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学位論文全文に代わる要約
Extended Summary in Lieu of Dissertation

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Name

学位論文題目：
Title of Dissertation

Dynamics of Soil Micronutrients under Frond Heaps at Oil Palm Fields in Malaysia
（マレーシア国アブラヤシ農園内の切除葉堆積区画における土壌中微量栄養素の動態）

学位論文要約：
Dissertation Summary

Oil palm (*Elaeis guineensis*) cultivation has become a strong driving force of economic growth and rural development in Malaysia by providing employment, income, and business opportunities for several millions of people. However, ongoing expansion of oil palm cultivation has caused the environmental degradation such as deforestation, biodiversity loss, and greenhouse gas emissions. In order to reduce environmental impacts of oil palm cultivation, oil palm growers have implemented the site-specific agronomic management practice in existing oil palm cultivation. Generally, each oil palm field can typically be considered as three micro sites under different agronomic management: 1) weeded circle to which fertilizers are applied under the palm canopy and the undergrowth is clear-slashed; 2) frond heap where pruned palm fronds are heaped up, usually between palm trees; and 3) harvest path along which workers move to harvest and transport fruit bunches. Among these practices, frond heaping is carried out at every plantation to reduce soil erosion and nutrient losses through surface runoff. It is believed that frond heaping can contribute to recycling organic matter and nutrient resources contained in the pruned fronds, and subsequently increase underlying soil fertility.

To date, most of attention and research related to the different agronomic management practices in oil palm cultivation has been focused on the fertilization at the weeded circle and its effects on soil physicochemical properties and the status of soil macronutrients. However, the effects of heaped fronds at the frond heap on dynamics of soil nutrients in oil palm cultivation remain poorly understood, especially for soil micronutrients.

Although micronutrient fertilizers are not applied in oil palm plantation except for boron (B), micronutrients such as manganese (Mn), iron (Fe), copper (Cu), and zinc (Zn) are essential for oil palm and their availability in soils can affect growth and development of oil palm tree. Existing studies regarding to micronutrients in oil palm cultivation focused only on deficiency symptoms in the palm trees, and no attention has been paid to the changes in status and dynamics of soil micronutrients related to the recycling system of frond heaping. Oil palm has an economic lifespan of 25 years and frond heaping is carried out throughout the entire life cycle of oil palm plantation. Understanding the dynamics of soil micronutrients affected by frond heaping is beneficial to develop more appropriate and effective recycling system for pruned fronds in oil palm cultivation.

Therefore, to evaluate the effects of frond heaping on the status and dynamics of soil micronutrients at the different growth and development stages (young, mature, old) of oil palm, three studies were set up : 1) to investigate status of soil micronutrients in terms of micro sites under different agronomic managements; 2) to compare status of soil micronutrients in terms of different planting ages of oil palm fields; and 3) to estimate nutrient amounts existing in frond heaps and underlying soils.

In the first study, the amounts and chemical forms of micronutrients, as well as the total and available amounts were compared among the micro sites (weeded circle, frond heap, and harvest path) at an 18-year-old oil palm field. Total Mn in the surface soil at the frond heap was significantly higher than at the weeded circle and the harvest path, whereas total Fe, Cu, and Zn did not differ among the micro sites at any soil depth, except for total Zn at 0-5 cm soil depth, which was highest at the weeded circle (Figure 1). Amounts of DTPA-extractable (i.e. available) Mn, Fe, Cu, and Zn at the frond heap were higher than at the harvest path (Figure 2). Results of sequential fractionation of soil micronutrients indicated that the amounts of Mn in the acid soluble, Mn oxide-occluded, and organically bound fractions in the surface soil were higher at the frond heap than at the harvest path (Figure 3). These results suggest that the release of Mn from heaped fronds during the decomposition process could increase the amounts of Mn in the above mentioned fractions, which in turn contributed to the increment of total and available Mn in the surface soil at the frond heap. In addition, the amounts of Fe and Cu in the organically bound fraction were significantly higher at the frond heap and the weeded circle than those at the harvest path, while the opposite tendency was found in the Fe oxide-occluded fraction (Figures 4 and 5). It is supposed that the frond heaping practice also affected the distribution of Fe, Cu, and Zn (Figure 6). On the other hand, higher amounts of total and available Zn at the weeded circle could be ascribed to the incorporation of Zn associated with long term application of phosphate rocks to the weeded circle.

