soils R01, rich in exchangeable base (Total, K, Ca, Mg), with a low cultural limitation due to aluminium toxicity, but poor in P. It must be stressed that R01 exhibited a deficiency in K, even if this soil type had the highest K content.
- Soils R51, poor in exchangeable base (Total, K, Mg), with a high cultural limitation due to aluminium toxicity, and with a mean P content.
- Soils W41 and W42, with a mean exchangeable base content, a mean cultural limitation due to aluminium toxicity, and rich in P.
- Soils R21, R22, and R41, poor in exchangeable base, with a mean cultural limitation due to aluminium toxicity Al, and poor in P.

4.3. Discussion

Most of the soils of Riau, especially R01, R21, R22, R41, R42 and R51 exhibited a deficiency in phosphorus. Fertilization in phosphorus should then improve the growth of Eucalyptus stands on these soil types. On the other hand, this fertilization should be less efficient on soil types W41 and W42 because theses soil types had higher P content.

Most of the soils of Riau, especially R01, R21, R41, R42, R51 and W41 exhibited a deficiency in potassium. Fertilization in potassium should improve the growth of Eucalyptus stands. This fertilization will have to be brought in several times because the fixation capacity of potassium by the soil is low. It is also possible that the fertilization in potassium has no effect on the growth of Eucalyptus stands. It is actually known that plants can uptake other kinds of potassium in the soil that so-called exchangeable potassium (Boyer 1982). Moreover Na may substitute K in eucalypt plantations located in coastal areas as observed in Congo, or in Brazil (Marschner 1995, Laclau 2001)

About 50% of soils of Riau, most of those that had low magnesium content, especially R51, R21, R22 and R41, exhibited an unbalance between magnesium and potassium. Mg application should be therefore applied to prevent a physiologic unbalance of K fertilized trees.

All the range of potential of fertility in N and pH has been observed in Riau, whatever the soil type. Fertilization in ammonium should have variable effect on the growth of Eucalypt stands within a soil type. This fertilization will have to be brought in several times because nitrates (NO_3^-) are very sensitive to leaching, especially on sandy soils.

The cultural limitation due to aluminum toxicity depended on the soil type, from low for R01 to high for R51.

Table 3: "Soil survey, Riau", Depth= [0-10 cm], results of Bonferroni's test for chemical parameters on which test of Fisher was significant at 5% threshold (*), 1 % threshold (**), or 1 ‰ threshold (***)

Soil	P	Total	K	Ca	Mg	Al	Mn	Mg/K	Kamprath
	(ppm)	Exchangeable cations (NH4OAc at pH7, cmol+/kg)							
F test	***	***	**	**	***	***	***	***	***
R01	1,2 b	1,1 a	0,11 a	0,33 a	0,72 a	0,05 b	0,019 a	6,6 ab	7 c
R21	1,1 b	0,4 b	0,08 ab	0,08 b	0,18 b	0,09 b	0,003 b	2,6 c	18 bc
R22	1,2 b	0,4 b	0,07 ab	0,09 b	0,20 b	0,07 b	0,002 b	3,2 c	16 bc
R41	1,4 b	0,5 b	0,08 ab	0,11 b	0,23 b	0,10 b	0,004 b	3,3 c	22 b
R42	2,3 ab	0,8 ab	0,06 ab	0,27 ab	0,36 ab	0,06 b	0,007 b	5,8 abc	14 bc
R51	3,3 ab	0,4 b	0,04 b	0,13 ab	0,16 b	0,18 a	0,003 b	3,8 bc	37 a
W41	4,8 a	0,8 ab	0,08 ab	0,23 ab	0,56 a	0,12 ab	0,005 b	6,9 a	17 bc
W42	6,9 a	0,6 ab	0,07 ab	0,14 ab	0,33 ab	0,06 b	0,004 b	5,3 abc	11 bc

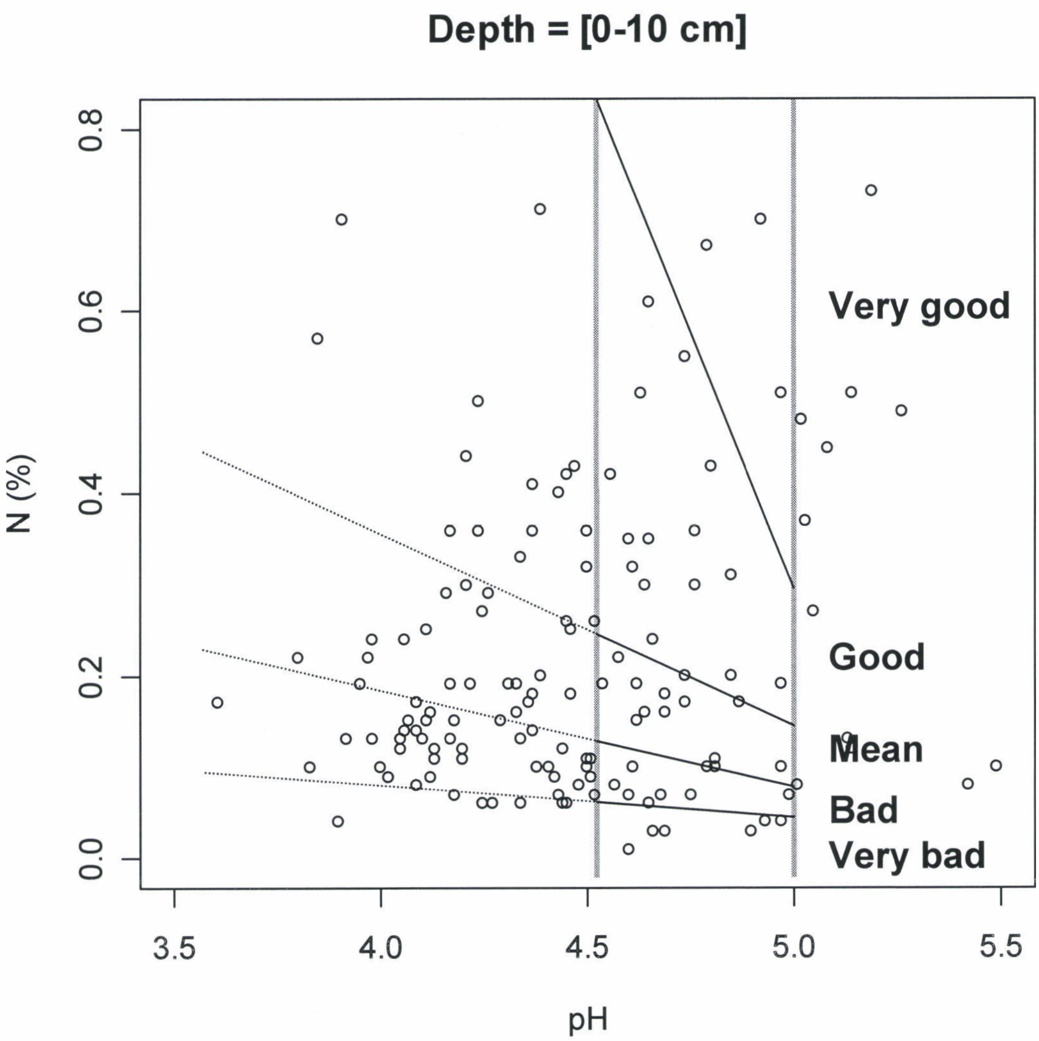


Figure 8: Potential of fertility of soils of Riau in function of N and pH.
The thresholds were extracted from Boyer (1992) according to Dabin (1961)

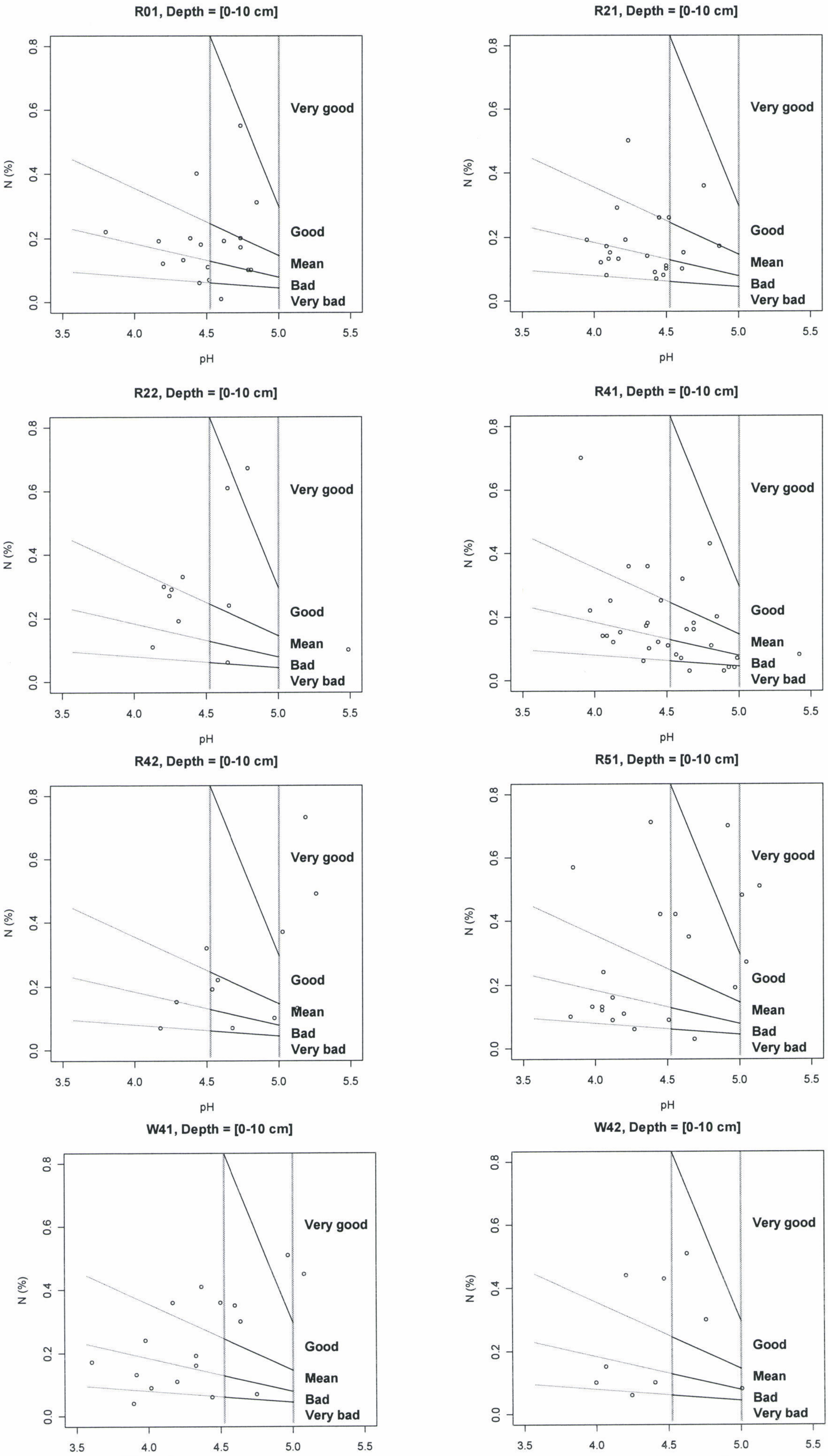
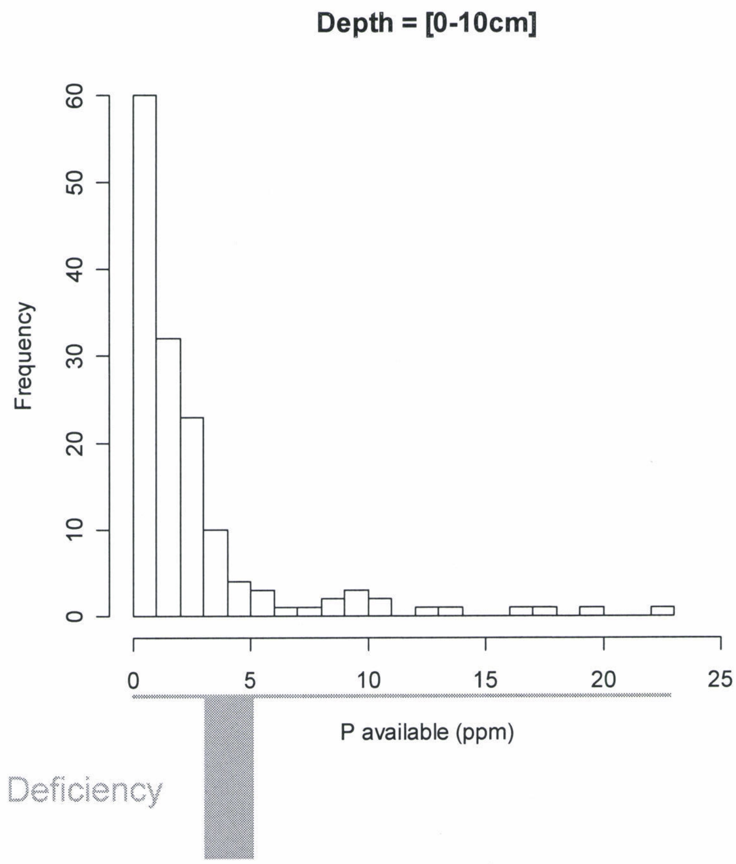


Figure 9: Potential of fertility of soils of Riau in function of N and pH per soil type

(a)



(b)

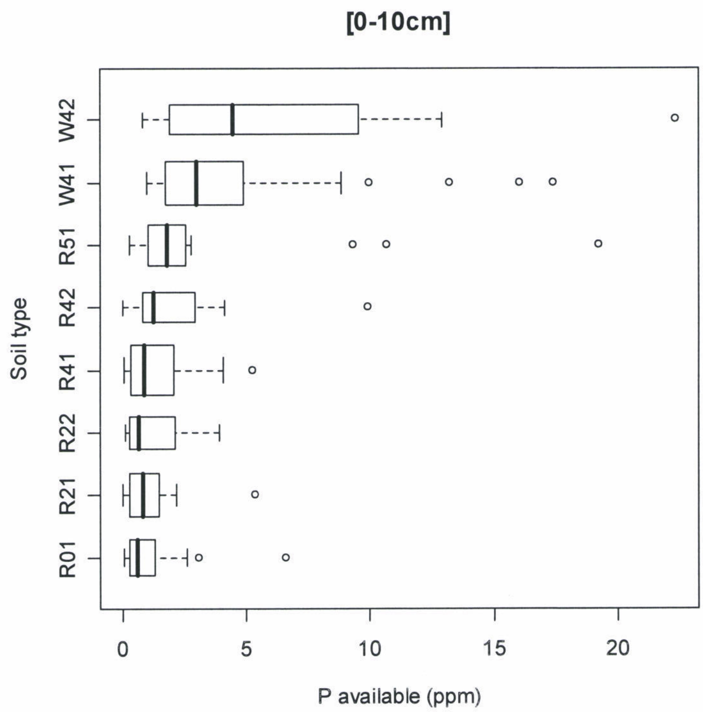


Figure 10: Phosphorus fertility of soils of Riau (a) globally (b) by soil type. The threshold of deficiency was extracted from Boyer (1992).

