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Chlorine Nutrition of Oil Palm Tree (*Elaeis Guinq* Jacq) in Eastern Amazon

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Abstract

In Brazil, the status of chlorine (Cl) nutrition in plants is still poorly studied. The micronutrient Cl plays an important role in cultures such as coconut and oil palm trees. This study aimed to evaluate the status of chlorine nutrition in oil palm trees as a function of planting age, which ranged from two to eight years of cultivation. The experiment was conducted in Tailândia, state of Pará, Brazil. The soil of the area is characterized as Yellow Latosol of medium texture. A total of four oil palm trees were sampled for each age and the following variables were analyzed: leaf, petioles, rachis, palm heart, arrows, stipe, male inflorescences, peduncles, spikelets and fruits, as well as the accumulated, recycled and immobilized levels of Cl. Oil palm trees proved to be demanding in Cl and the accumulation in the different vegetative organs increased with the development of the plant. The stipe was the main storing vegetative organ of this micronutrient. The highest demand of Cl (16.9-26.0 g/kg) occurred in the palm heart, while for male inflorescence, the values ranged from 3.3-4.1 g/kg of Cl. The levels of Cl recycled by the plant were higher than the immobilized and exported levels considering the development up to 4 years of age. After this age, the levels of recycled Cl are lower than those immobilized. As for the amount of Cl exported by clusters in 8-year-old plants, the values were 3.2 and 1.3 times lower than the recycled and immobilized levels, respectively.

Keywords: micronutrient, nutritional assessment, absorption march

1. Introduction

Chlorine (Cl) occurs predominantly as Cl- in soils in levels varying from 1 to more than 1000 kg ha-1, depending on the location and agricultural practices, such as irrigation and fertilization (WHITE & BROADLEY, 2001). It is an essential micronutrient of higher plants and participates in several physiological metabolism processes (MELLO et al., 1983).

The essentiality of chlorine for plants was firstly demonstrated by BROYER et al. (1954), and since then some studies have been carried out worldwide, proving its importance to the Arecaceae family (OLLAGNIER, 1973; DANIEL & OCHS, 1975; von UEXKULL & SANDERS, 1986; von UEXKULL, 1990; SOUZA et al., 1997; SOBRAL & LEAL, 1999; FERREIRA NETO et al., 2007; MATOS et al., 2013). Chlorine plays an important role in the process of photosynthesis, stomatal regulation, the enzyme ATPase and in plant growth (von UEXKULL, 1985; FLOWERS, 1988; MAGAT et al., 1988; BRACONNIER & D'AUZAC, 1990; SOUZA et al., 1997; XU et al., 1999; CHEN et al., 2010; MARSCHNER, 2012).

In the oil palm tree (*Elaeis guineensis* Jacq.), the importance of Cl was firstly noted by OLLAGNIER & OCHS (1971a, b) in a study conducted in San Alberto (Colombia). The authors found that chlorinated fertilization provided a significant increase of 3 to 4 tons year-1 of clusters by correcting the leaf content from 2 to 5 g/kg of Cl, which is a range considered appropriate for the crop (von UEXKULL & FAIRHURST, 1991).

Nevertheless, the function of Cl in oil palm trees is not yet fully understood. According to von UEXKULL (1972), Cl could be involved in the efficiency of water use by the plant, since in low Cl nutrition plants the stomata do not perform their function activity properly. Guard cells require chloroplasts and starch to open the stomata, and when these organelles are not sufficient to meet the demand, the stomata do not move since Cl is required (FLOWERS, 1988; BRACONNIER & D'AUZAC, 1990).

Thus, due to the importance of Cl nutrition in oil palm trees and the lack of research with this micronutrient regarding plant nutrition, this study aimed to evaluate the nutritional status of Cl in oil palm tress as a function of planting age, using commercial plants, in Tailândia, state of Pará, Brazil.

2. Material and Methods

The experiment was conducted in the municipality of Thailand, Pará, Brazil, located in the mesoregion of Northeast Paraense, (02º31'S and 48º52'O), in commercial oil palm plantations by the company Companhia Real Agroindustrial S.A. (Agropalma®). The choice was made because it is the main company in the segment in Brazil, cultivating an area of 39,543 hectares, which represents 61.93% of the total cultivated area in the country (QUEIROZ et al., 2012). The chemical attributes of the soil prior to the experiment and after liming application are shown in Table 1.

Table 1. Chemical and physical attributes of soil samples (0-30 cm) from different plant ages.