In the second study, the status of soil micronutrients at the frond heap over the duration of frond heaping were compared among oil palm fields with different planting ages of 5 years (a younger stage; designated as OP5), 10 years (the prime stage; OP10), and 18 years (an old stage; OP18). In the surface soil, total Mn at the frond heap and the weeded circle increased with planting age due to long-term practice of frond heaping and turnover of oil palm roots over time, respectively. Total Fe and Cu showed no significant differences among OP5, OP10, and OP18 in terms of soil depth while total Zn at 0-5 cm soil depth at the weeded circle were significantly higher in OP10 and OP18 than in OP5. The increase of total Zn at the weeded circle could be attributed to long term application of phosphate rocks which may contain Zn impurity. Amounts of available Mn, Fe, Cu, and Zn in surface soil at the frond heap tended to be higher in OP18 than in OP5 and OP10. The sequential fractionation analysis showed that the amounts of Mn in the acid soluble, Mn oxide-occluded, and organically bound fractions in surface soil at the frond heap increased with planting age. These results suggest that the incorporation of Mn from decomposed heaped fronds increased with planning age and incorporated Mn in the above mentioned fractions increased total and available Mn at the frond heap during decomposition of fronds. In addition, the distribution of Fe and Zn at the frond heap was also affected by frond heaping practice over time.

In the third study, the amounts of micronutrients in heaped fronds were examined, and possible inputs of the micronutrients into the underlying soil were estimated, assuming that heaped fronds were completely decomposed. The concentrations and contents of nutrients in the whole frond were found to be in the order of C > K > N > Ca > Mg > P > Mn > Fe > Zn > Cu (Table 1). In term of micronutrients, Mn concentration was highest in frond lamina samples (Figure 7) which is the most quickly decomposed part of the frond compared to the rachis and petiole. Meanwhile, the amounts of Mn in the frond heap and the estimated inputs into the underlying soil were the highest among the examined micronutrients (Table 2). The incorporated Mn from decomposed fronds increased the total and available Mn in the surface soil at the frond heaps and the magnitude of this increase was greater for older oil palm field than for younger oil palm field.

Based on these studies, it was clarified that long-term practice of frond heaping increases the availability of micronutrients in the surface soil at the frond heap, especially for Mn. Since oil palm trees have adventitious root system which can reach to the frond heaping area, the increased available micronutrients are supposed to be utilized by the tree. Therefore, it was concluded that the frond heaping practice plays a significant role in the internal recycling of soil micronutrients at the oil palm plantation. In addition, frond heaping practice is beneficial to oil palm grown on micronutrient-deficient soil (peat) or oil palm plantation owned by smallholders who only rely on mineral fertilizers and do not have enough resources to develop a spatial strategy for effective use of pruned fronds and mineral fertilizers in their plantation.