(a)

(b)

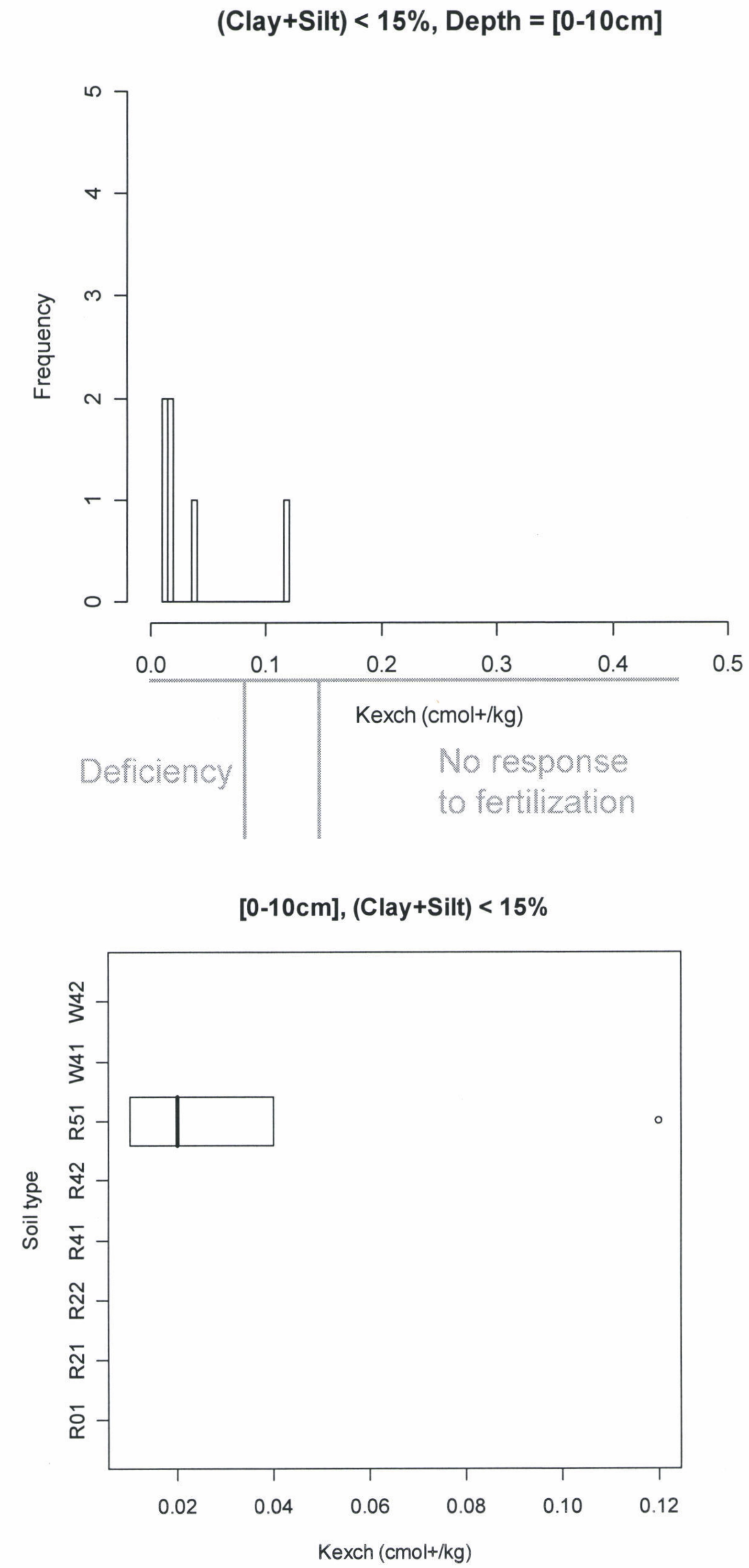
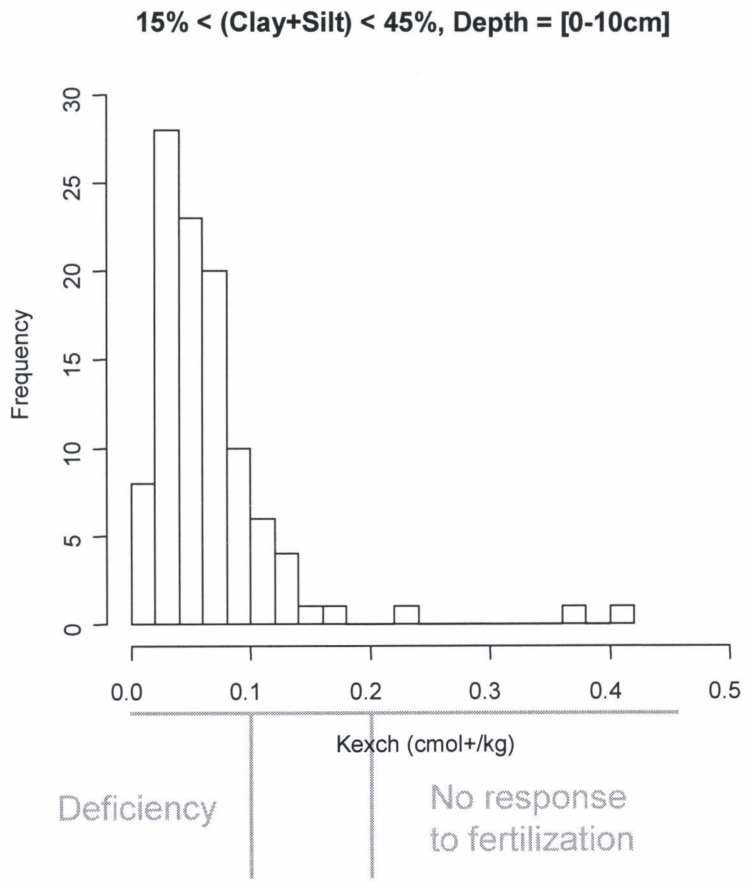


Figure 11: Potassium fertility of sandy soils (Silt+Clay<15%) of Riau (a) globally (b) by soil type. The thresholds of deficiency and of no-response to fertilization were extracted from Boyer (1992).

(a)



(b)

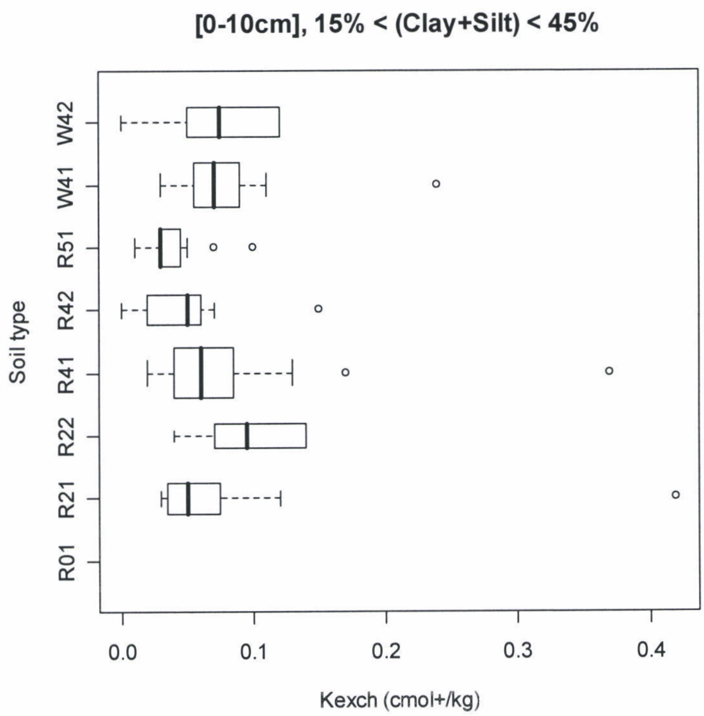
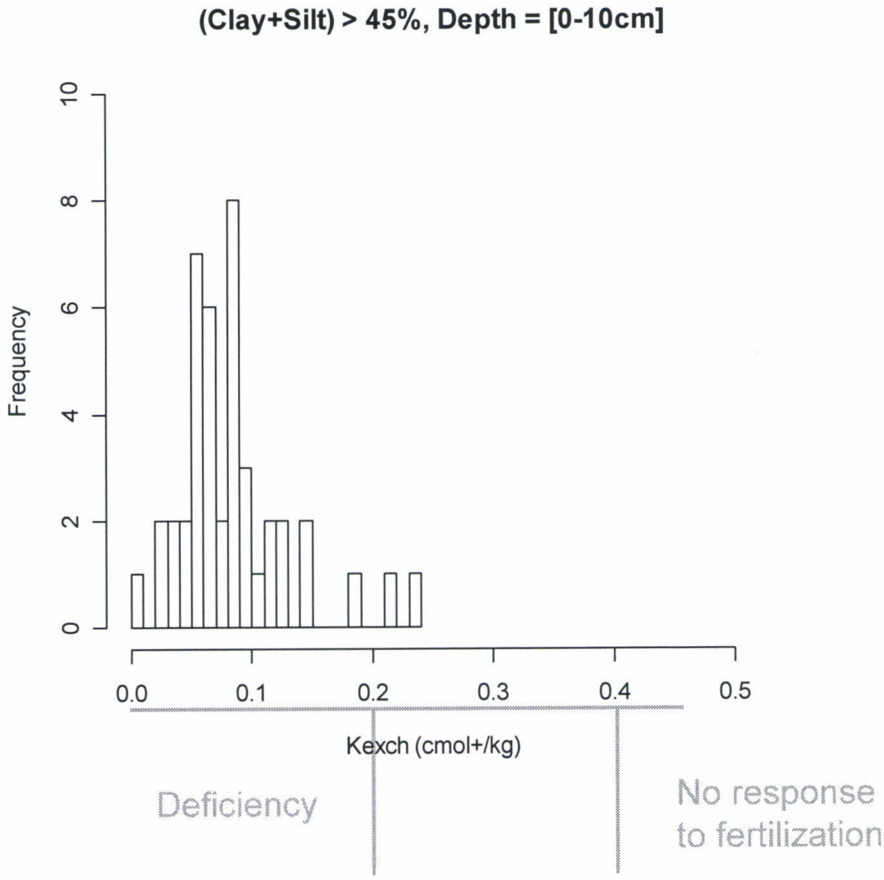


Figure 12: Potassium fertility of sandy clayed soils (15% < (Silt + Clay) < 45%) of Riau (a) globally (b) by soil type.
The thresholds of deficiency and of no-response to fertilization were extracted from Boyer (1992).

(a)



(b)

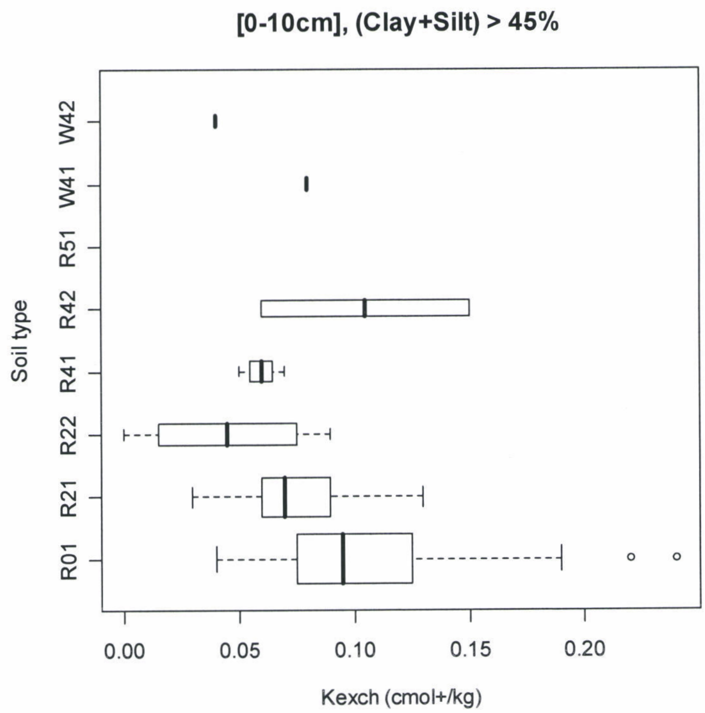
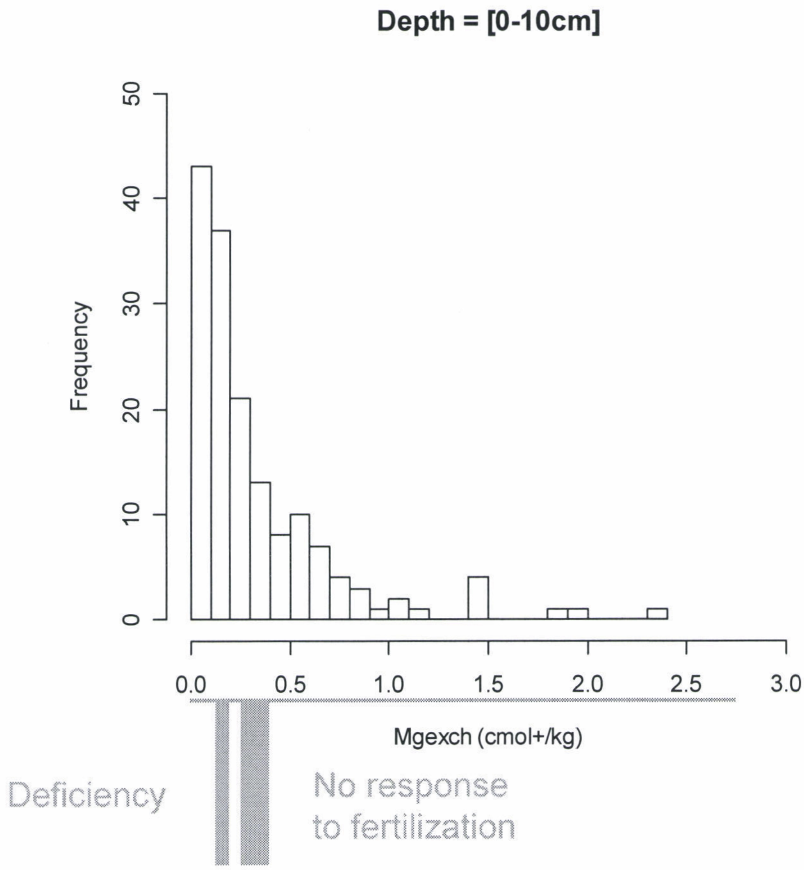


Figure 13: Potassium fertility of clayed soils (Silt + Clay > 45%) of Riau (a) globally (b) by soil type. The thresholds of deficiency and of no-response to fertilization were extracted from Boyer (1992).

(a)



(b)

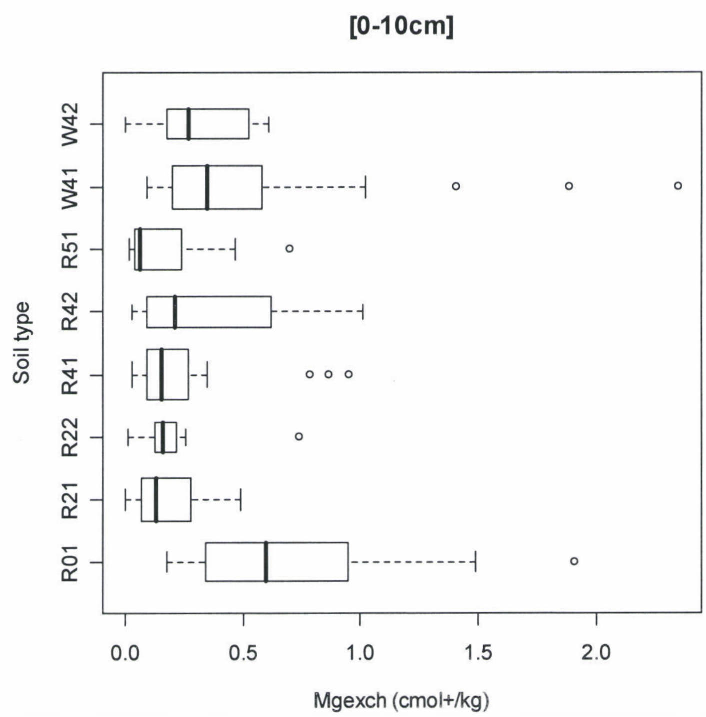
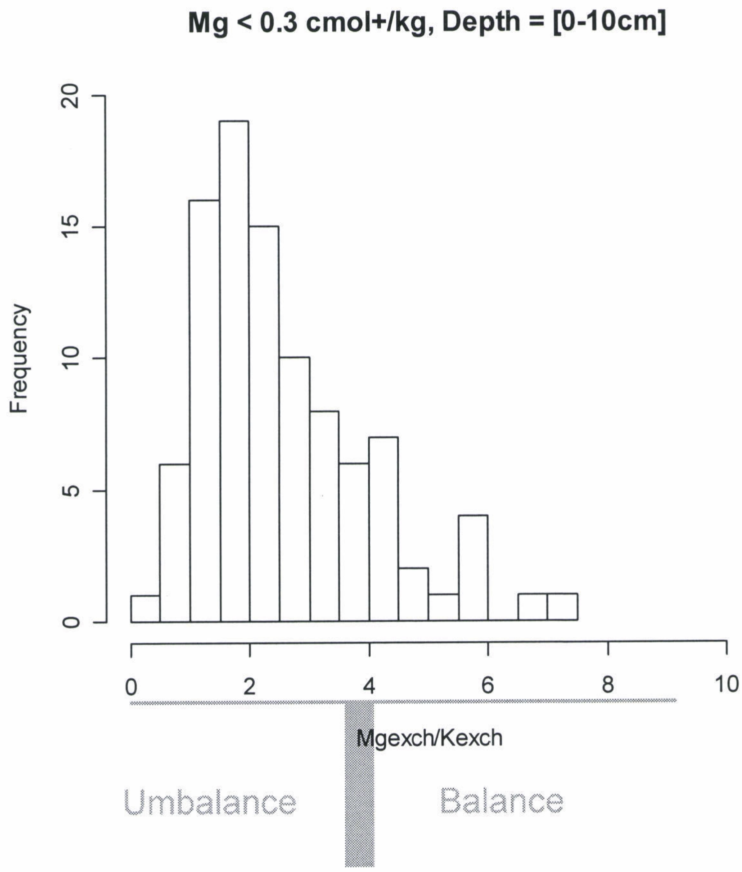


Figure 14: Magnesium fertility of soils of Riau (a) globally (b) by soil type.
The thresholds of deficiency and no-response to fertilization were extracted from Boyer (1992).