Attributes	Plant age (year)						
	2	3	4	5	6	7	8
pH ($CaCl_2$)	4.3	4.4	4.1	4.0	4.0	4.3	4.0
K* ($mmol_c\ dm^{-3}$)	0.7	0.6	0.5	0.7	0.5	0.5	0.6
Ca* ($mmol_c\ dm^{-3}$)	7.0	7.0	9.0	8.0	7.0	7.0	6.0
Mg* ($mmol_c\ dm^{-3}$)	4.0	2.0	2.0	3.0	3.0	3.0	3.0
Al ($mmol_c\ dm^{-3}$)	4.0	3.0	3.0	5.0	8.0	4.0	6.0
H+Al** ($mmol_c\ dm^{-3}$)	34.0	28.0	31.0	38.0	34.0	26.0	34.0
SB ($mmol_c\ dm^{-3}$)	11.7	9.6	11.5	11.7	10.5	10.5	9.6
P* ($ug\ cm^{-3}$)	4.0	6.0	5.0	6.0	6.0	6.0	8.0
V ($g\ dm^{-3}$)	24.0	24.0	26.0	22.0	22.0	27.0	20.0
O.M*** ($g\ dm^{-3}$)	16.0	23.0	15.0	19.0	20.0	21.0	18.0
Coarse sand (g/kg)	450	320	500	370	380	340	510
Fine sand (g/kg)	280	300	190	310	210	320	230
Silt (g/kg)	40	160	80	100	80	100	60
Clay (g/kg)	230	220	230	220	330	240	200

* extracted with ion exchange resin.

** SMP method.

*** colorimetric method.

The evaluated palm oil plants the commercial hybrid Tenera (Dura x Pisifera crossing), and were cultivated in a spacing of 9.0 m between holes in an equilateral triangle (9.0 m within the line and 7.8 m between lines), making a population density of 143 plants ha-1 between rows. *Pueraria phaseoloides* was cultivated as ground cover crop. Information regarding oil palm planting ages, cluster production and mineral fertilization carried out in the experimental area is presented in Table 2.

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Table 2. Ages, yields and mineral fertilization used in the cultivated oil palm trees over the years.

Plant age	Cluster production*	Mineral fertilization					
		N	P_2O_5	K_2O	Mg	S	H_3BO_3
Year	t ha^{-1}	g $plant^{-1}$					
2	---	35	60	60	---	24	---
3	1.5	18	77**	154	---	---	---
4	7.0	56	115	300	60	45	---
5	9.0	97	336	240	60	45	---
6	15.0	135	470	335	77	58	---
7	19.0	135	470	335	102	58	50
8	20.0	160	384	324	68	52	60

Source: Real Agroindustrial S.A.;

* in megagrams of fresh clusters per hectare;

** application of 500 kg ha-1 of phosphine (rock phosphate).

In the selection of palm trees, in order to collect homogeneous plants, the following criteria was applied: palm trees preferably located in the same plot, representative of age, uniform, well developed, in good nutritional condition, without visual deficiencies, without insect attacks and diseases and with good productivity. The criteria for the selection of uniform palm trees was measured by the circumference of the stem and plant height, starting at the base of the leaf 33, which corresponds to the height of the mature cluster to be harvested.

A completely randomized design with seven treatments was used in the experiment, consisting of different plant ages (2, 3, 4, 5, 6, 7 and 8 years of planting) with four replications. Each plant corresponded to an experimental unit.

At the time of sampling, the plants were separated into leaflets, leaf 17, which best represents the nutritional status of oil palm (RAJARATNAM et al., 1980), petioles, rachis, palm, arrows, stipe, male inflorescences, peduncles, spikelets and fruits. The fresh matter of each component (DMCC) and the representative sample were obtained.

The samples of each component were sent to the Agropalma® Phytosanitary Laboratory, by removing a subsample (SAMC), stored in a paper bag and dried in a forced air oven (at 70ºC) until reaching constant mass. Subsequently, the dry mass of the sub-samples (DMSA) of the different vegetative organs of the plant was quantified. The DMCC, SAMC and DMSA data of each component were replaced in the equation DM= ((DMSA*DMCC))/SAMC to obtain the dry matter (DM) of each part of the plant.

The plant tissue was milled in a Willey mill and then the chlorine content of the plant tissue was determined by the silver nitrate titration method, described by MALAVOLTA et al. (1997).

From the content of Cl in the plant tissue and the dry mass, the accumulated (by multiplying the chlorine contents by the dry mass values of each organ), immobilized (obtained by the sum of the accumulated values of the stem, palm heart and arrows) and recycled (made by the sum of the accumulated values of the leaflets, rachis, petiole and male inflorescences) levels of the micronutrient in the different vegetative organs of the oil palm were determined.

Based on the results, the analysis of the content of Cl amplitude for each vegetative organ of the plant was performed. Then, polynomial regression analysis was performed, observing the results of the F test ($p<0.05$) of the analysis of variance and the Student`s t-test ($p<0.05$) for the determination coefficients (R^2), using Sisvar statistical software (FERREIRA, 2011).