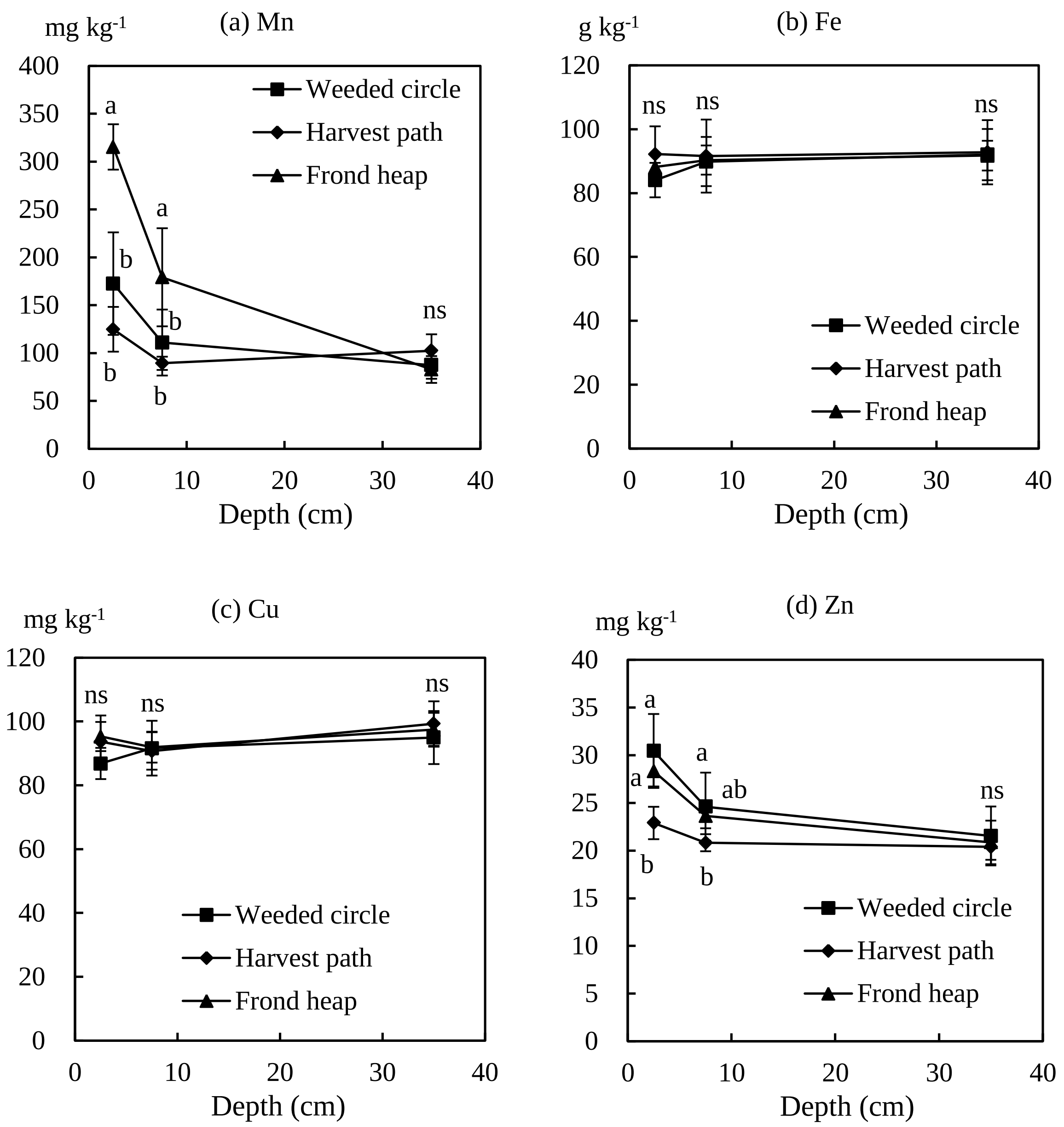

Figure 1 Total amounts of micronutrients at different micro sites. (a) Mn, (b) Fe, (c) Cu, and (d) Zn. Vertical bars indicate the standard deviations (n=6). Letters indicate significant differences between the micro sites at each soil depth (Scheffe's multiple comparison tests; $p \leqslant 0.05$); ns, not significant.

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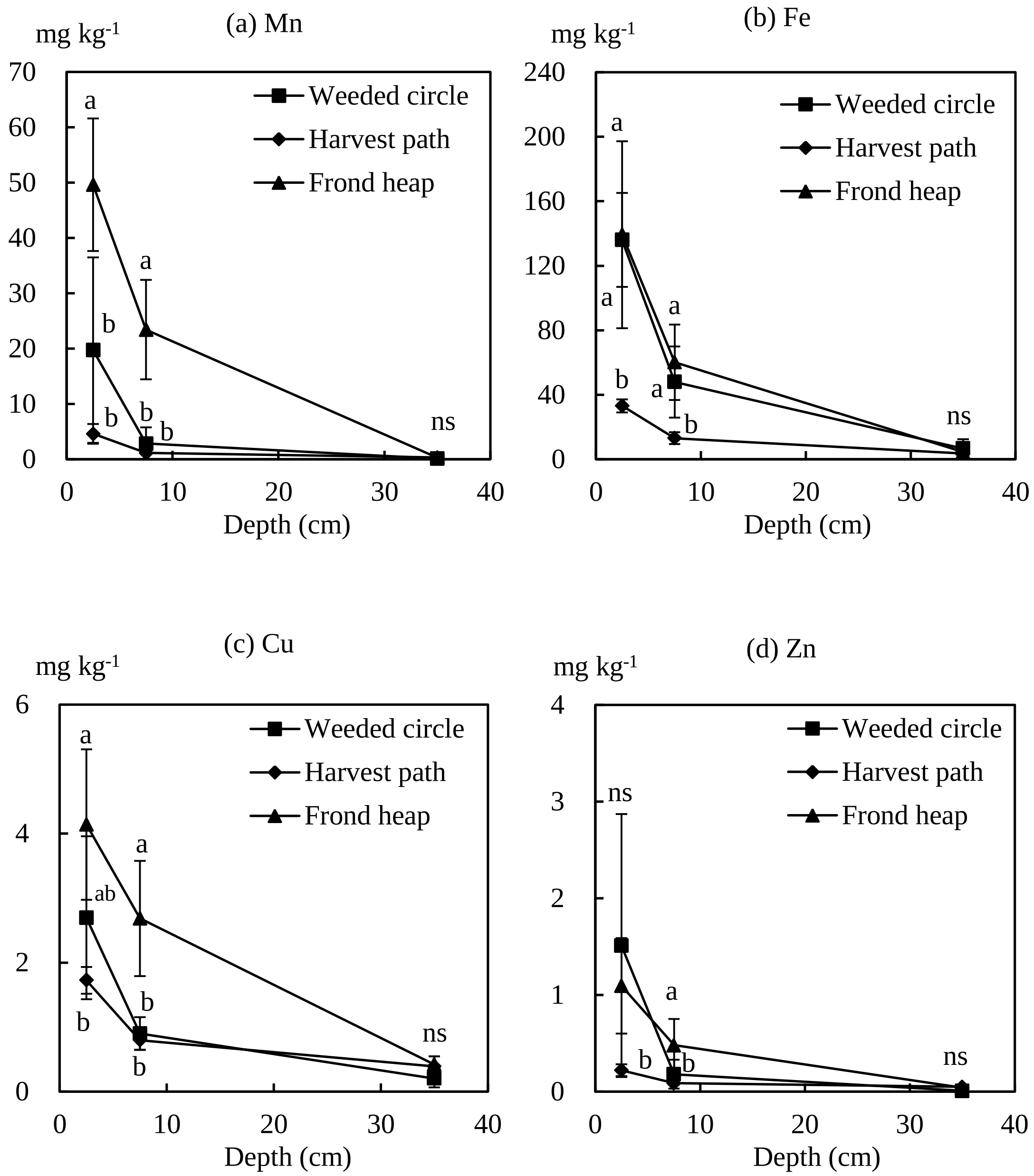