(a)



(b)

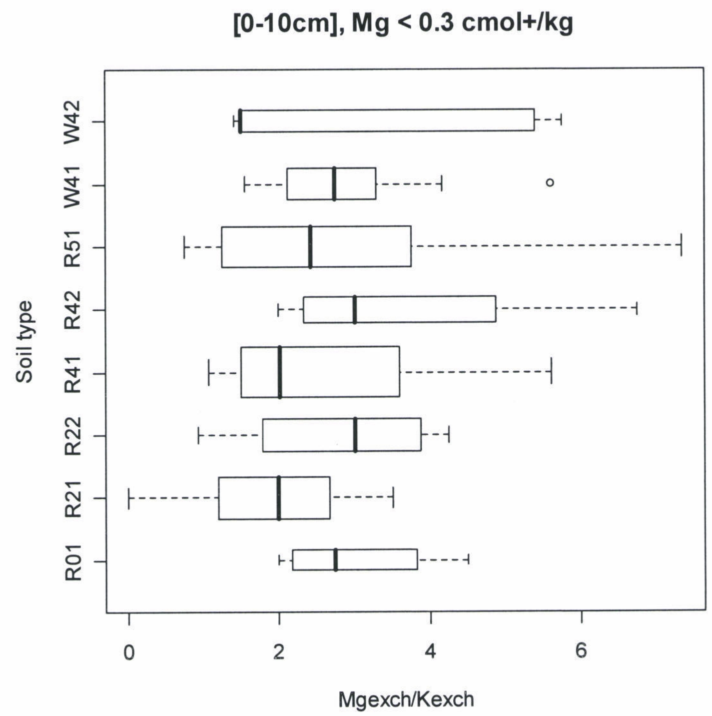
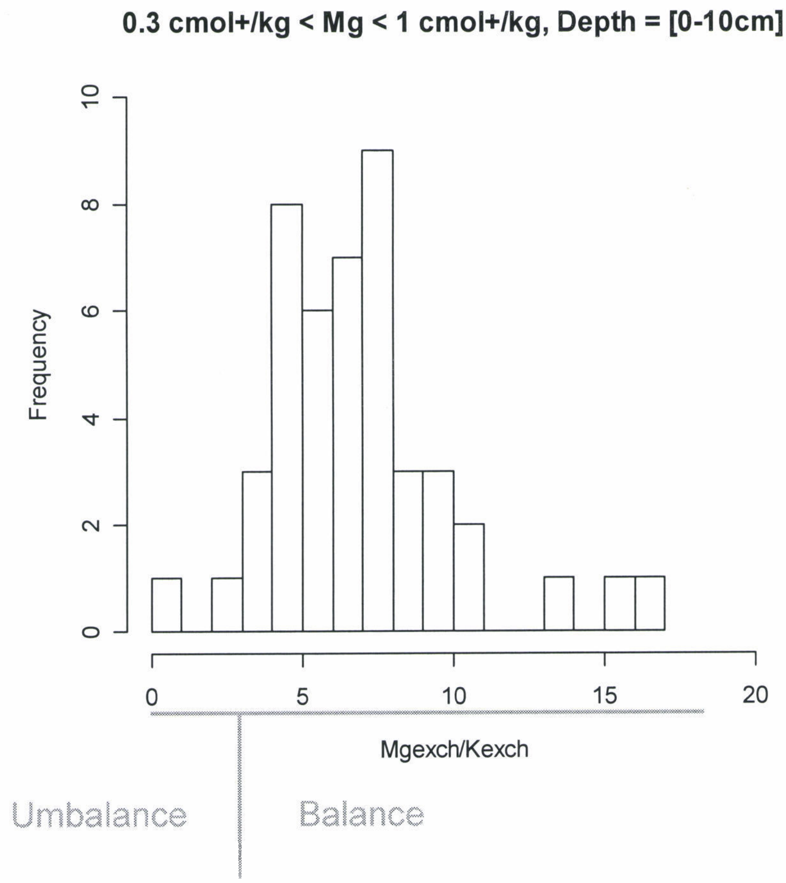


Figure 15: Balance between magnesium and potassium exchangeable of soils of Riau with low exchangeable magnesium content (Mg < 0.3 cmol+/kg) (a) globally (b) by soil type. The thresholds were extracted from Boyer (1992).

(a)



(b)

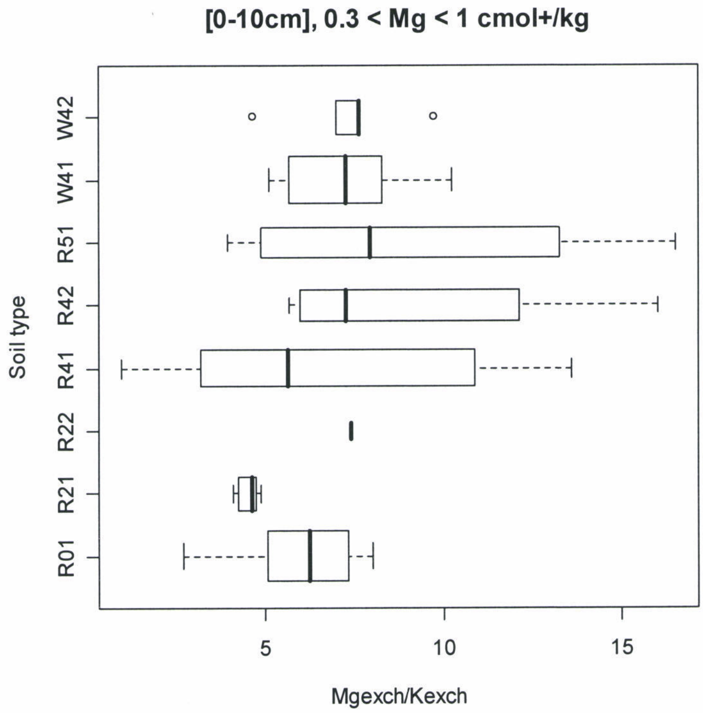
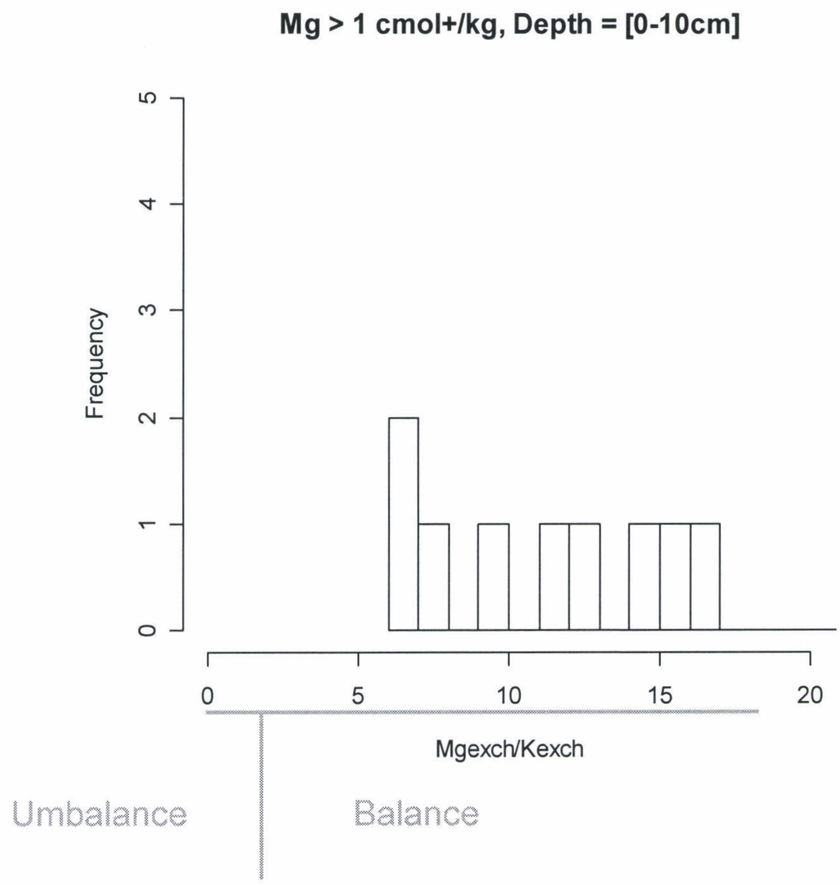


Figure 16: Balance between magnesium and potassium exchangeable of soils of Riau with medium exchangeable magnesium content (0.3 cmol+/kg < Mg < 1 cmol+/kg) (a) globally (b) by soil type. The thresholds were extracted from Boyer (1992).

(a)



(b)

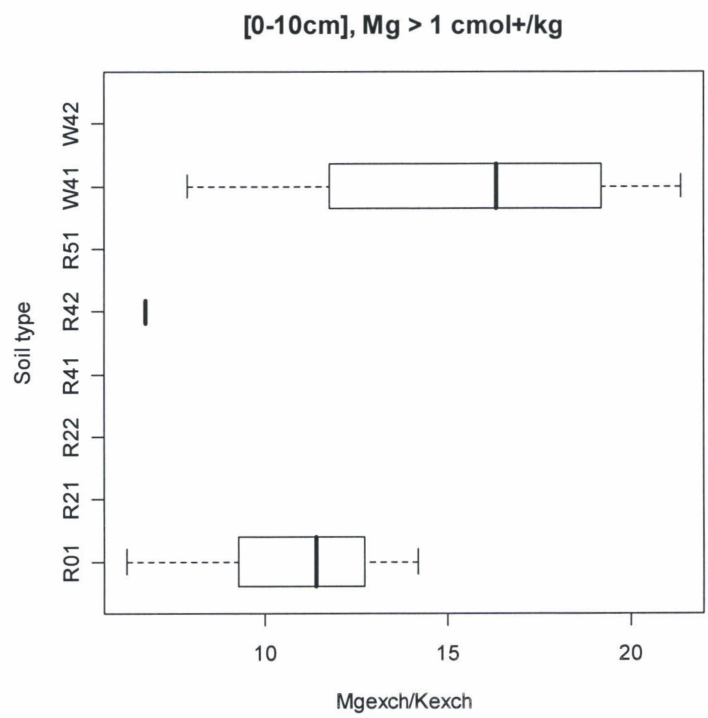
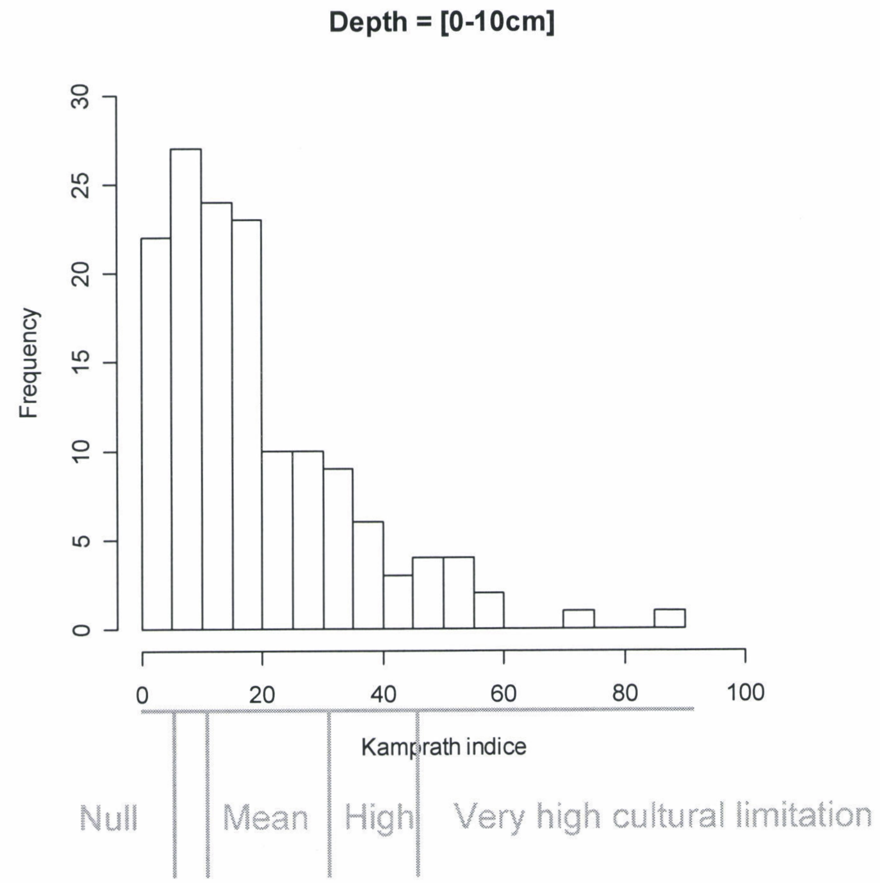


Figure 17: Balance between magnesium and potassium exchangeable of soils of Riau with high exchangeable magnesium content (Mg > 1 cmol+/kg) (a) globally (b) by soil type. The thresholds were extracted from Boyer (1992).

(a)



(b)

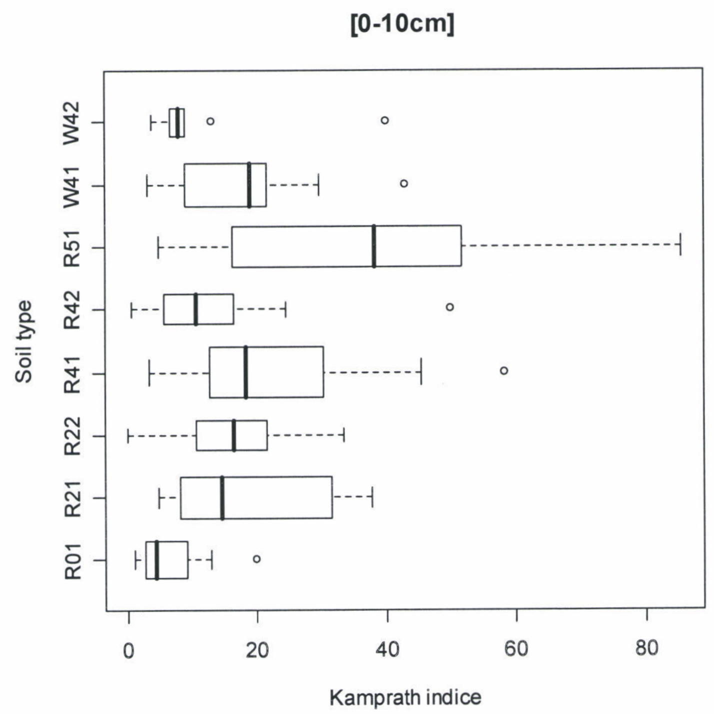


Figure 18: Cultural limitation of soils of Riau due to aluminium toxicity (Kamprath indice) (a) globally (b) by soil type.
The thresholds of cultural limitation were extracted from Boyer (1992).

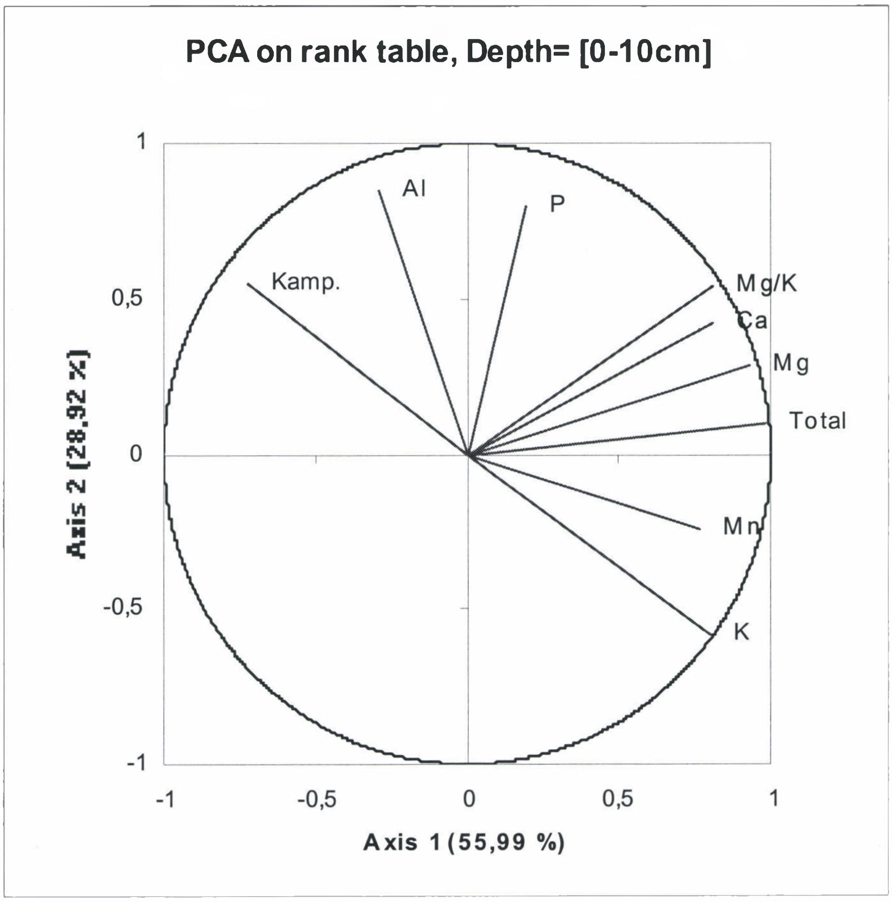


Figure 19: "Soil survey, Riau", Depth= [0-10cm], PCA on rank table, projection on (Axis1, Axis 2) of the chemical parameters

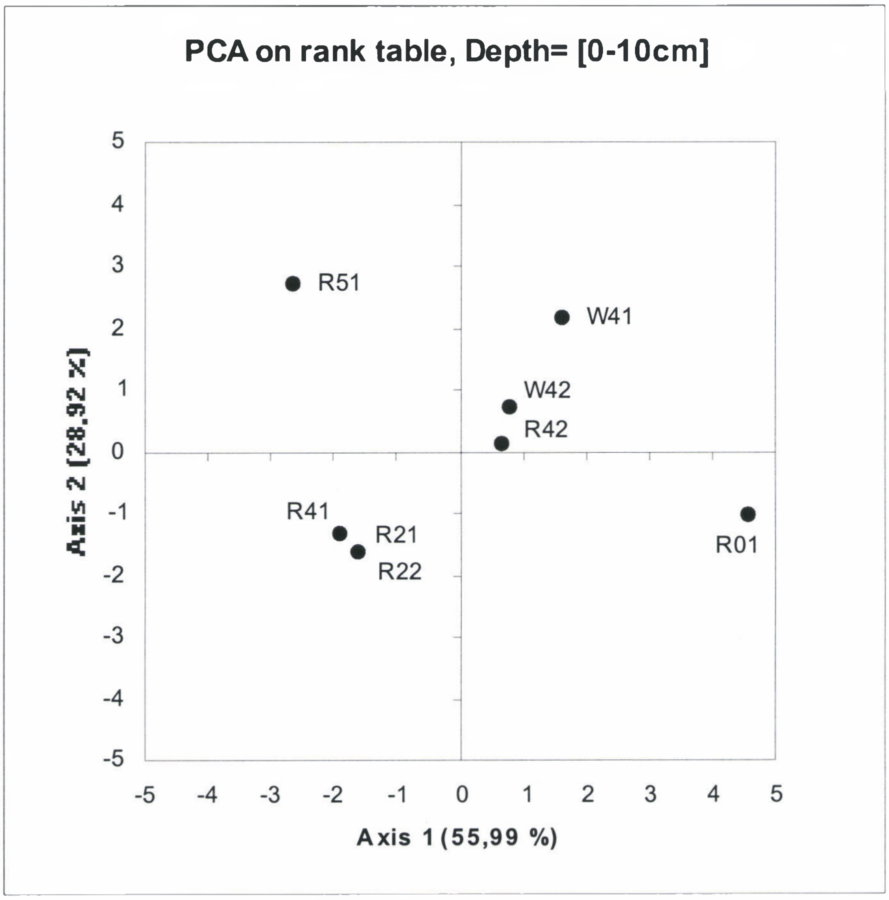


Figure 20: "Soil survey, Riau", Depth= [0-10cm], PCA on rank table, projection on (Axis1, Axis 2) of the soil types

B. PATTERN OF SOILS OF RIAU AT DIFFERENT SCALES

5. Pattern of soils of Riau at district scale

The objectives were the following:
- Were soil types equally distributed among the different districts of Riau?
- Was there a relationship between the district and the variability of chemical fertility of soils of Riau?