3. Results and Discussion

Chlorine contents in the vegetative organs of oil palm trees

The results of the contents of Cl in the different vegetative organs of the plants according to the planting age are presented in Figures 2 and 3. In general, it was observed that regardless of the evaluated plant part, oil palm presented high Cl demand, which increased with the plant development. The arrows and clusters showed a decrease in Cl requirement (Figure 3) within age, possibly due to the increase in cluster yield per plant, which ranged from 1.5 to 20.0 clusters-1 ha-1 in oil palm trees of 3 and 8 years (Table 2). Thus, there was a redistribution of Cl absorbed and stored by the plant to a larger amount of clusters and arrows produced, causing the effect of micronutrient dilution.

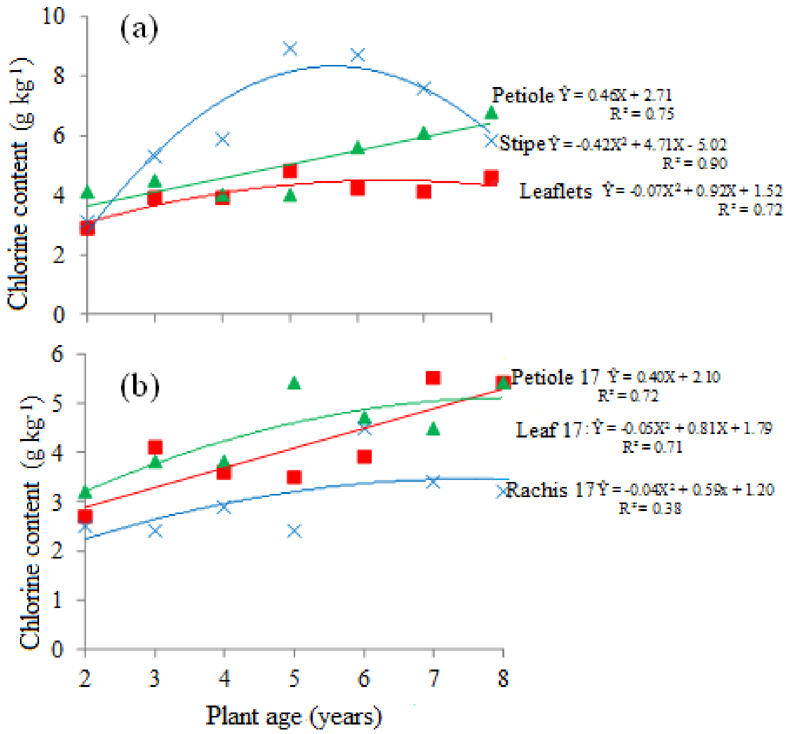

Figure 2. Chlorine contents of petioles, stipe, leaflets (a) and petiole17, rachis17 and leaf17 (b) as a function of plant age

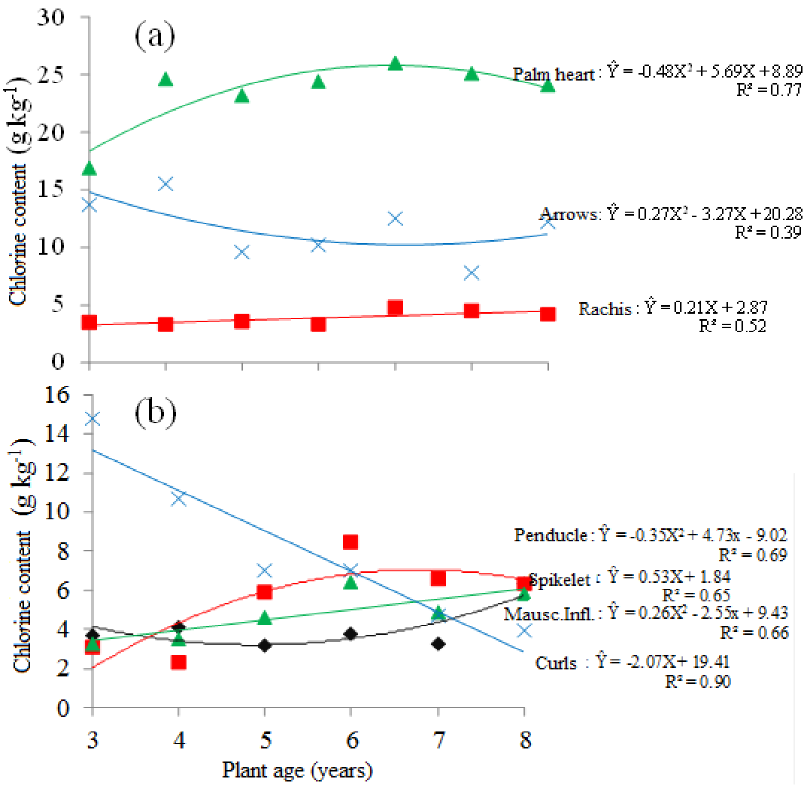

Figure 3. Chlorine contents in palm heart, arrows and rachis (a) and peduncle, spikelet, male inflorescence and clusters (b) as a function of plant age