Figure 2 Available amounts of micronutrients at different micro sites. (a) Mn, (b) Fe, (c) Cu, and (d) Zn. Vertical bars indicate the standard deviations (n=6). Letters indicate significant differences between the micro sites at each soil depth (Scheffe's multiple comparison tests; $p \leqslant 0.05$); ns, not significant.

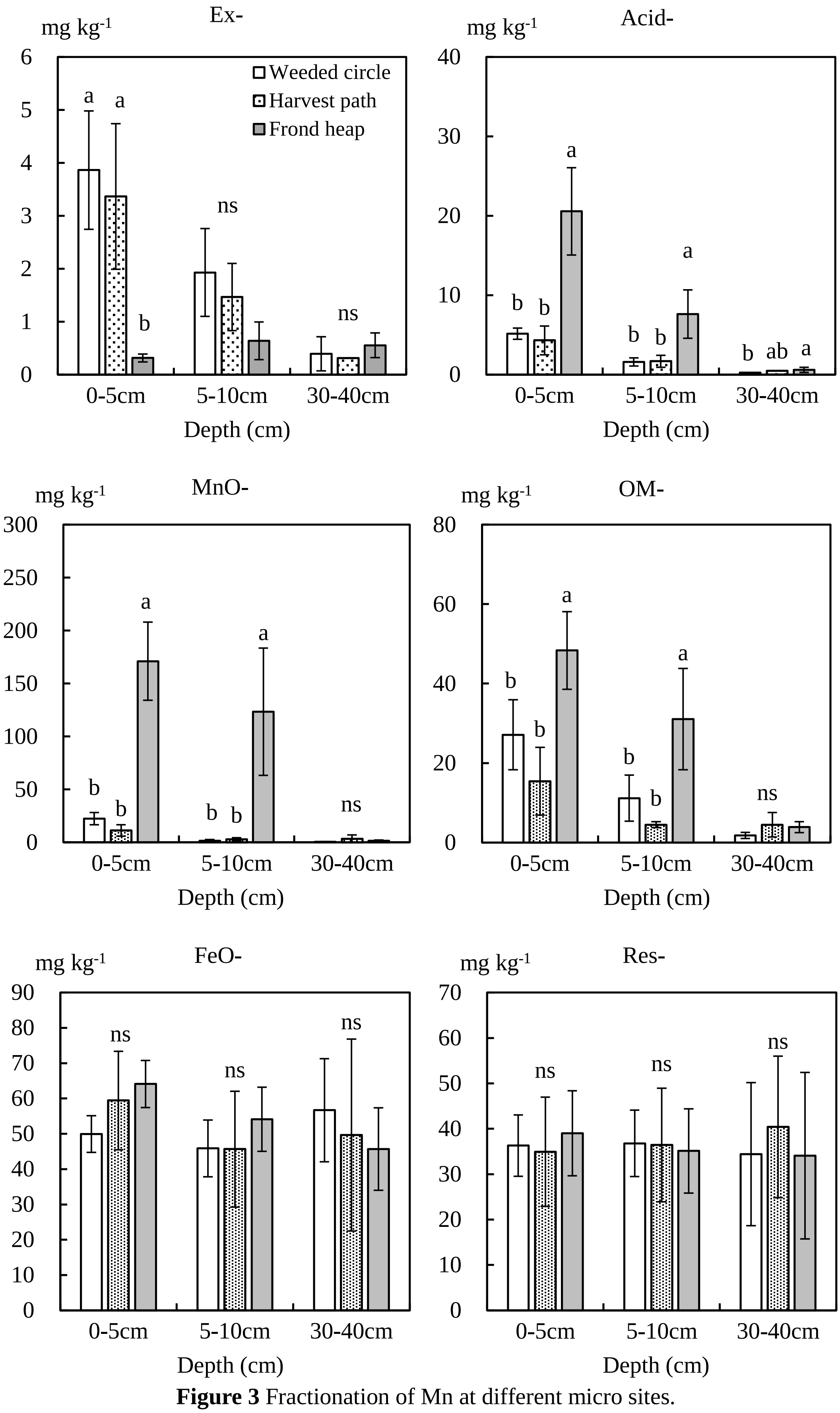

Figure 3 Fractionation of Mn at different micro sites.
Vertical bars indicate the standard deviations (n=6). Letters indicate significant differences between the micro sites at each soil depth (Scheffe’s multiple comparison tests; $p \leq 0.05$); ns, not significant.