5.1. Material and Methods

Data

To answer the first question, we used "Soil survey, Riau" data file that has been described in §2. To answer the second question, using "Soil survey, Riau" data file would not be relevant because this data file had too many missing data in order to test both effects of district and soil type on chemical parameters (Annex 4). We answered partially the second question, using an extract of "Soil survey, Riau" data file, and testing the effect of district on chemical parameter for soil type R41. More precisely, we kept only the data of 26 profiles, those of soil type R41 locating in districts Dber, Dseb, Knil, Ksor, and Mras (Annex 4).

Analysis

We carried out an analysis of variance at one factor, District, on different chemical parameters: C, N, C/N, P, Total base, Mg and Al.

5.2. Results

Supposing that "Soil survey, Riau" data file was representative of the frequency of the soils of Riau, districts had not the same frequency of soil types (Annex 4).

For example:
- R01 was located especially in Dber and Dseb
- R51 was located especially in Mgel
- W41 was located especially in Dber and Dseb.

Soil type R41 was common in five of the ten districts studied: Dber, Dseb, Knil, Ksor, Mras.

We found a significant effect of district on available phosphorus and exchangeable magnesium. For example, soils R41 of the district Knil had a lower available phosphorus (mean = 0.2 ppm) than soils R41 of the district Mras (mean = 3.1 ppm) (Figure 21). Or, soils R41 of the district Dber had a higher magnesium content (mean = 0.5 cmol+/kg) than soils R41 of the districts Ksor and Mras (mean = 0.1 cmol+/kg) (Figure 22).

5.3. Discussion

We found that, within the same soil type R41, the chemical soil fertility was dependent on the district where the soil was located. This result explains a part of the variability of chemical fertility within a soil type. A special attention must be therefore paid to extrapolate results of fertilization trials obtained on one given district.

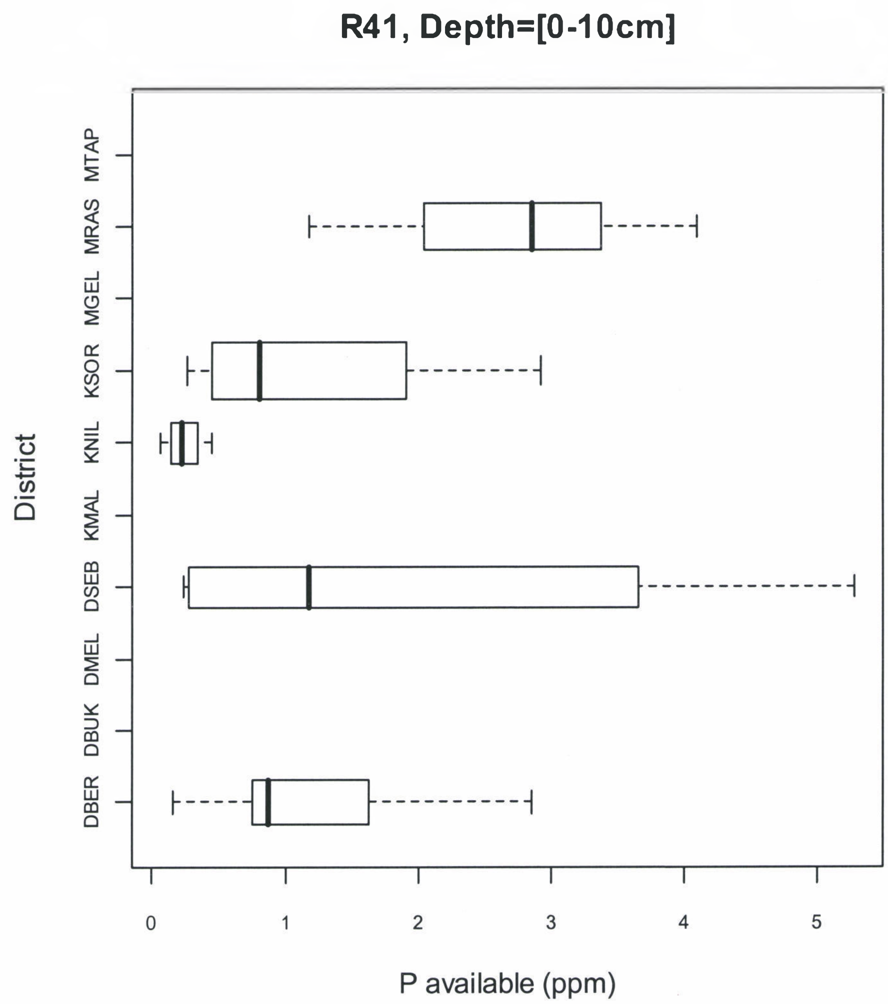


Figure 21: Variability of available phosphorus within soil type R41 of Riau, in function of the district

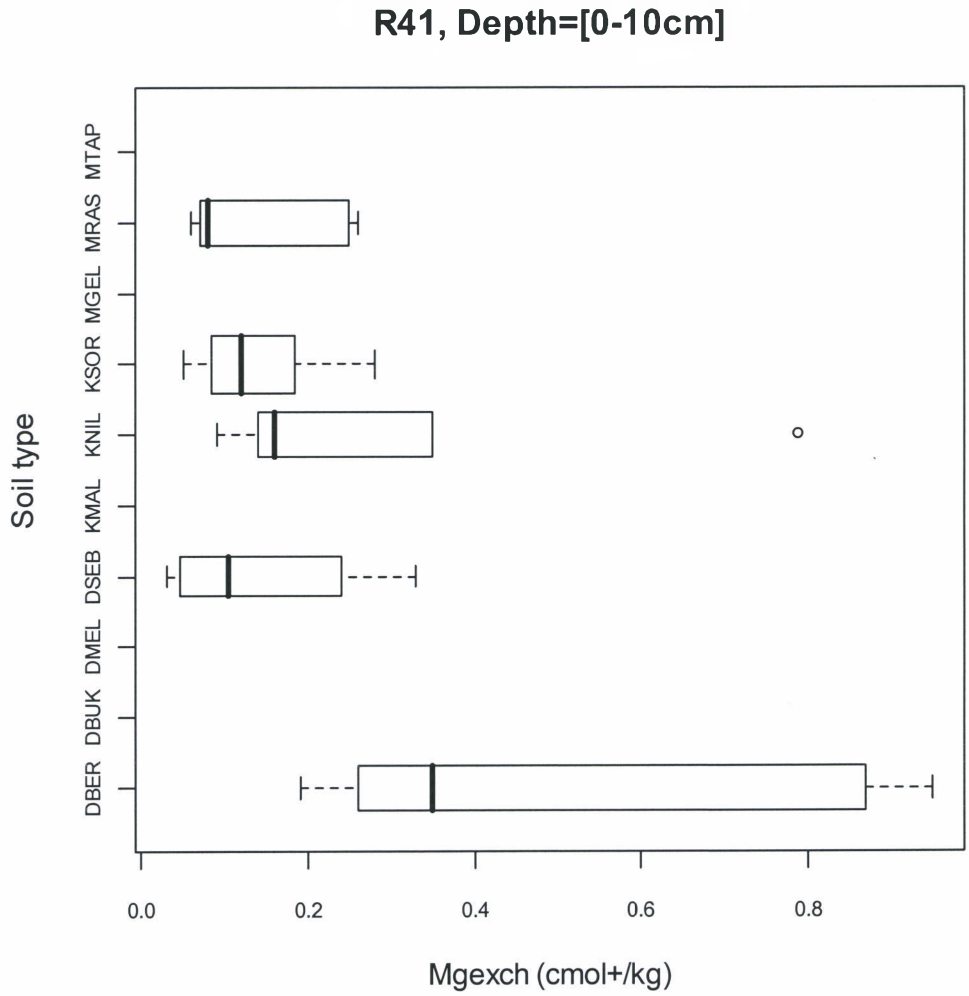


Figure 22: Variability of exchangeable magnesium content within soil type R41 of Riau, in function of the district

6. Pattern of soils of Rasau Kunig and Gelombang at landscape scale and relationship with physiographic map

The objectives were the following
- Was there a good relationship between field soil classification and laboratory soil classification?
- Was there a spatial pattern of soil types at landscape scale?
- Was physiographic map relevant to detect spatial patterns of soil types at landscape scale?

6.2. Material and Methods

Data

We used (i) "Rasau Kunig, 11 profiles" data file, (ii) "Soil nutrients, 60 samples" data file,
(iii) Soil survey map of Gelombang and Rasau Kuning, (iv) and physiographic map (Bouillet et al. 2007)

Analysis data

For each data file, we carried out a contingency table between field soil classification and laboratory soil classification.
Soil maps of the most representative soil types of Gelombang and Rasau Kuning were carried out by Effendi, using ArcGis.
We visually compared spatial pattern of soil map and physiographic map.

6.3. Results

6.3.1. Soil survey map is not consistent

Warning: there was not a perfect relationship between laboratory soil classification (classification from laboratory measure, giving particle soil size) and field soil classification (classification from a field appreciation, giving a texture class).

Example 1: "Rasau Kuning, 11 profiles" data ***(Table 4)***
Six profiles on eleven profiles (55%) had been well classified.
The three profiles with clay content higher than 35% (classified as R1n or R2n) had not been detected in the field. Consequently, the soil type R41 had been overestimated in the field.

Example 2: « Soil nutrients, 60 samples, 13th March 2007 » data ***(Table 5)***
Thirty-eight samples on fifthy-nine samples (64%) had been well classified.
The clay content had been often underestimated. Consequently, the soil type R21 had been underestimated in the field while the soil type R41 had been overestimated.

Therefore, as soil survey map had been carried out from field soil classification, soil survey map contains sometimes wrong information and is not consistent. We suppose that R41 had been overestimated on the soil survey map.

6.3.2. Spatial pattern of soils of Rasau Kuning and Gelombang

The soil survey map allowed seeing a spatial pattern of soils of Rasau Kunig and Gelombang.
In hilly landform, R41 was the most representative soil (Figure 23a), even if R41 had been overestimated (see §6.3.1). In the area where the density of streams was high, especially in Rasau Kuning district, R41 was generally replaced by R42 at the top of the streams and along the streams (Figure 23b). In the areas where the density of streams was low, especially in Gelombang, R41 was associated with R42 and W41 (Figure 23b, 23d), and was replaced along the streams by different soil: W41 (Figure 23d), W32, W52, R22, and R42 (maps not represented in this report).

From the hilly landform to the piedmont slope, the soil survey map allowed distinguishing a succession from R41 to R51 (top of the piedmont slope) and then to W41 or W51 (bottom of the piedmont slope) (Figure 23c, 23d, 23e).

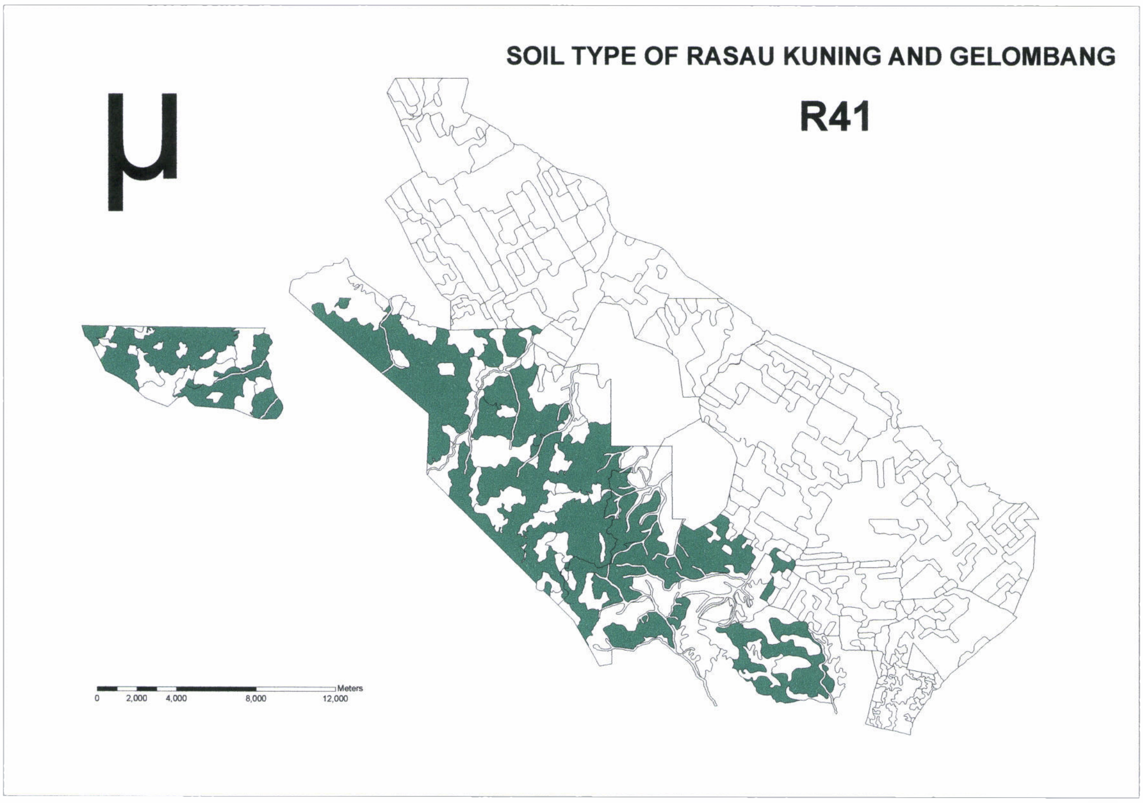
Finally, physiographic map (Bouillet et al. 2007) was relevant to detect different spatial patterns of soils between hilly landform and piedmont slope landform (Figure 24). On the other hand, the physiographic map was not relevant to detect different spatial patterns of soils between the two kinds of hilly landform: hilly landform with steepy slopes, and hilly landform with gentle slopes. We suppose that the method to obtain the soil survey map and its scale were not adapted to detect different spatial patterns of soils at the scale of a hill.

Table 4: « Rasau Kuning, 11 profiles », contingency table between field classification and laboratory classification

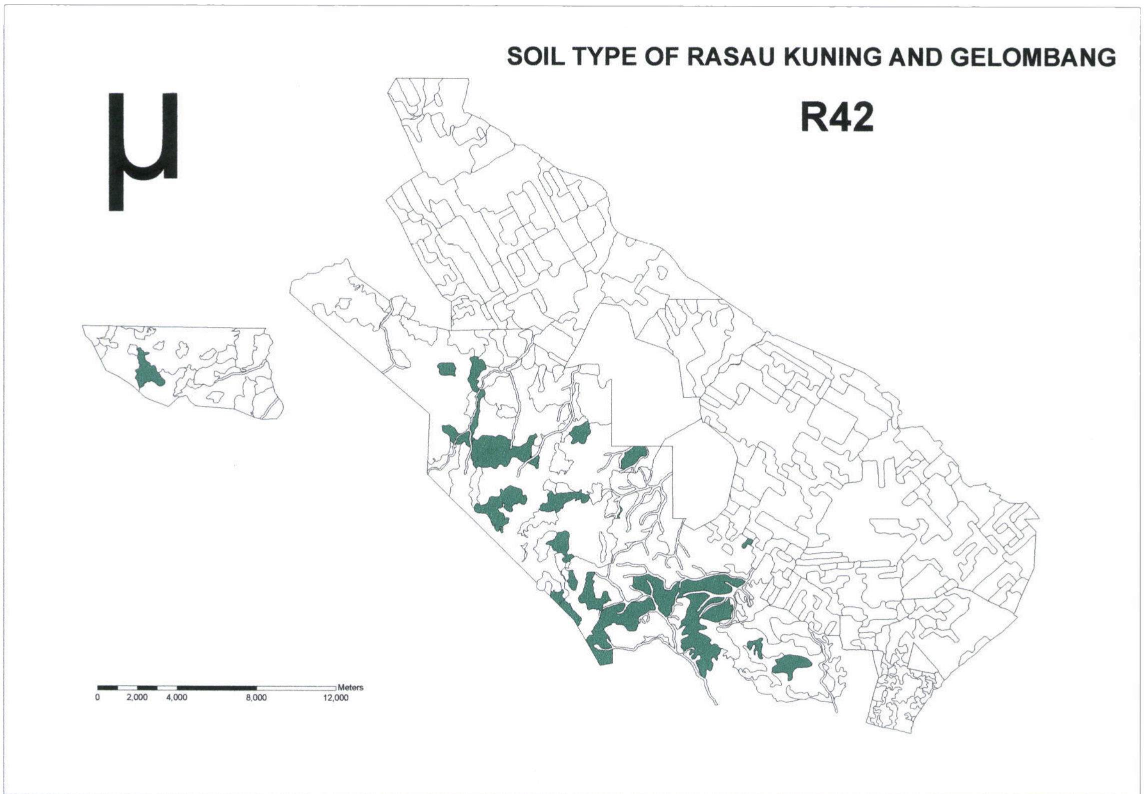
Soil Type classification (field)		Soil type classification (laboratory)									
		G34	G44	R11	R21	R22	R41	R42	R43	R51	Total
	G34		1								1
	G44										
	R11										
	R21										
	R22										
	R41			1	1		2			1	5
	R42					1		2			3
	R43								1		1
	R51									1	1
	Total		1	1	1	1	2	2	1	2	11