The increase in Cl contents did not present a chronological sequence. However, the highest contents in spikelets, male inflorescence, rachis, petioles and petiole17 presented better adjustment for linear regression (Figures 2 and 3), in plants with 8 years of development. In this case, the evaluation until this planting age was not enough to reach the maximum efficiency of the evaluated variables. Possibly, there was greater absorption of Cl for the nutrition of the new plant formed tissues due to the fact that the plants presented a linear growth regarding plant height, stem diameter and dry matter production (VIÉGAS et al., 2001).

Regarding leaflets, leaf17, peduncle, palm heart, rachis17 and stipe, the variables presented best fit for the quadratic model, with the highest efficiency obtained in plants with estimated developmental ages between 5.61 to 7.38 years (Figures 2 and 3), close to the period of maximum production of oil palm clusters.

Among the different organs that make up the morphological structure of the plant, more specifically the crown, the palm heart reached the highest Cl content, followed by arrows, stipe, petiole, leaflets and rachis (Figures 2 and 3). Similar results were described by GONÇALVES (2008), who verified higher levels of palm heart nutrients (growth point), followed by leaflets, spears and rachis.

In the vegetative parts of the clusters, the highest Cl content was obtained in the fruits of oil palm up to 6 years old, to be later surpassed by the stems. Regarding the spikelets, they presented values above those found in the fruits of the oil palm with development near 7 years of age (Figures 2 and 3). In turn, the levels of Cl obtained in the present study are lower than those reported by OLLAGNIER & OCHS (1971a), in research conducted in Peru, Africa and Colombia.

The critical Cl level assessed on leaf17 is not yet fully established. The following optimum levels were already considered: 2.0 g/kg of Cl (DANIEL & OCHS, 1975), 3.5 g/kg of Cl (OLLAGNIER & OCHS, 1971a) and 5.0-7.0 g/kg of Cl (von UEXKULL & FAIRHURST (1991)). Thus, an appropriate optimal value would range from 2.0 to 7.0 g/kg of Cl. By comparing the Cl levels determined in leaf 17, according to the planting age (Figure 2b), with the critical range proposed by von UEXKULL & FAIRHURST (1991), it is verified that, regardless of the oil palm age, the plants did not present Cl contents in the nutritionally adequate range. Using the critical level data suggested by OLLAGNIER & OCHS (1971a), only the 2-year-old plants would be nutritionally deficient. In turn, if it is taken as reference the values of DANIEL & OCHS (1975), none of the plants presented Cl nutritional deficiency.

Considering all ages, there were great amplitudes in the levels of chlorine in the organs of the plants (Table 3), especially for palm heart (16.9 to 26.0 g k-1 of Cl). On the other hand, the smallest amplitude was observed for male inflorescence from 3.3 to 4.1 g/kg of Cl. Variations in Cl levels in oil palm trees occurred due to the fact that the evaluated plants were at the beginning of the vegetative development when compared with the other ages. This fact alters the metabolism of the plant and, consequently, the absorption rates of the nutrients, since at the beginning of the vegetative development the production is relatively low from 6 to 8 ton ha-1 year-1 of clusters, being gradually increased until the plants with 8 years old, when it reaches the maximum yield of 20-30 ton ha-1 year-1 of clusters.

Table 3. Amplitude of chlorine contents (g/kg) in the different vegetative organs (leaflets, leaf 17, petioles, rachis, palm heart, arrows, stipe, male inflorescence, peduncles, spikelets and fruits) of palm oil

Vegetative organs	Chlorine content (g/kg)
Leaflets	2.9-4.6
Leaf 17	3.2-5.4
Petioles	4.0-6.8
Rachis	3.3-4.8
Palm heart	16.9-26.0
Arrows	7.8-15.5
Stipe	3.1-8.9
Male inflorescence	3.3-4.1
Peduncles	2.3-8.5
Spikelets	3.5-6.4
Fruits	3.9-14.8

Chlorine accumulation in the plant organs

From the results presented in Figure 4, it can be seen that there was an increase in Cl accumulation with increasing age of the plants in all the vegetative organs, probably influenced by dry matter production, which showed the same tendency of increase from plants from 2 to 8 years old (VIÉGAS et al. 2001).