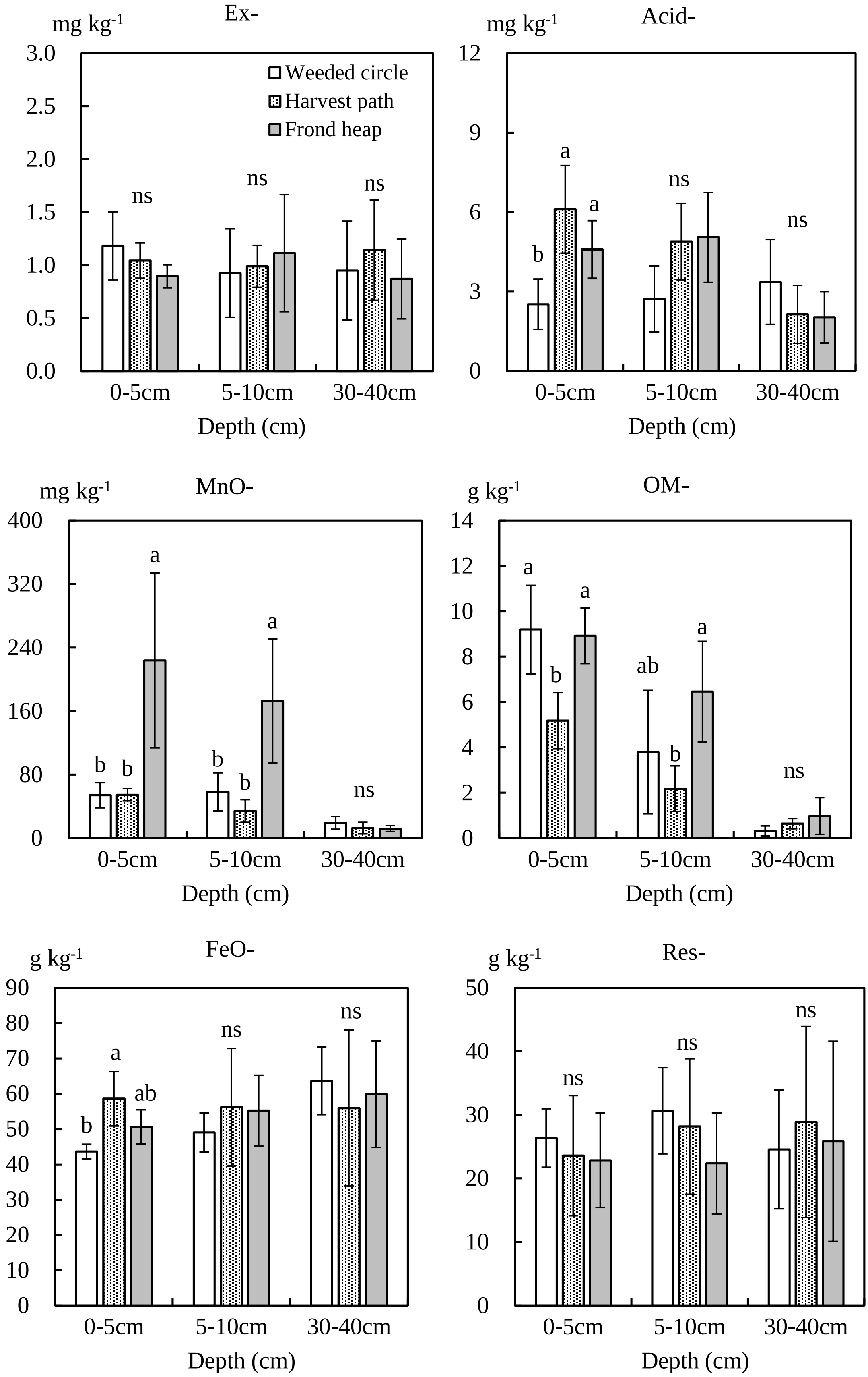

Figure 4 Fractionation of Fe at different micro sites.
Vertical bars indicate the standard deviations (n=6). Letters indicate significant differences between the micro sites at each soil depth (Scheffe's multiple comparison tests; $p \leq 0.05$); ns, not significant.