Table 5: « Soil nutrients, 60 samples », contingency table between field classification and laboratory classification

Soil Type classification (field)		Soil type classification (laboratory)									
		R01	R02	R11	R12	R21	R22	R41	R42	R51	Total
	R01										
	R02										
	R11	1		1							2
	R12		1			1					2
	R21										
	R22				2		1				3
	R41			2		11		21			34
	R42		1				2		13		16
	R51									2	2
	Total	1	2	3	2	12	3	21	13	2	59

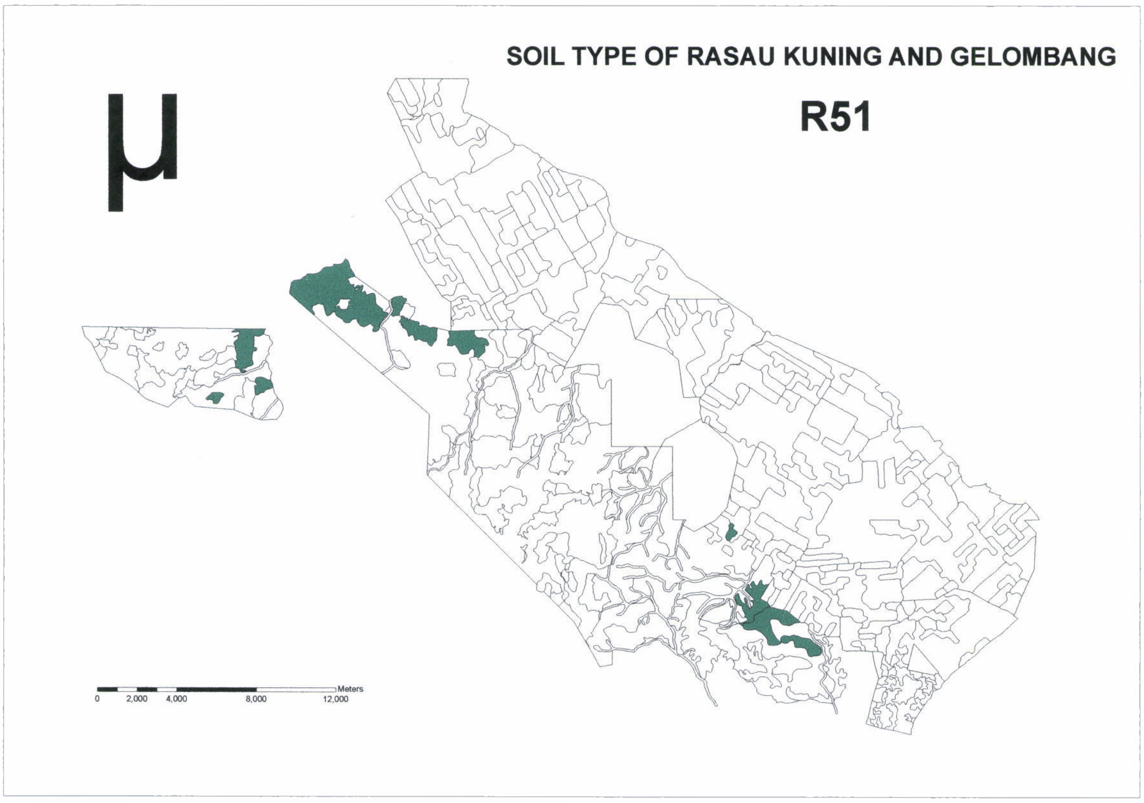


(a)

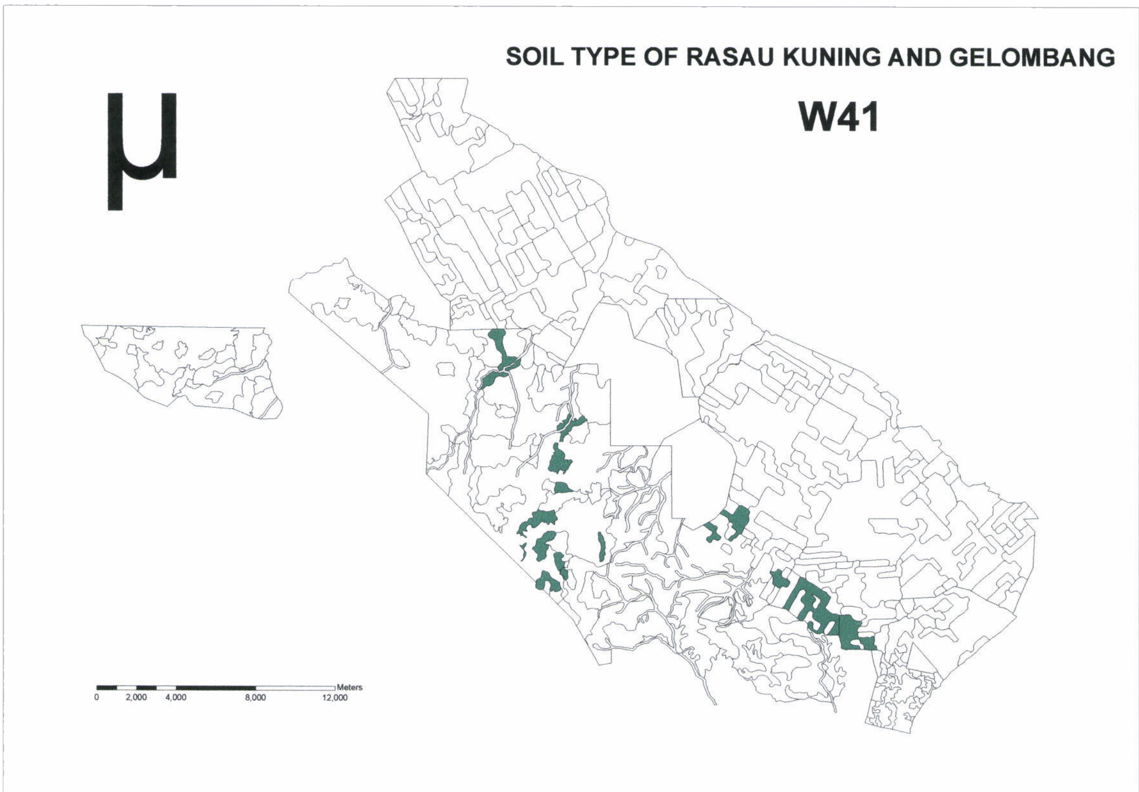


(b)

Figure 23: Soil map – soil type – of Rasau Kuning and Gelombang districts



(c)



(d)

Figure 23 (Continued): Soil map – soil type – of Rasau Kuning and Gelombang districts

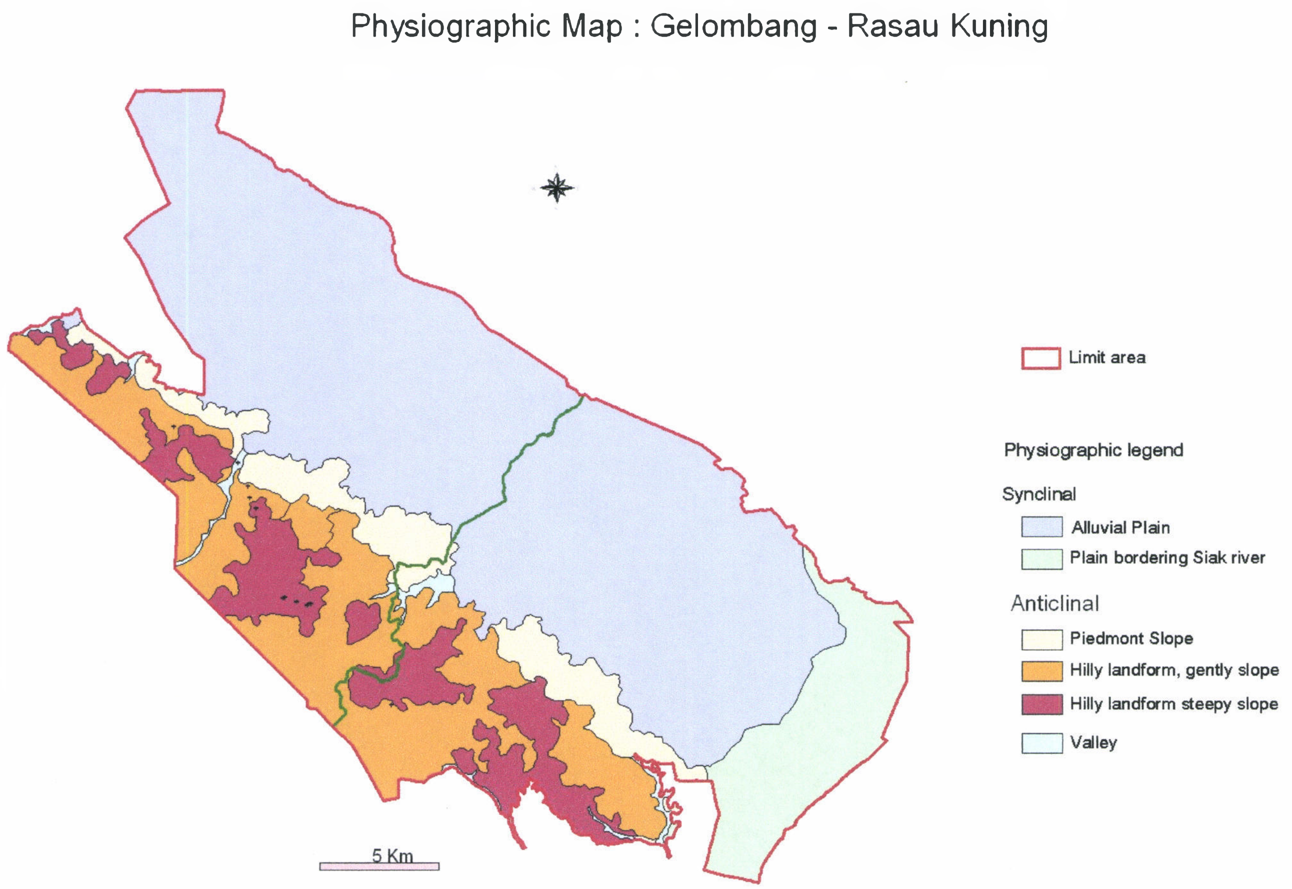


Figure 24: Physiographic map of Rasau Kuning and Gelombang (Bouillet et al. 2007)

7. Pattern of soils of Rasau Kuning and Gelombang at petak scale and relationship with topographical position

The objectives were the following:

- Was there a spatial pattern of soil types at petak scale?
- Was topographical position relevant to explain the variability of the chemical fertility?

7.2. Material and Methods

Field and laboratory

During Cirad missions in March 2007 and June 2007, we sampled in the field fifty-one soil profiles along seventeen toposequences and at three topographical positions (upper, middle, and lower). For each profile, samples had been taken at five depths: [0-10cm], [10-20cm], [20-30cm], [30-50cm], and [50-80cm]. We tried to choose toposequences within each physiographical unit, but finally, we sub sampled toposequences within "Hill with gently slopes". For each profiles, we measured its location with a GPS and its highest slope. The soil samples had been analyzed by AA laboratory.

Data
We gathered several data files sent by R. Marolop in May 2007 (for two toposequences studied in the field in March 2007: Mgel25 and Mgel65B) and in September 2007 (for fifteen toposequences studied in the field in June 2007). Finally, we used the "Topographical position * soil" data file that contained the soil analyses of 255 samples (51 profiles x 5 depths).

Analysis data
The analysis has been carried out for the [0-10cm] layer. To test the effect of topographical position on chemical parameter, considering soil particle, we carried out for each chemical parameter an analysis of covariance (Ancova) at one factor, topographical position (Upper, middle, and lower), using sand content as covariable. If student's test was significant for topographical position, we carried out Bonferroni's test to compare the means between the topographical positions. If student's test was significant for the sand content, we calculated a determination coefficient, carried out the correlation's test and drew a plot between sand content and the chemical parameter.

7.3. Results

7.3.1. Different successions of soil types

The characteristics of the profiles (topographical position, slope, location, soil type, etc.) are given in Annex 10. The characteristics of the toposequences (length, succession of soil types, etc.) are given in **Table 6**.

The soil profiles have been located on DEM (Figure 25), physiographic map (Figure 26), and on topographical map at scale 1/50000 (Figures 27a, 27b, and 27c) or on contour lines from DEM (Figures 27d, and 27e).

We observed three groups of toposequences (i) toposequences on which soil type was the same at upper, middle, and lower position (Figure 28), (ii) toposequences on which soil type changed moderately from the upper to the lower position (Figure 29), (iii) and toposequences on which soil type changed from the upper to the lower position (Figure 30).

The first group contained 5 toposequences (Mgel28, Mgel38, Mgel65B, Mras30, and Mras95). We observed always soil type R41 at upper, middle and lower position. The typical toposequence of this first group has a length lower than 120 m, slopes lower than 30% and a maximum elevation of 50 m.

The second group contained 7 toposequences (Mgel25, Mras58, Mras172, Mras190, Mras196, DuriII6, and DuriII31). Soil type changed moderately along a toposequence, e.g. from R51 to R41/R51 (Mras196). Toposequences of "Plateau" are typical of this second group with a length higher than 120 m, slopes lower than 10% and a maximum elevation of 30 m.

The third group contained 5 toposequences (Mras64, Mras171, Mras175.1, Mras175.2, and DuriII9). Soil types changed along a toposequence, e.g. from R51 at upper position to W41/W42 at lower position (Mras175.2). The typical toposequence of this third group has a length higher than 120 m, slopes lower than 30% and a maximum elevation of 70 m. We found also a toposequence (Mras64) with a length lower than 120 m but with a slope of 55% at lower position.

7.3.2. Different pattern of soil particle size.

We observed different patterns of soil particle size from upper to lower position (Figure 31). The two most representative patterns were the following:
- A decrease in sand content from upper position to lower position (e.g. Mras64). This pattern has been almost always observed in convex slope.
- A higher sand content at lower position (e.g. Mgel65B). This pattern has been almost always observed in convexo-concave slope.

7.3.3. A chemical fertility in function of sandy content

At [0-10cm] of depth, the model of Ancova was significant for C, N, P, K, Mg/K, Fe and Al. We found a significant effect of topographical effect for only one chemical parameter, P, and a significant effect of sand content for the other parameters. Available P was higher at middle position (P=10 ppm) than at upper and lower position (P= 4 ppm and 5 ppm, respectively). Sand content was correlated positively with C (R^2=0.20), and N (R^2=0.24), and correlated negatively with K (R^2=0.21), Fe (R^2=0.24) and Al (R^2=0.17) (Figure 32). All these correlations were significant even if their value were not very high.

7.4. Discussion

We found different successions of soil types along toposequences, depending on some landscape characteristics: elevation, slope, and length between the upper and the lower position. It could be relevant for AA to precise these relationship to better predict the soil type in area of Eucalypt plantations. This objective may be achieved through sharp topographical information of the planted area implemented in the GIS. This information is available in Indonesia (i.e. topographical map at 1:50000 produced by JANTOP) and/or should be created by AA (e.g. DEM with about 10 m of vertical accuracy on 20m x 20 m cells).

We found different patterns of soil particle size along a toposequence. Some of these patterns can be explained.

- Soils more sandy at upper position can be associated with the alteration of sandstone, a relatively hard rock. On the opposite, clayed soils located on lower position can be linked to the alteration of mudstone, a soft rock.
- When soils were more sandy at the lower position of a convexo-concave slope, this pattern could be associated with processes of erosion and transport of soil particle size (sand, silt, clay) at upper position and, on the other hand, with process of transport of fine particle size (silt, clay) and process of colluvial deposit of coarse particle size (sand) at lower position. It seems that these different patterns were linked with topographical characteristics (slope, distance to the head of a stream, etc.). Arara Abadi R&D could carry out complementary sampling to establish such relationships in order to better predict the different patterns of soil particle size and chemical fertility.

We found that the sand content explained partially the chemical fertility of soils at [0-10cm] depth, for C, N, K, Fe and Al. More particularly, we found that sand content was positively correlated with C and N. This result is surprising because many studies showed a negative correlation between sand content and C and N (Oades 1988, Spain 1990, Powers & Schlesinger 2002, Zinn et al. 2005). In Indonesia, East-Kalimantan, Ohta & Effendi (1992a, 1992b) showed also this negative correlation on acrisols (i.e. ultisols) in lowland *Dipterocarp* Forest. We suppose that extracting timber with heavy machinery during harvesting induced a soil compaction that decreases the chemical fertility of soils. For example, Ilstedt et al. (2006) showed that in a Malaysian plantation, the soils' organic content were 25% lower on disturbed plots compared to non disturbed plots, three months after planting. We may suppose that soil compaction was more marked on clayed soils than on sandy soil, especially if there was an argic horizon near the top of the soil. It could explain that, in Riau, the organic content and ammonium content were globally better in sandy soils than in clayed soils.