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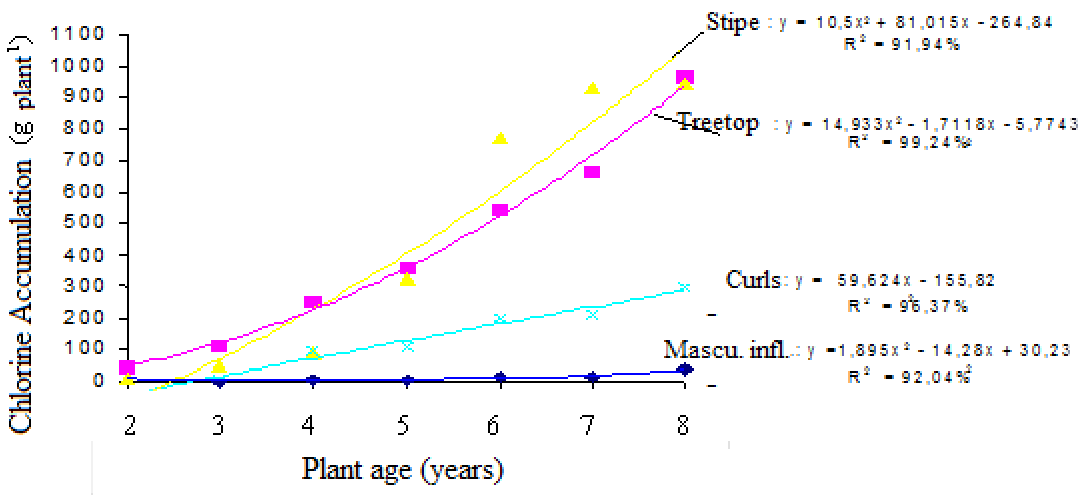

Figure 4. Chlorine accumulation in the crown, stem, clusters and male inflorescences in oil palm trees as a function of age

Figure 5 shows the regression equations of the accumulated levels of Cl in the different oil palm vegetative organs as a function of age. With the exception of fruits whose maximum estimated Cl accumulation occurred at 6.9 years, 113.29 g plant-1 of Cl, the other organs showed ascending behavior.