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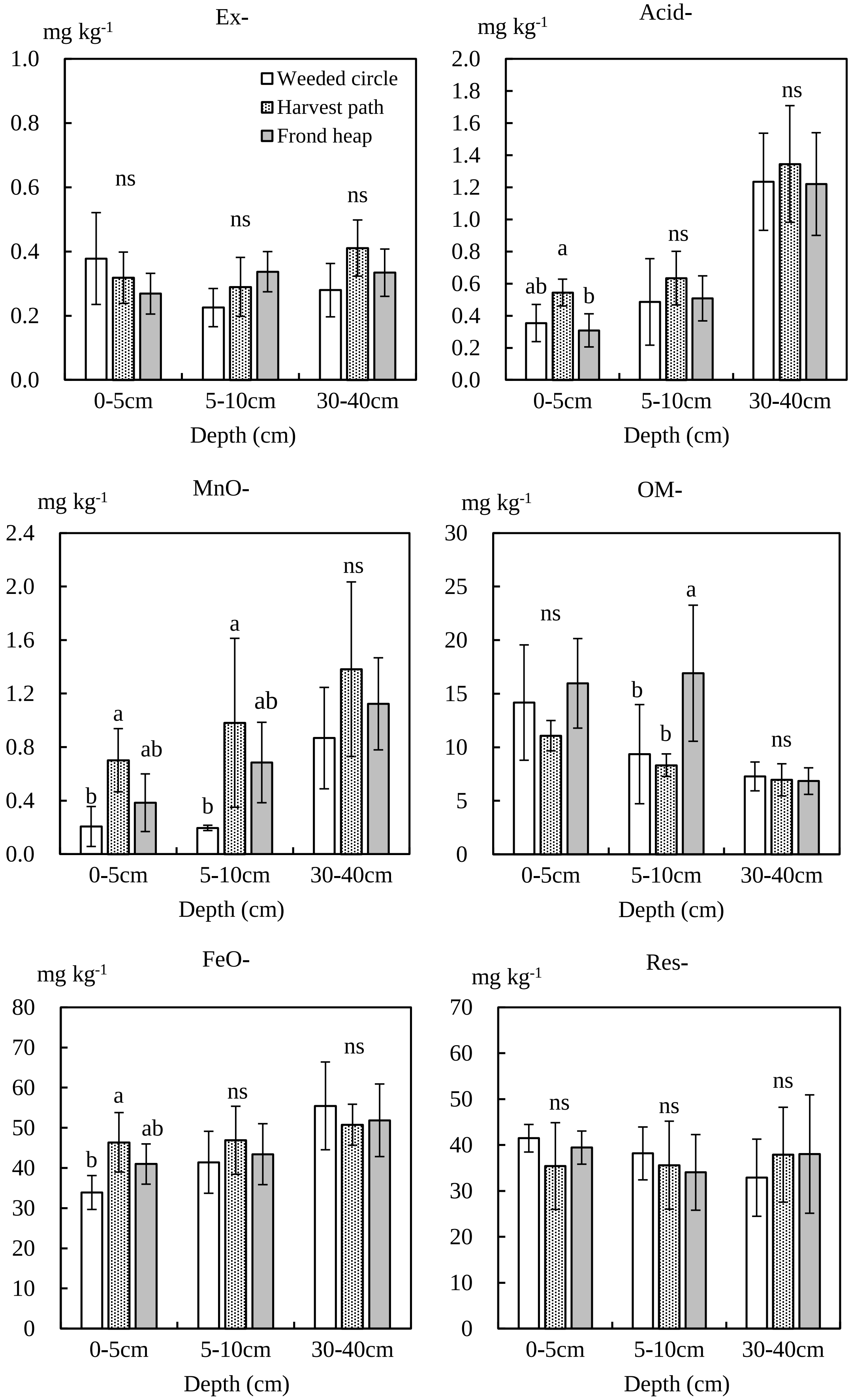

Figure 5 Fractionation of Cu at different micro sites.
Vertical bars indicate the standard deviations (n=6). Letters indicate significant differences between the micro sites at each soil depth (Scheffe's multiple comparison tests; $p \leq 0.05$); ns, not significant.