We did not find that the topographical position explains the chemical fertility of soils at [0-10cm] depth, except for P. The main cause is that, in Riau, there were different successions of soil types and different patterns of soil particle size along the toposequences. Another cause may be that we did not take into account the history of the plantation when we chose and took the soil samples. It is known that the chemical fertility depends on stand age (Setiawan 1993 after Siregar et al. 1998), species (Acacia mangium, Eucalyptus ...) and number of rotations. Consequently, because of different succession soil types, different patterns of soil particle size and different histories of the petak, this study did not allow to predict the chemical fertility according to the topographical position.

*Table 6: "Topographical position * soil", characteristics of toposequences*

Toposequence		Soil sequence	Length	Max.	Elevation	Physiographic
District	Petak	(slope %)	(m)	Slope (%)	of upper position (m)	unit
MGEL	25	R41/R21 → R41 → R41 (15%, 26%, 13%)	88	26	50	Steep
MGEL	65B	R41 → R41 → R41 (8%, 31%, 25%)	80	31	50	Steep
MRAS	30	R41 → R41 → R41 (15%, 20%, 30%)	119	30	75	Steep
MRAS	64	R41 → R21 → R11 (16%, 33%, 55%)	50	55	75	Steep
MRAS	58	R51/W51 → W52 → W51 (6%, 2%, 0%)	232	6	30	Plateau
MRAS	95	R41 → R41 (12%, 24%)	48	24	50	Gentle
MRAS	172	R41 → R21/R41 → R41/R21 → R41 (18%, 14%, 22%, 34%)	163	34	70	Steep/Gentle
MRAS	175.1	R41 → R11 → R21 (11%, 28%, 29%)	94	29	70	Steep
MRAS	175.2	R51 → R41 → W41/W21 (5%, 9%, 16%)	282	16	60	Gentle
MRAS	196	R51 → R51/R41 → R41/R51 (3%, 8%, 5%)	118	8	30	Plateau
MRAS	190	R51 → R51 → R41/R51 (1%, 7%, 8%)	235	8	30	Plateau
MRAS	171	R41 → R41 → R42/R12 (4%, 12%, 24%)	210	24	70	Steep/Gentle
MGEL	38	R41 → R41 → R41 10%, 16%, 30%)	65	30	40	Gentle
MGEL	28	R41 → R41 → R41 (7%, 20%, 8%)	96	20	50	Steep
DURI II	9	R41/R51 → R32 → R32 (7%, 5%, 11%)	90	11	-	-
DURI II	31	R41 → R41 → R41/R51 (6%, 8%, 5%)	149	8	-	-
DURI II	6	R01 → R01/R11 (7%, 5%)	194	7	-	-

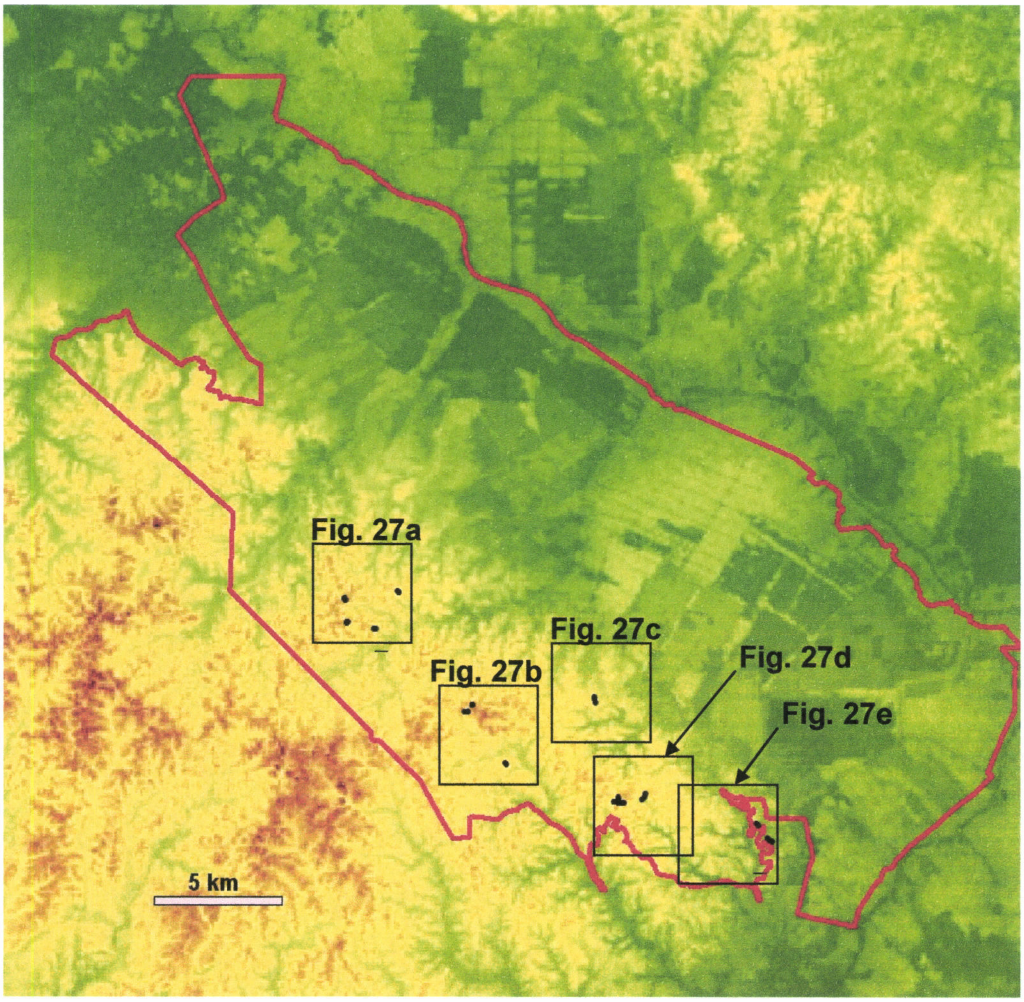


Figure 25: Location of toposequences on DEM

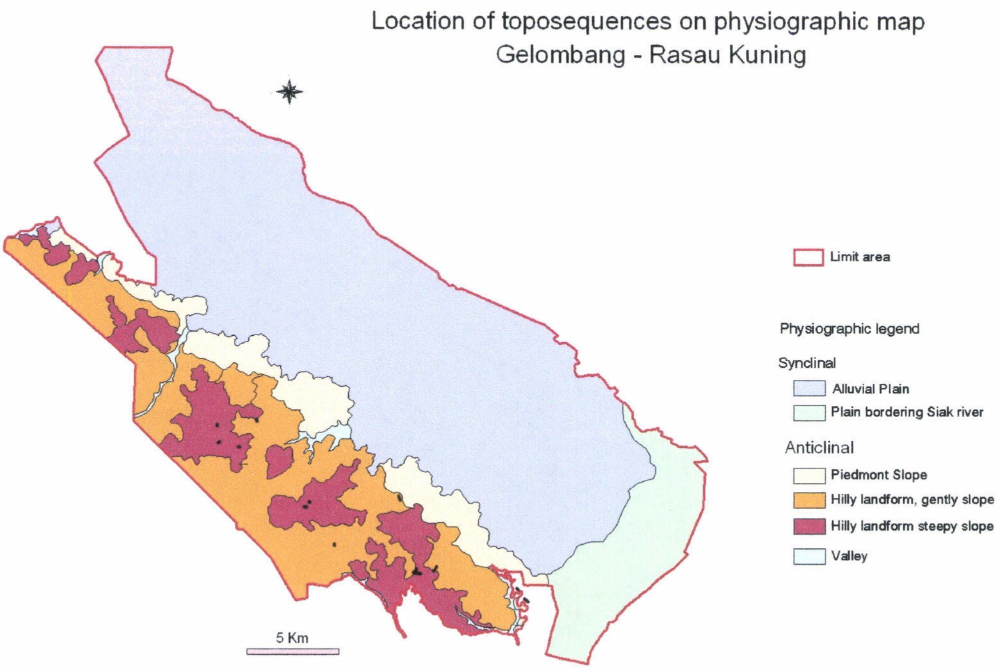
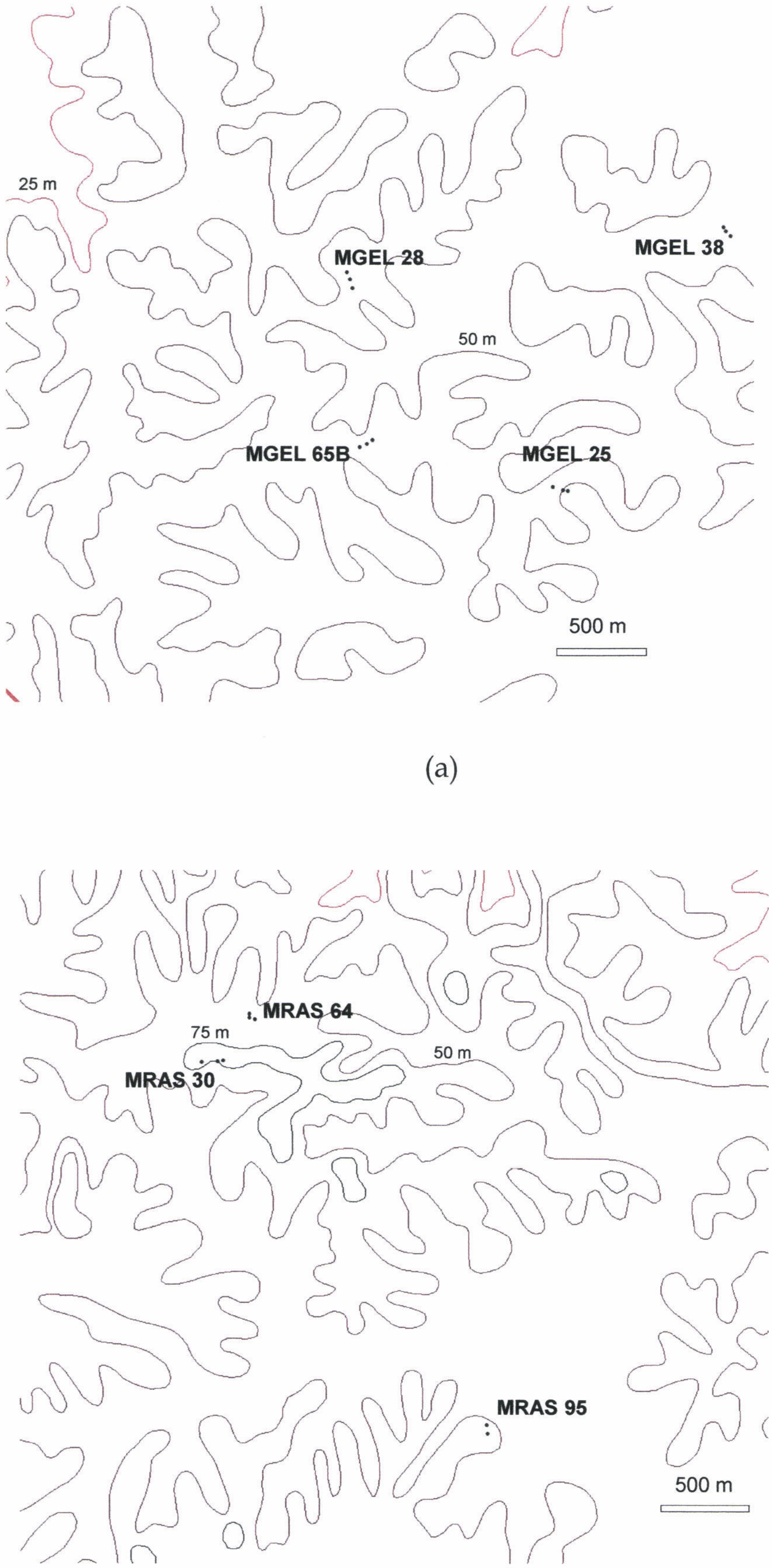


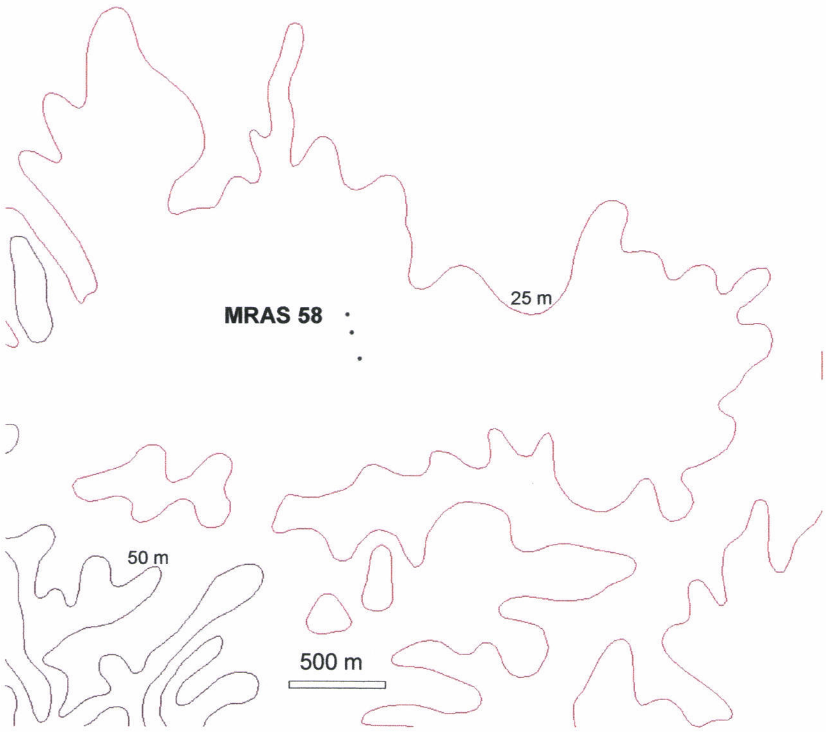
Figure 26: Location of toposequences on physiographic map



(a)

(b)

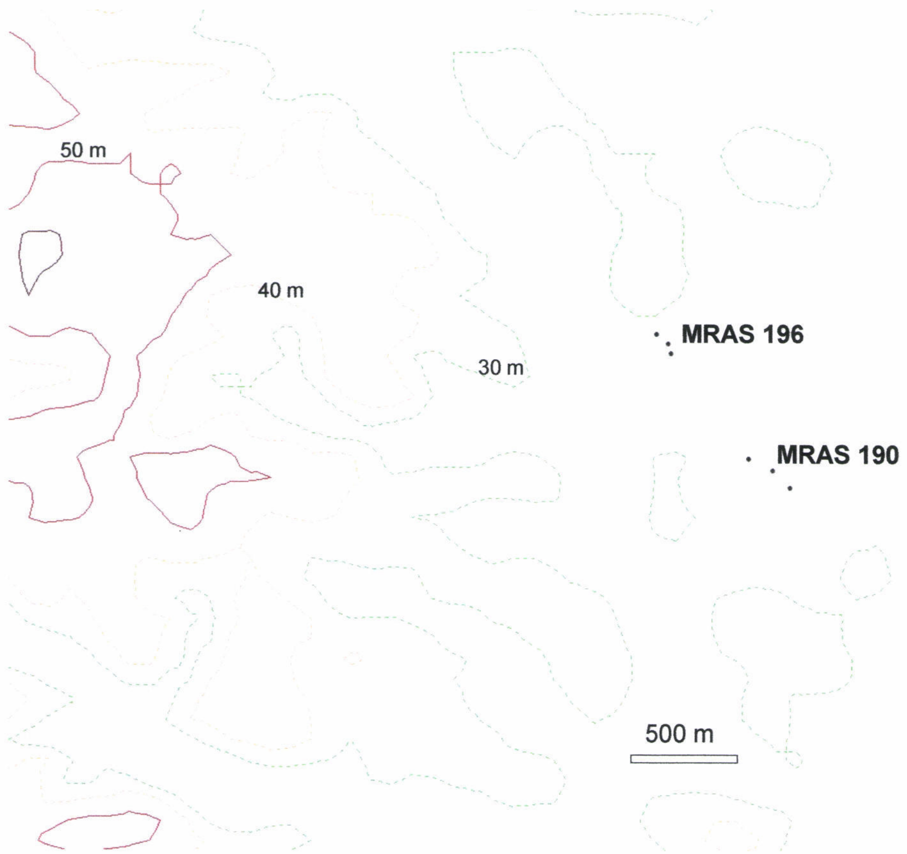
Figure 27: Location of toposequences on contour lines



(c)

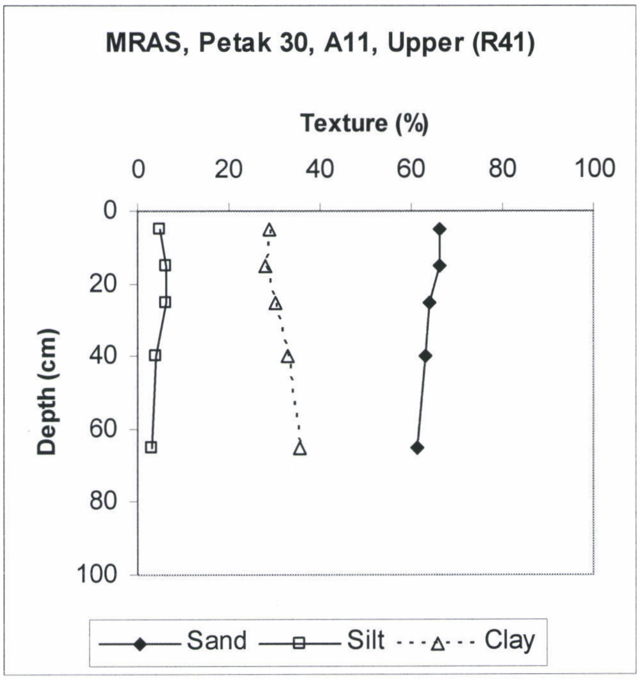
(d)