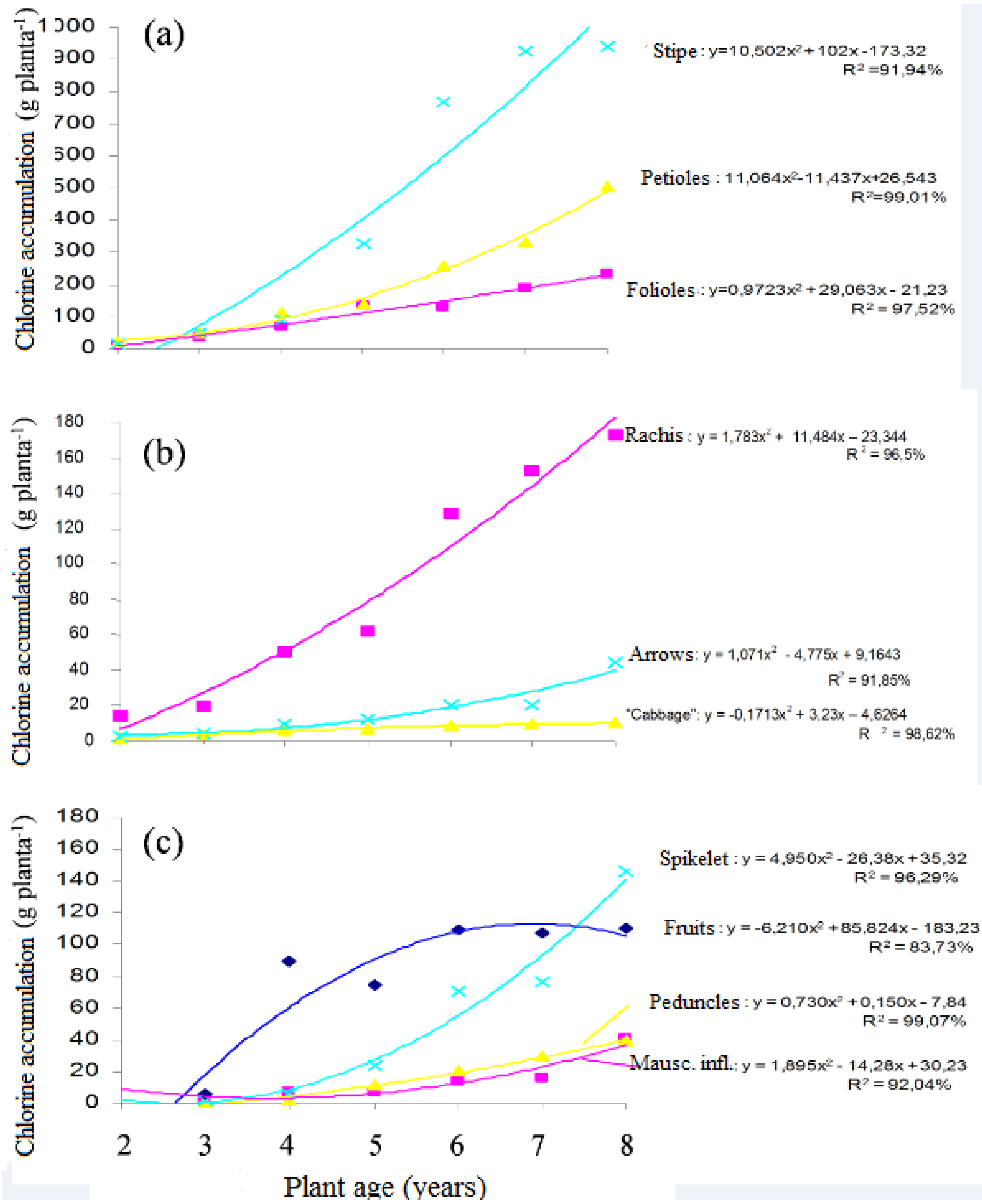

Figure 5. Accumulation of chlorine in the stem, petioles and leaflets (a), rachis, arrows and cabbage (b), spikelets, fruits, stems and male inflorescence (c) of oil palm trees as a function of age

The decreasing sequence of Cl accumulation in the different plant organs was: stipe> petiole> leaflets> rachis> fruits> spikelet> arrows> male inflorescences> palm heart (Figure 5). By this order, it can be observed that in the crown, the most Cl-accumulating organ was the petiole. In contrast, the one with the smallest accumulation was the palm heart, although this vegetative organ presented the highest Cl content (Figure 3a).

The vegetative parts: petioles, leaflets and rachis were the main accumulators of Cl (Figure 5).

These results are relevant and of great importance to oil palm producers, since it is recommended, as a way to properly manage the crop, the practice of pruning, which is characterized by the removal of the leaves of the oil palm, consisting of leaflets, rachis and petioles, which produced 50.45, 70.66 and 41.48 kg plant-1 of dry matter, respectively (VIÉGAS et al., 2001), being this amount 162.59 kg plant-1 of dry matter of the leaf, deposited in the between rows which will allow the recycling of Cl and other nutrients in the soil. KEE & CHEW (1997) reported that the decomposition and distribution of nutrients in the pruned branches of oil palm trees are relatively fast, with 43% N, 63% P, 76% K and 60% Mg in a 24-month period.

After five years of cultivation, the stem was the main Cl accumulator organ, reaching values ≥50% of the total accumulated by the 6, 7 and 8-year-old oil palm trees (Figure 4a). In the 8-year-old oil palm tree, there was an accumulation of 1314.81 g plant-1 Cl in the stem, which is the main micronutrient storage organ and, as needed, can supply other vegetative parts, mainly the fruits.

The petiole stands out as the second Cl-storing vegetative organ, with accumulation of 643.14 g Cl-1 in 8-year-old plants. At 4 years of age, this organ was superior to the stem (Figure 5a).

As for fruits, the maximum accumulation efficiency of 119.85 g plant-1 Cl was obtained in 7-year-old plants (Figure 5c). The high value observed in this period possibly occurred due to the accumulated micronutrient being required by the respective vegetative organ, since Cl influences the amount of albumen the fruit (MAGAT et al., 1988). Finally, in male inflorescence, there was an increase in Cl accumulation according to the plant development, reaching levels of 40.73 g plant-1 in 8-year-old oil palm trees (Figure 5c).

3.1 Total Extraction of Chlorine by Oil Palm Trees

The best-fit regression equation model to explain the relationship between total Cl extraction and age was quadratic (Figure 5). According to the information in Figure 6, the 8-year-old oil palm tree extracted 2334 kg ha-1 Cl, approximating the calcium values, and higher than those absorbed for phosphorus, magnesium and sulfur, in turn, inferior to nitrogen and potassium (VIÉGAS, 1993). In the coconut palm culture PB-121 Cl is removed in smaller amounts when compared with nitrogen and potassium (OUVRIER, 1984).

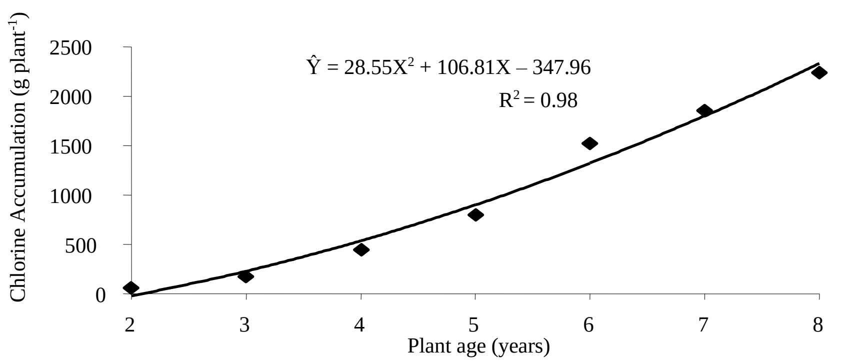

Figure 6. Total accumulation of chlorine in oil palm trees as a function of age

The period of highest Cl uptake by oil palm trees was in the 4, 5 and 6 years old plants, with increment values of 21.2, 18.9 and 36.9 g ha-1 day-1 of Cl, respectively (Table 4).