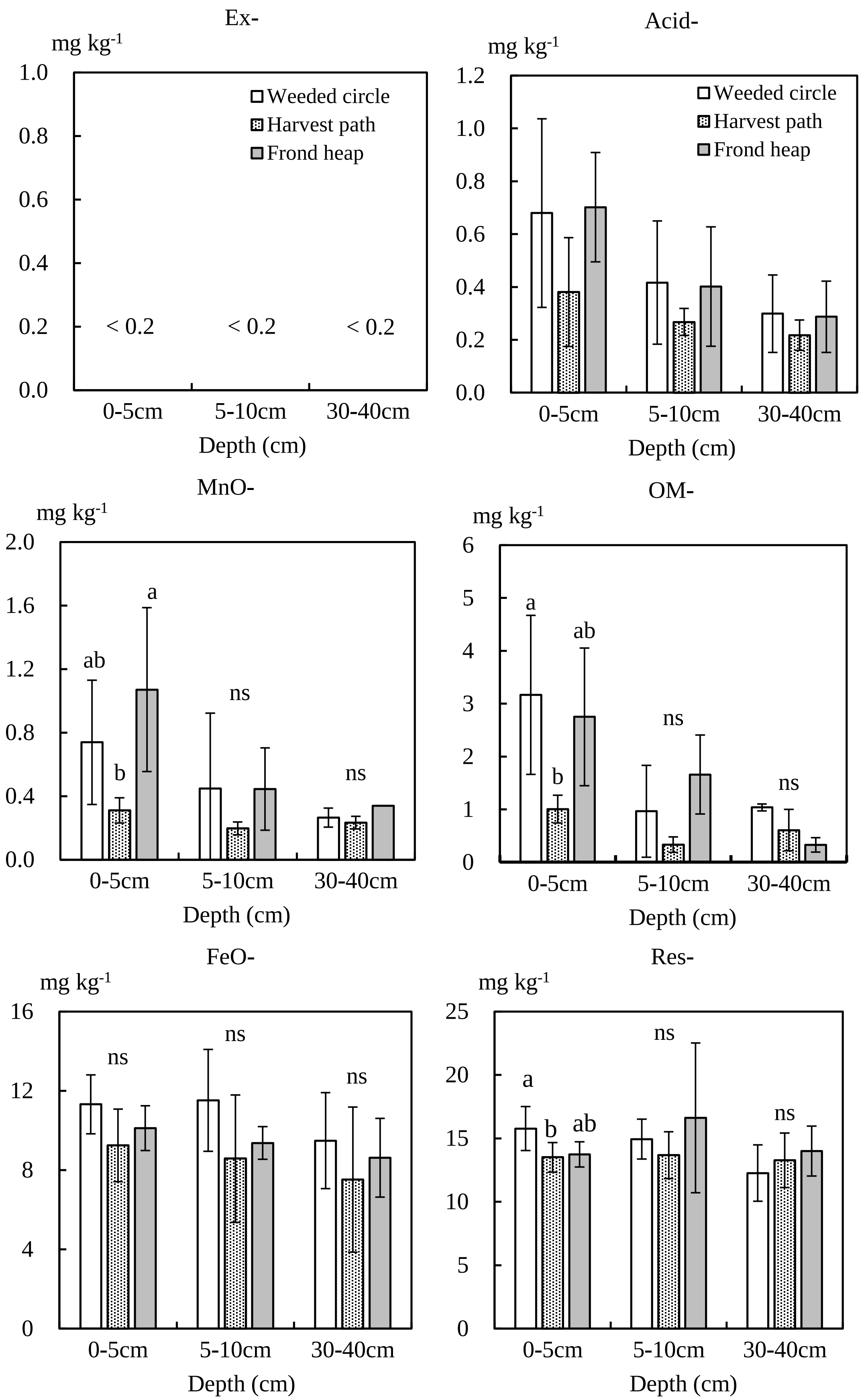

Figure 6 Fractionation of Zn at different micro sites.

Vertical bars indicate the standard deviations (n=6). Letters indicate significant differences between the micro sites at each soil depth (Scheffe’s multiple comparison tests; $p \leq 0.05$); ns, not significant.