Figure 27 (Continued): Location of toposequences on contour lines

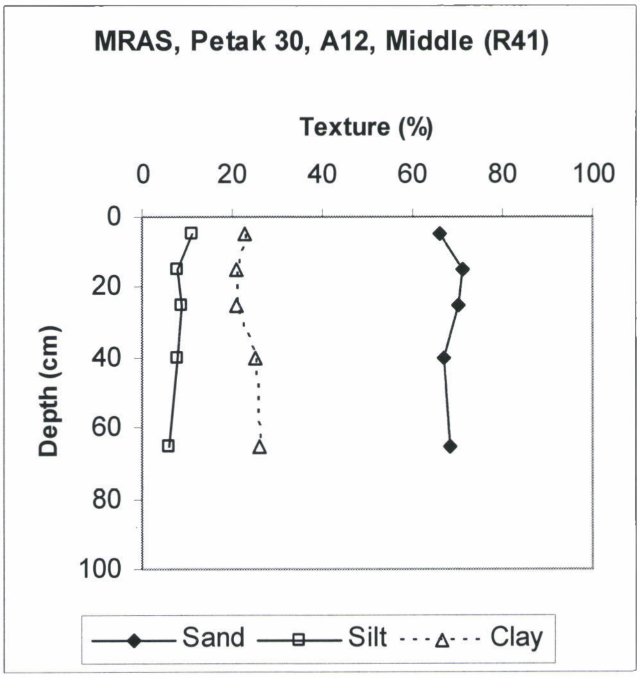


(e)

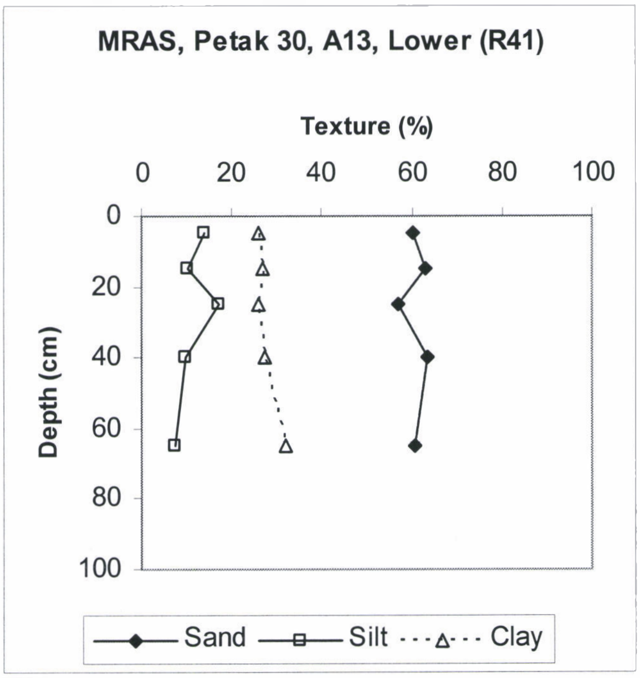
Figure 27 (Continued): Location of toposequences on contour lines



(a)



(b)



(c)

Figure 28: Example of a toposequence with the same soil type at (a) upper, (b) middle, (c) and lower position.

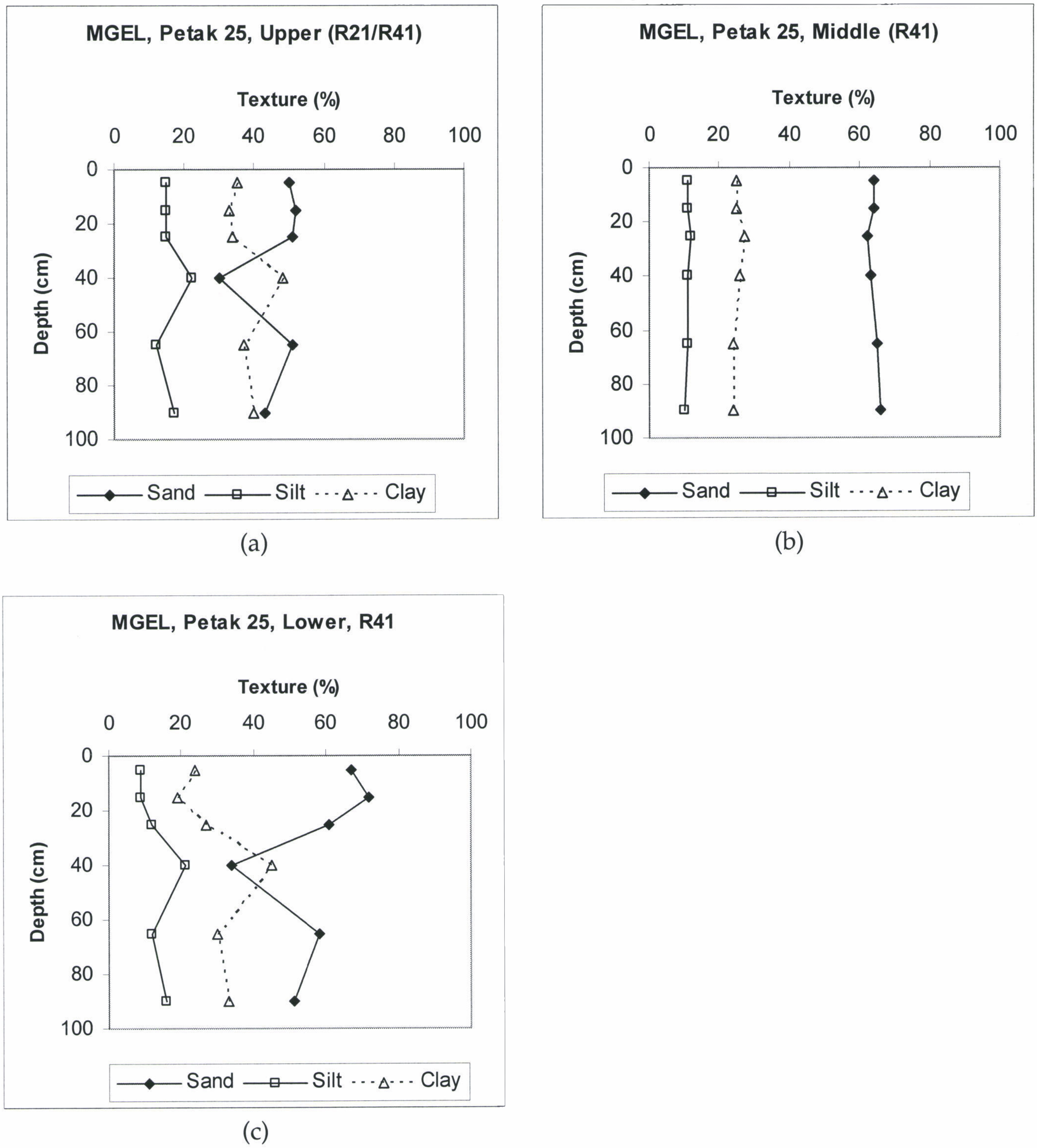
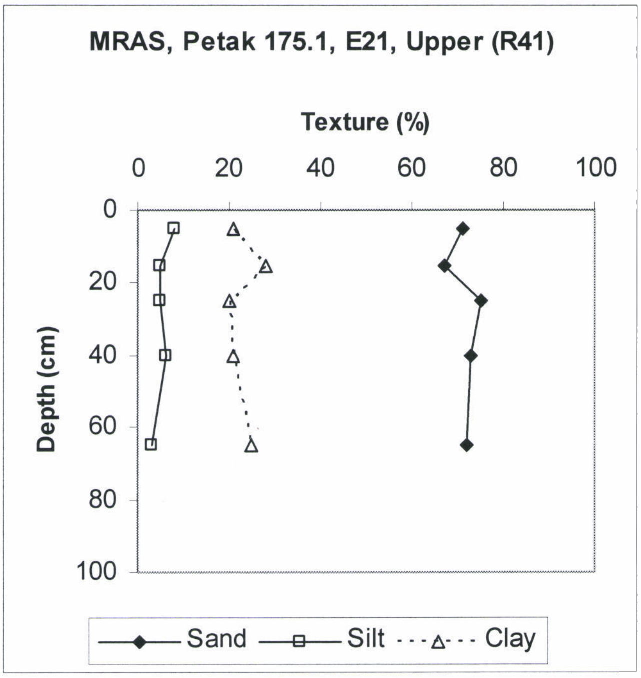
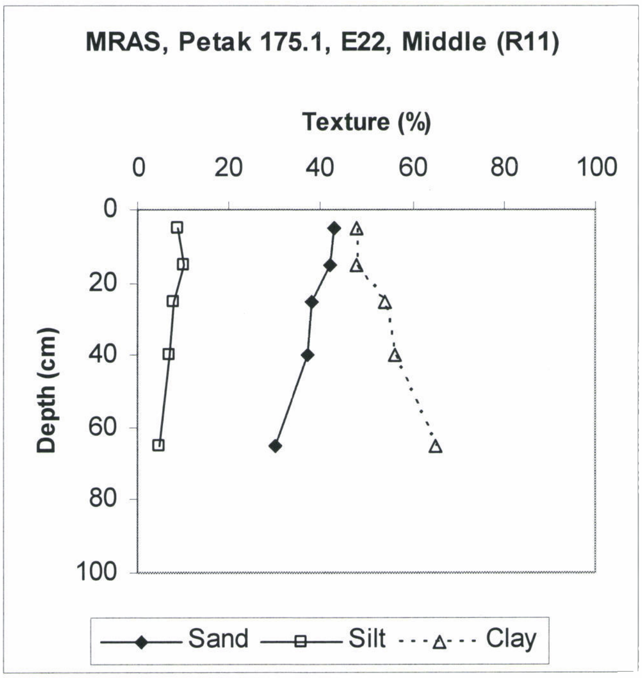


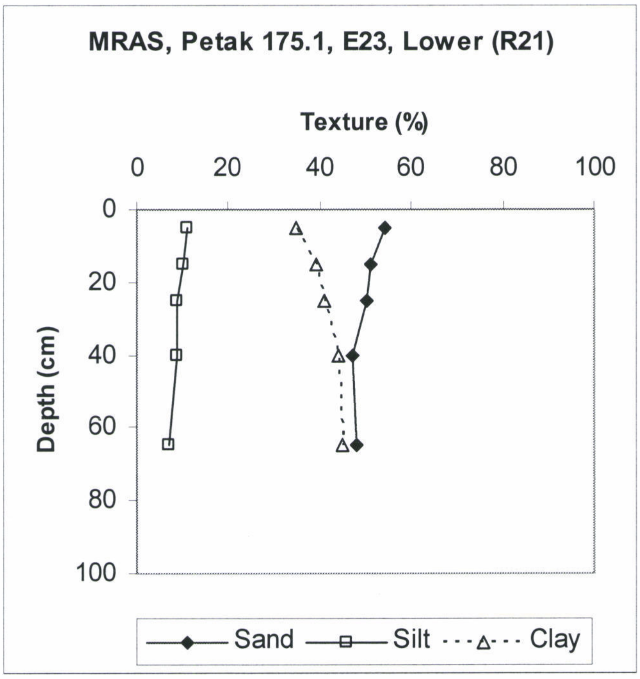
Figure 29: Example of a toposequence with a moderately change of soil type at (a) upper, (b) middle, (c) and lower position.



(a)



(b)



(c)

Figure 30: Example of a toposequence with a change of soil type at (a) upper, (b) middle, (c) and lower position.

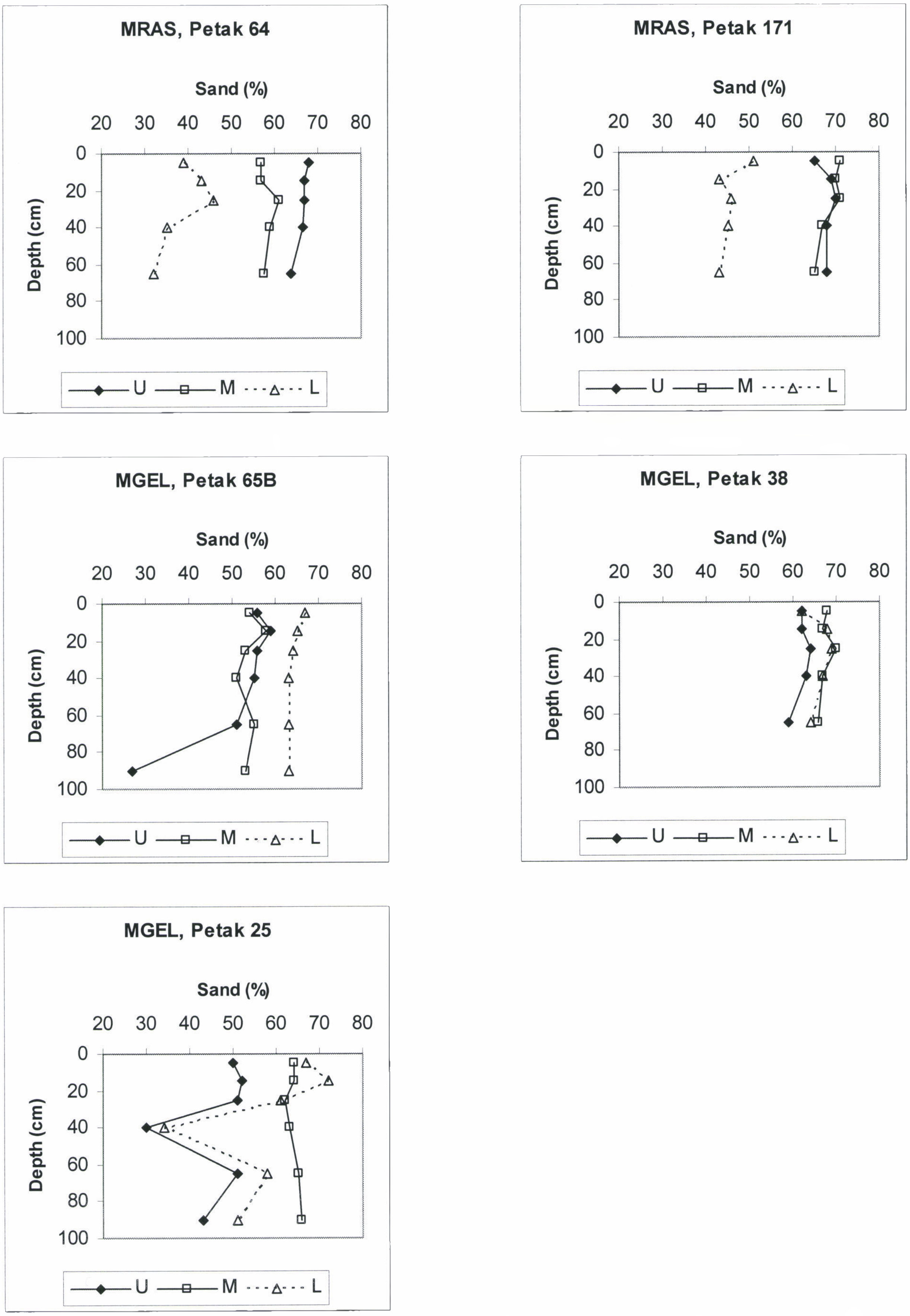


Figure 31: Patterns of sand content at upper (U), middle (M) and lower (L) position of some toposequences

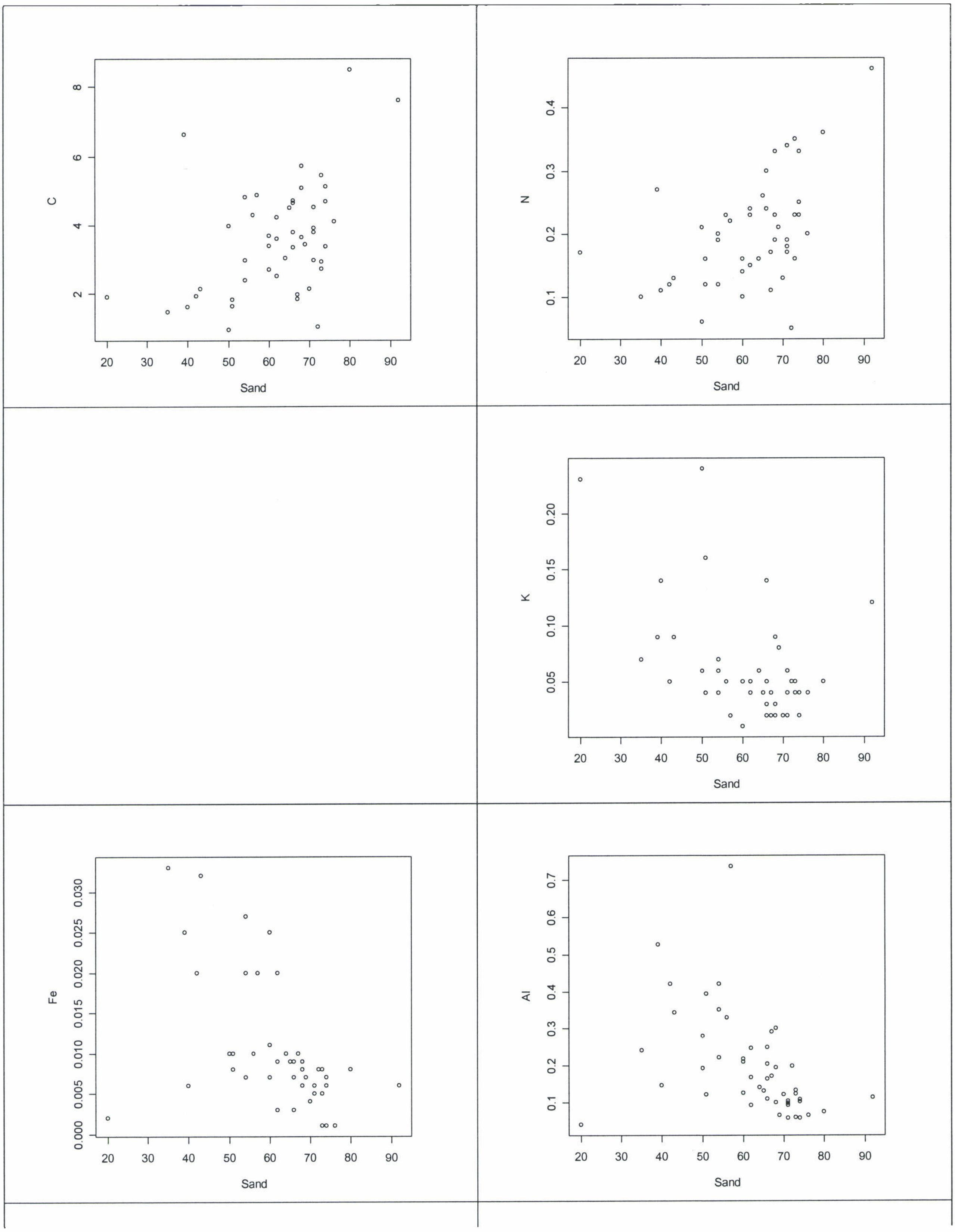


*Figure 32: "Topographical position * soil", relationship between sand content and some chemical parameters at [0-10cm] depth.*

8. Conclusion

We found that the variability of chemical fertility was partially explained by soil type, sand content, topographical position, type of slope along toposequence (convex, convexo-concave), stand characteristics (species, age) and number of stand rotations. Nowadays, it is not yet possible to find and use a simple and general model that easily predicts the chemical fertility of the soils.