Table 4. Cumulative absorption of chlorine in oil palm trees as a function of plant age

Age (years)	Total accumulation (kg ha^{-1})	Absorbed Cl (g ha^{-1} dia^{-1})	Cl absorption increment (g ha^{-1} dia^{-1})
2	8.64	11.8	-
3	24.65	22.5	10.7
4	63.79	43.7	21.2
5	114.27	62.6	18.9
6	217.82	99.5	36.9
7	265.51	103.9	4.4
8	320.33	109.7	5.8

The immobilized, recycled and exported levels of Cl showed the same tendency of accumulation and chlorine content in the oil palm vegetative organs, increasing according to the evolution in the crop development (Figure 7).

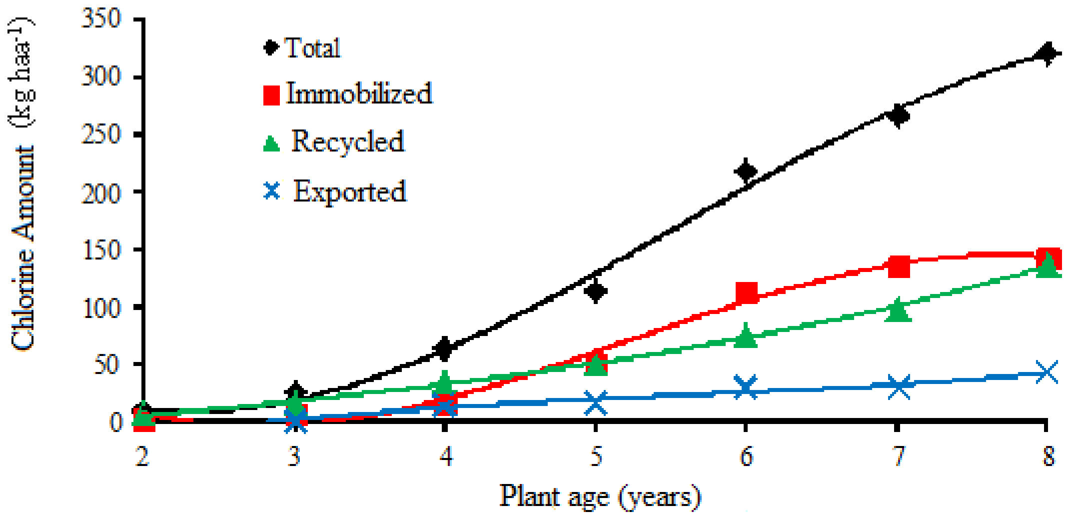

Figure 7. Immobilized, recycled, exported and total chlorine levels in oil palm trees as a function of age

The recycled amount of Cl provided by the leaves demonstrated superiority in the amount immobilized until the plants with 4 years of cultivation. The values were higher for the immobilized levels of Cl. In turn, the amounts of Cl exported by clusters in 8-year-old plants were 3.2 and 1.3 times lower when compared with the recycled and immobilized levels, respectively (Figure 7).

3.2 Oil Palm and Other Crops

In general, the fruits of oil palm concentrate higher amount of Cn (in g/kg) when compared with other crops of agronomic interest (Figure 8). However, the same is not observed when there is a comparison between the contents of leaflets in leaf17, since the contents contained in the oil palm are higher only when compared with sugarcane and orange.

Thus, the following decreasing order of crops that concentrate the highest Cl content in the leaflets is found: lettuce> coconut> tomato> eggplant> pepper> palm oil> sugar cane> orange (Figure 8).