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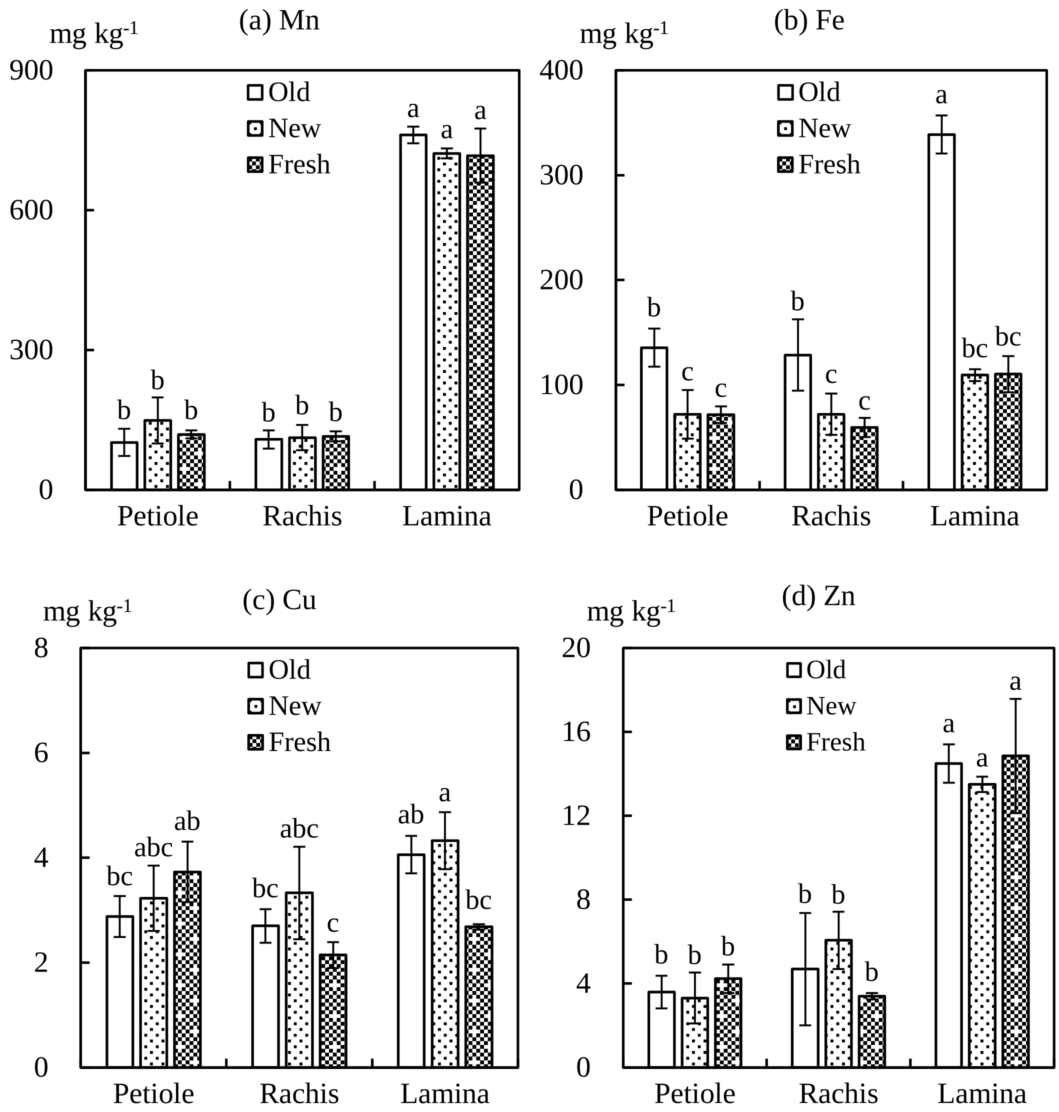

Figure 7 Micronutrient concentrations in petiole, rachis and lamina of old, new and fresh oil palm fronds at frond heap at 18-year-old oil palm field (dry weight base). (a) Mn, (b) Fe, (c) Cu, and (d) Zn. Vertical bars indicate the standard deviations (n=3). Different letters indicate significant differences in comparison between all pairs of the data irrespective of plant components and frond ages (Tukey's method; $p \leq 0.05$).

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Table 1 Nutrient concentrations and contents in fronds at 18-year-old oil palm field (dry weight base)

Planting age	Nutrient concentrations in one frond									
	C	N	P	Ca	Mg	K	Mn	Fe	Cu	Zn
	(g kg^{-1})						(mg kg^{-1})			
OP18	467	7.97	0.548	5.42	1.83	12.7	300	119	3.3	7.1
Planting age	**Nutrient amounts in one frond**									
	C	N	P	Ca	Mg	K	Mn	Fe	Cu	Zn
	(g / frond)						(mg / frond)			
OP18	1551	27.3	1.89	17.8	6.1	42.8	955	379	10.9	24.0

OP18 indicates samples taken at 18-year-old oil palm field.

Table 2 Estimated amounts of nutrient increase when all nutrients in heaped fronds were incorporated into 0-5 cm soil

Planting age	Amounts of nutrient in frond heap*									
	C	N	P	K	Ca	Mg	Mn	Fe	Cu	Zn
	g m^{-2}						mg m^{-2}			
OP18	697	11.83	0.81	18.90	8.05	2.73	447	181	4.85	10.5
Planting age	**Estimated nutrient input into 0-5 cm soil layer****									
	C	N	P	K	Ca	Mg	Mn	Fe	Cu	Zn
	g kg^{-1}						mg kg^{-1}			
OP18	17.27	0.29	0.02	0.47	0.20	0.07	11.08	4.48	0.12	0.26

OP18 indicates samples taken at 18-year-old oil palm field. * The amounts of nutrients existing in the frond heap (mg m^{-2}) were estimated by multiplying the total biomass of heaped fronds per unit area (kg m^{-2}) by the nutrient concentrations in whole fronds (mg kg^{-1}). ** Soil bulk density was 0.807 g cm^{-3} at 18-year-old oil palm field.