In the short term,we propose to Arara Abadi to take and analyse soil samples systematically before a new planting or between two rotations, at least along one toposequence. This information will be needed to apply fertilisation adapted to site characteristics according to the results of the site specific fertilizer trials (cf following chapter) .

In the medium term it is proposed to Arara Abadi R&D to complete the soil survey data base through complementary soil sampling. This study will be carried out to establish robust relationships between chemical fertility and environment factors (slope, elevation distance to streams …) in order to better predict chemical fertility pattern at petak scale and refine fertilisation inputs.

C. DEFINING THE MAIN REPRESENTATIVE SITES FOR FERTILISATION TRIALS.

Two criterions must be considered to define the main representative sites for fertilisation trials. The trials have to be set (i) on the most frequent soil types of Riau, especially in the districts of Rasau Kuning and Gelombang (ii) on soils types that differ highly by their chemical fertility

In Rasau Kuning and Gelombang, the most frequent soil type is R41 (Figure 23a), even if we know that this soil type had been overestimated in the soil survey map (See §.6.3.1). Other soil types, like R42, R51, W41, and W42, are well represented in these two districts (Figure 23b, 23c, 23d, and 23e).

In Riau, the analysis of "Soil survey, Riau" data file allowed us distinguishing four soil types with different chemical fertility: R01, R41, R51, and W41/W42 (See §4., Fig. 20). Except R01, these soil types are frequent in Rasau Kunig and Gelombang.

Therefore we propose to set fertilisation trials on the four soil types R01, R41, R51, and W41/W42, as they cover a large range of soil particle size and chemical fertility in Riau (**Table 7**), and because these soils are frequent except for R01.

Table 7: Chemical fertility of the main representative sites suggested for fertilization trials

Soil type	Total exchangeable base	Mg exch.	K exch.	P	Aluminium toxicity
R01	+	+	- -	- -	- -
R41	- -	-	- -	- -	+
R51	- -	- -	- -	-	+ +
W41/W42	-	+	-	+	-

We found that the variability of chemical fertility was partially explained by soil type, sand content, topographical position, and the kind of slope along a toposequence (convex, convexo-concave). But, at petak scale, we did not find a simple and general model that easily predicts the spatial pattern of soil type, sand texture and chemical fertility. Therefore, in the fertilisation trials, it will be necessary (i) to quantify the variability of soil type, sand content, and chemical fertility within a plot, and (ii) to control a potential effect of topographical effect on soil type, sand content and chemical fertility.

In practical, four main recommendations are given to establish the site specific fertilizer trials.
1) The land survey within a plot will have to be well known. For each plot, a soil-survey map at 1/5000 scale will have to be carried out.
2) Within each plot, two transects will be more specifically studied considering the slope, soil type, soil particle size and chemical fertility.
3) Blocks will have to be set parallel to contour lines.
4) For R41 that is the most representative soil type, a trial will be set up near the head of a stream and another trial will be set up far from the head of a stream to test the effect of fertiliser inputs on two kinds of slopes (convex vs convexo-concave), at least.

The main objective of fertilisation trials is to achieve the best combination of nutrient (N, P, K, etc.) for eucalypt stands. But considering the variability of soils, other hypotheses could be tested. For example a positive effect of fertiliser splitting can be observed on sandy soils but not on clay soils.

It is recommended to AA to set up a core of experiments in all the chosen sites. Complementary experiments could be set up in a few plots according to the specific site characteristic, as.input of magnesium in case of unbalanced Mg/K ratio. A tentative list of fertiliser experiments has been already proposed, and will be refined with AA R&D staff during the Cirad mission of December 2007.

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List of Annexes

Annex 1: Participants and schedule of the second mission of WP1 in June 2007.

Participants
Dr JP Bouillet: sylviculturist, WP coordinator
Dr V Freycon: morphopedologist

Mission schedule
- Monday 25th June, 13h50: departure from Montpellier (France)
- Tuesday 26th June, 17h: arrival at Jakarta
- Wednesday 27th June: departure from Jakarta and arrival at Pekanbaru; meeting with AA R/D team
- Thursday 28th to Friday 29th: field observations and soil sampling on toposequences
- Sunday 1st July: Departure of J.P. Bouillet
- Monday 2nd to Tuesday 3rd July: field observations and soil sampling on toposequences
- Wednesday 4th July: meeting with R. Marolop and Effendi; wrap-up meeting with AA R/D
- Thursday 5th July: travel by road to Pekanbaru and by plane to Jakarta, Amsterdam
- Friday 6th July: arrival at Montpellier (14h50).

Annex 2: Correspondences between different soil classifications
(i) local classification (Arara Abadi), (ii) Indonesian classification, (iii) USDA classification,
(iv) and international WRB classification. According to Soil survey staff and IUSS Working group WRB (2006)

Local Classification (Arara Abadi)	Indonesian classification	USDA classification			WRB classification
		Order	Great group	Subgroup	Group
R01	?	?	?	?	?
R11	Red Yellow Podzolic	Ultisol (-ults)	Tropudults/Hapludults	Typic Hapludult	Acrisol
R12	Red Yellow Podzolic	Ultisol (-ults)	Tropudults/Hapludults	Typic Hapludult	Acrisol
R21	Red Yellow Podzolic	Ultisol (-ults)	?	?	Acrisol
R22	Red Yellow Podzolic	Ultisol (-ults)	?	?	Acrisol
R41	Red Yellow Podzolic	Ultisol (-ults)	Tropudults/Paleudults	Typic Paleudult	Acrisol
R42	Red Yellow Podzolic	Ultisol (-ults)	Tropudults/Paleudults	Typic Paleudult	Acrisol
R51	Red Yellow Podzolic	Ultisol (-ults)	Tropudults/Paleudults	Psammentic Paleudult	Acrisol
R52	Red Yellow Podzolic	Ultisol (-ults)	Tropudults/Paleudults	Psammentic Paleudult	Acrisol
W41	White Yellow podzolic	Enceptisol (-epts)	Dystrudepts	Typic Dystrudept	?
W42	White Yellow podzolic	Enceptisol (-epts)	Dystrudepts	Typic Dystrudept	?
Alluvial	Alluvial	Enceptisol (-epts)	Dystrudepts	Fluvaquentic Dystrudept	Fluvisol
Gleysol	Gleysol	Enceptisol (-epts)	Humaquepts	Typic Humaquept	Gleysol
Podzol	Podzol	Spodosol (-ods)	Fragiaquods	Typic Fragiaquod	Podzol

Annex 3: "Soil survey, Riau", number of profiles by soil types
Only soil types in bold type had been kept in the analysis.

Soil type	**R01**	R11	R12	**R21**	**R22**	R32	**R41**	**R42**	**R51**	R52	W21	W22	W31	**W41**	**W42**	W51	W52
n	21	7	6	24	12	1	32	12	22	6	1	1	2	24	11	5	5

Annex 4: "Soil survey, Riau", frequency of soil types in function of the districts

	District										
Soil	DBER	DBUK	DMEL	DSEB	KMAL	KNIL	KSOR	MGEL	MRAS	MTAP	Total
R01	10			5	3		1	1	1		21
R21	1		1	1	2	4	1	7	6	1	24
R22	1							7	4		12
R41	5	1		4		5	8	2	5	2	32
R42	3			2	1			3	3		12
R51	1	3			2	1	1	9	4	1	22
W41	7			15			1	1			24
W42				6	2		2	1			11
Total	28	4	1	33	10	10	14	31	23	4	158

Annex 5: Conversion of unit from cmol+/kg (=mé/100g) to ppm (=mg/kg)

Chemical element	**Code**	**Z**	**Molar mass**	**Valence**	**1 mol (g)**	**1 cmol (g)**	**1 cmol+ (g)**	**1cmol+/kg (g/kg)**	**1cmol+/kg (mg/kg=ppm)**	**Baize (2000)**
Hydrogen	**H**	1	1,01	1	1,01	0,0101	0,0101	0,0101	10,1	
Sodium	**Na**	11	22,99	1	22,99	0,2299	0,2299	0,2299	229,9	230
Magnesium	**Mg**	12	24,31	2	24,31	0,2431	0,1216	0,1216	121,6	121,5
Aluminium	**Al**	13	26,98	3	26,98	0,2698	0,0899	0,0899	89,9	90
Silicon	**Si**	14	28,09	4	28,09	0,2809	0,0702	0,0702	70,2	
Potassium	**K**	19	39,10	1	39,10	0,3910	0,3910	0,3910	391,0	391
Calcium	**Ca**	20	40,08	2	40,08	0,4008	0,2004	0,2004	200,4	200,4
Manganese	**Mn**	25	54,94	2	54,94	0,5494	0,2747	0,2747	274,7	
Iron	**Fe**	26	55,85	2	55,85	0,5585	0,2793	0,2793	279,3	

Annex 6: "Soil survey, Riau", characteristics of outlier values

Id	District	Comp	Stand	Petak	Depth	Parameter	Value	Unit
196	KMAL				0-10	P available	37,8	ppm
242	KSOR			218	10-20	Bulk	0,26	g/cm3
295	MRAS	055	02	034	50-80	Na	0,56	cmol+/kg
						K	0,4	cmol+/kg
						Ca	1,34	cmol+/kg
						Mg	1,83	cmol+/kg
314	DBER	019		163	30-50	Bulk	0,15	g/cm3
395	MGEL	021	02		50-80	C/N	90	
396	MGEL	030		261	0-10	C	10	%
397					10-20	P available	26,5	ppm
398					20-30	P available	19,4	ppm
402	MGEL	023	11	238	10-20	N	1,75	%
412	MGEL	098		262R	0-10	Bulk	0	g/cm3
496	DBER	006	02		0-10	Mn	0,23	cmol+/kg
504	DBER	007	01		30-50	Bulk	4,19	g/cm3
506	DBER	049	01		0-10	pH	6,5	
						Ca	2,64	cmol+/kg
517	DBER	0047	04	08P	10-20	C/N	80	
550	DSEB	032		389	0-10	C/N	80	
						Ca	4,31	cmol+/kg
554	DSEB	032	-	389	50-80	C/N	71	
579	MRAS	044	08		50-80	H	43,02	cmol+/kg
620	DSEB	-	-	217	0-10	pH	7	
631	KSOR	001	00	001	10-20	N	1,9	%
						Fe	0,25	cmol+/kg
632					20-30	N	2,1	%
669	KSOR	006	00	049	50-80	N	2,5	%
914	DSEB	038	06	307	50-80	C	18,6	%
930	DSEB	033	10	342	0-10	Ca	1,84	cmol+/kg
938	DSEB	038	10	393	30-50	C/N	107	

Annex 7: Potential of soil fertility in function of pH and ammonium content (Extract of Boyer 1982, after Dabin 1961).

Parameter	Conditions	Potential of soil fertility				
		Very bad	Bad	Mean	Good	Very good
N	pH = 4.5	N < 0.06%	0.06%<N<0.12%	0.12% <N<0.25%	N > 0.25%	
	pH=5	N < 0.05%	0.05%<N<0.08%	0.08% <N<0.15%	0.15% <N<0.30%	N > 0.30%
	pH=6	N < 0.03%	0.03%<N<0.05%	0.05% <N<0.08%	0.08% <N<0.15%	N > 0.15%

Annex 8: Thresholds of deficiency, no-response to fertilization, or imbalance between two parameters for a few chemical parameters
(According to Attiwill & Adams 1996 and Gonçalves & Benedetti 2004 for available phophorus, and according to Boyer 1982 for K exch, Mg exch and Mg/K).

Parameter	Conditions	Deficiency	No-response to fertilization	Embalance between two parameters
P available		< 3 to 5 ppm		
K exch.	Clay + Silt < 15%	< 0.07 cmol+/kg	> 0.14 cmol+/kg	
	15% < Clay + Silt < 45%	< 0.10 cmol+/kg	> 0.20 cmol+/kg	
	Clay + Silt > 45%	< 0.20 cmol+/kg	> 0.40 cmol+/kg	
Mg exch.		< 0.10 cmol+/kg to 0.17 cmol+/kg	> 0.25 cmol+/kg to 0.40 cmol+/kg	
Mg/K	Mg < 0.3 cmol+/kg			< 3.5 to 4
	0.3 < Mg < 1cmol+/kg			< 3
	Mg > 1 cmol+/kg			< 2

Annex 9: Thresholds of cultural limitation due to aluminium toxicity (According to Boyer 1982).

Parameter	Cultural limitation				
	Null	Low	Mean	High	Very high
Kamprath indice (Kpt) = Al/(Al+Na+K+Ca+Mg)*100	Kpt < 5	5 < Kpt < 10	10 < Kpt < 30	30 < Kpt < 45	Kpt > 45

Annex 10: "Topographical position * soil", characteristics of samples profiles

District	Petak	Profile	Position (UTM 47, m) X	Position (UTM 47, m) Y	Topo. position	Slope (%)	Soil type
MGEL	25		777 090	89 276	Upper	15	R21/R41
	25		777 146	89 261	Middle	26	R41
	25		777 175	89 254	Lower	13	R41
MGEL	65B		776 089	89 536	Upper	8	R41
	65B		776 059	89 516	Middle	31	R41
	65B		776 019	89 499	Lower	25	R41
MRAS	30	A11	780 767	86 060	Upper	15	R41
	30	A12	780 737	86 056	Middle	20	R41
	30	A13	780 648	86 054	Lower	30	R41
MRAS	64	A21	780 944	86 292	Upper	16	R41
	64	A22	780 914	86 300	Middle	33	R21
	64	A23	780 916	86 319	Lower	55	R11
MRAS	58	F11	785 693	86 634	Upper	6	R51/W51
	58	F12	785 715	86 543	Middle	2	W52
	58	F13	785 752	86 410	Lower	0	W51
MRAS	95	C11	782 233	84 046	Upper	12	R41
	95	C12	782 238	83 998	Middle-Lower	24	R41
MRAS	172	E11	786 616	82 517	Upper	18	R41
	172	E12	786 562	82 548	Middle	14	R21/R41
	172	E13	786 480	82 582	Middle-Lower	22	R41/R21
	172	E14	786 468	82 581	Lower	34	R41
MRAS	175.1	E21	786 744	82 502	Upper	11	R41
	175.1	E22	786 802	82 499	Middle	28	R11
	175.1	E23	786 837	82 505	Lower	29	R21
MRAS	175.2	E31	787 703	82 882	Upper	5	R51
	175.2	E32	787 621	82 716	Middle	9	R41
	175.2	E33	787 562	82 639	Lower	16	W41/W21
MRAS	196	H11	792 007	81 706	Upper	3	R51
	196	H12	792 060	81 664	Middle	8	R51/R41
	196	H13	792 077	81 617	Lower	5	R41/R51
MRAS	195	H21	792 431	81 138	Upper	1	R51
	190	H22	792 544	81 083	Middle	7	R51
	190	H23	792 620	81 005	Lower	8	R41/R51
MRAS	171	E41	786 651	82 539	Upper	4	R41
	171	E42	786 623	82 628	Middle	12	R41
	171	E43	786 603	82 743	Lower	24	R42/R12
MGEL	38	D11	778 079	90 662	Upper	10	R41
	38	D12	778 053	90 689	Middle	16	R41
	38	D13	778 039	90 713	Lower	30	R41
MGEL	28	B11	775 947	90 466	Upper	7	R41
	28	B12	775 965	90 424	Middle	20	R41
	28	B13	775 979	90 376	Lower	8	R41

Annex 10 (Continued): "Topographical position * soil", characteristics of samples profiles

District	Petak	Profile	Position (UTM 47, m) X	Position (UTM 47, m) Y	Topo. position	Slope (%)	Soil type
DURI II	9	I11	774 173	124 884	Upper	7	R41/R51
	9	I12	774 223	124 895	Middle	5	R32
	9	I13	774 261	124 924	Lower	11	R32
DURI II	31	I21	777 304	128 089	Upper	6	R41
	31	I22	777 347	128 103	Middle	8	R41
	31	I23	777 449	128 085	Lower	5	R41/R51
DURI II	6	I31	774 060	124 290	Upper-Middle	7	R01
	6	I32	773 934	124 142	Lower	5	R01/R11