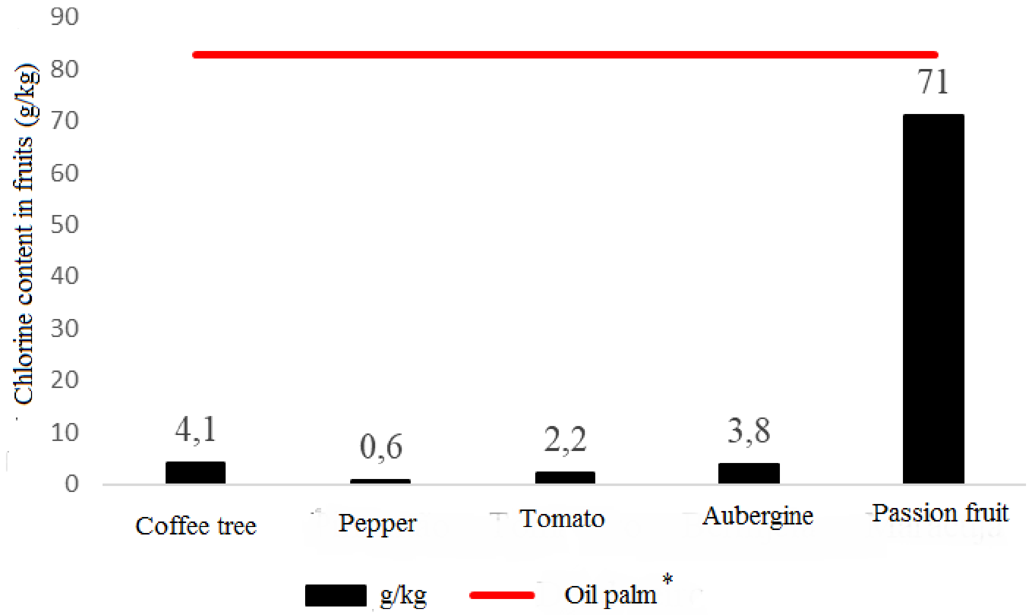

Figure 8. Chlorine contents in fruits of different crops in comparison with the oil palm tree

*Average Cl content in palm oil fruits (2 to 8 years)

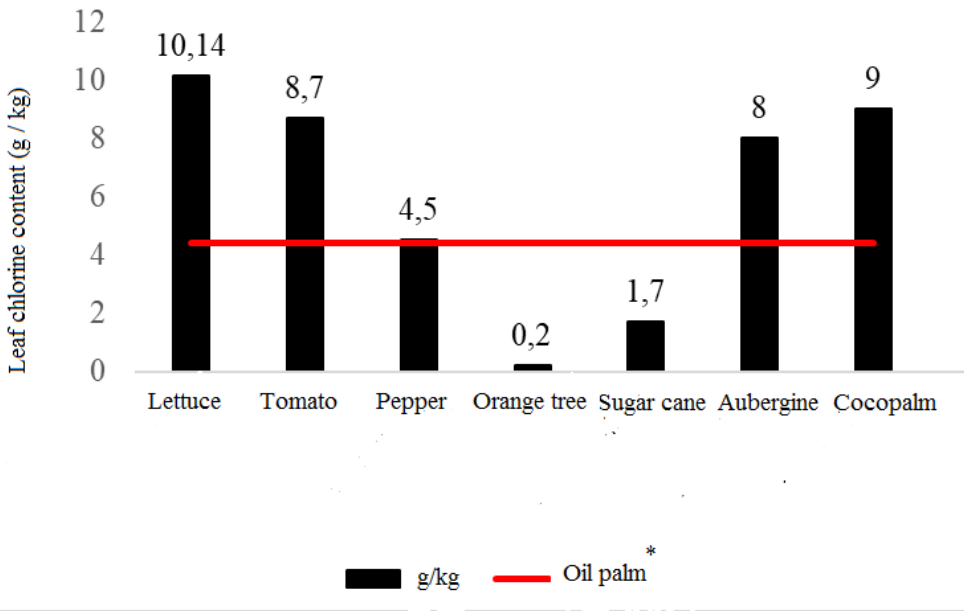

Figure 8. Chlorine contents in leaves of different crops in comparison with the oil palm tree.

* Average Cl content in oil palm leaves (3 to 8 years)

The information presented in this study shows the importance of Cl in the development and productivity of oil palm cultivated in the edaphoclimatic conditions of the Eastern Amazon, state of Pará, Brazil, which reinforces the results obtained by other researchers, who reported the importance of chlorine micronutrient for oil palm trees (OLLAGNIER & OCHS, 1971a, b; von UEXKULL, 1985, 1990; SOUZA et al., 1997).

4. Conclusion

Oil palm tree is demanding in the micronutrient chlorine, with low levels at the beginning of the growth development and increasing gradually as the crop develops, except for the arrows and fruits, which presented reduced contents.

The highest chlorine demand was 16.9-26.0 g/kg of Cl in the palm heart, while the lowest values were found for male inflorescences (3.3-4.1 g/kg of Cl).

The culture accumulated larger amounts of chlorine with the increase of the oil palm trees development, being the stipe the main storage vegetative organ.

The amount of chlorine recycled by the plant was greater than the immobilized and exported levels in plants up to 4 years old. After this age, the recycled levels were lower than those immobilized.

The levels of chlorine exported by clusters in plants with 8 years of planting were 3.2 and 1.3 times lower than the recycled and immobilized levels, respectively.

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