LEAF NUTRIENT CONCENTRATIONS AMONG PROGENIES OF INTERSPECIFIC OIL PALM HYBRID

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ABSTRACT

The objective of this work was to evaluate the variation in diagnostic leaf nutrient concentration of oil palm interspecific hybrid (*Elaeis oleifera* x *Elaeis guineensis* - HIE OxG) progenies and its effect on fertilizer recommendation. A plant nutrition study was conducted in a plant breeding experiment installed at a farm of the Grupo Marborges, Moju municipality, Pará state, Brazil. Significant differences were observed in K, Mg, B, Cu and Mn concentrations in the leaves among the progenies evaluated. The variation on K and Mg concentration in the diagnostic leaf influenced the fertilizer recommendation based on the criterion of the leaf analysis.

KEYWORDS: *Elaeis guineensis*; *Elaeis oleifera*; fertilization; leaf nutritional diagnosis

TEORES FOLIARES DE NUTRIENTES ENTRE PROGÊNIES DE HÍBRIDO INTERESPECÍFICO DE PALMA DE ÓLEO

RESUMO

O objetivo deste trabalho foi avaliar a variação nos teores de macro e micronutrientes na folha diagnóstico (número 17) de 16 progênies de híbrido interespecífico de palma de óleo (*Elaeis oleifera* x *Elaeis guineenses* - HIE OxG) e seu efeito na recomendação de adubação. Um estudo de nutrição de plantas foi conduzido em um experimento de melhoramento genético instalado em uma fazenda do Grupo Marborges, Moju, Pará, Brasil. Observaram-se diferenças significativas nos teores foliares de K, Mg, B, Cu e Mn entre as progênies avaliadas. A variação nos teores de K e Mg influenciou a recomendação de adubação com base no critério da análise foliar.

PALAVRAS-CHAVE: Adubação, diagnose nutricional foliar, *Elaeis guineensis*; *Elaeis oleifera*

INTRODUCTION

The edible oil consumption by world population is increasing**,** and the future demand for vegetable oil has been estimated around 240 million tons in 2050 (CORLEY, 2009). Palm oil is an important source of edible oil and also a potential feedstock for biodiesel production (CORLEY, 2009). Oil palm is one of the most important oleaginous crops in the world and a highly profitable crop in the humid tropics (CORLEY, 2009; SAYER et al., 2012).

The selection and breeding programs in oil palm have mainly focused on yield of bunches and oil extraction rate, however little attention is given to the interaction between plant nutrition and origin of the cultivar (OLLIVIER et al., 2013). Although the oil palm breeding programs will continue to focus on increasing crop yield, balanced fertilization is an immediate challenge that lay ahead for the improving of smallholder agriculture (BARCELOS et al., 2015).

The knowledge of both inter- and intra-specific nutritional crop requirements is important to establishment an adequate and balanced fertilizer recommendation. Nutrients requirement of oil palm is large to support its vegetative growth and bunch yield (GOH & HÄRDTER, 2003). On the other hand, the crop is commonly grown on highly weathered soils with low availability of nutrients (GOH & HÄRDTER, 2003). Thus, mineral fertilizers applications are compulsory to ensure suitable yields, since they compensate the natural low fertility of soils (COMTE et al., 2012). Generally, oil palm growers apply large amounts of mineral fertilizer (FAIRHURST & HÄRDTER, 2003). In Brazil, fertilizers account for about 30 and 40 % of production cost of oil palm for large-scale plantation and small-scale plantation (i.e., family farming), respectively (DENDÊ, 2014; SANTOS et al., 2014).

Understanding the factors that contribute to efficient fertilizer use is essential to maximize yields and enhance economic returns (GOH & HÄRDTER, 2003). The existence of specific nutritional requirements according to the oil palm cultivar is still unknown since this factor is not considered as a selection criterion in plant breeding programs (OLLIVIER et al., 2013). Significant intraspecific variation for acidity tolerance (CRISTANCHO et al., 2011a; CRISTANCHO et al., 2011b) and for phosphorus uptake efficiency has been reported for oil palm (TAN et al., 2010). However, the most of the oil palm nutritional research were carried out on palms derived from Dura x Psífera AVROS cultivars in the 1960s to 1990s (LEE et al., 2011).

Most commercial oil palm plantations in the world consist of African palm (*Elaeis guineensis*) Tenera hybrid cultivars, however, in recent years, due to the presence of the bud rot disease, plantations of the American palm (*Elaeis oleifera*) x African palm interspecific hybrid (HIE OxG) have increased substantially in Latin America because of its apparent partial resistance to this plant disease (CUNHA et al., 2010; HORMAZA et al., 2012, DUBOS et al., 2013)

There are few studies investigating crop management of the HIE OxG because it is a new genetic material grown in commercial oil palm plantations in relation to African oil palm. Recently, morphological and phenology stages of the HIE OxG have been described (HORMAZA et al., 2012). There is no information on nutritional behavior of the HIE OxG in the Brazilian Amazon.

The leaf chemical analysis is commonly used to evaluate the nutritional status of oil palm and as a diagnostic tool for fertilizer recommendation to the crop in Brazil (RODRIGUES et al., 2010). We hypothesized that nutrient concentration in diagnostic leaf can vary among interspecific hybrid progenies of oil palm grown on the same soil and under the same fertilization management, and this variation may affect the fertilizer recommendation.

The objectives of this work were to evaluate, in the field, the variation in diagnostic leaf nutrient concentration in HIE OxG progenies in Eastern Amazon and its effect on fertilizer recommendation.

MATERIAL AND METHODS

The experiment was conducted at a farm of the Grupo Marborges (01º59'29” S, 48º36'34” W, 16 m altitude), Moju municipality, Pará state, Brazil. The climate is Af, according to the Köppen climate classification system, with an average rainfall (1994-2010) of 2,890 mm and it is classified as a preferred location for oil palm crop according to the Brazilian agroecological zoning for this crop (RAMALHO FILHO et al., 2010). Soil in the experimental site is a dystrophic Yellow Latosol (Oxisol) (EMBRAPA, 2013).

A plant nutrition study, to evaluate the variation in diagnostic leaf nutrient concentration in oil palm interspecific hybrid progenies, was conducted in a competition field experiment of 16 HIE OxG progenies, installed in 2007, with four replications in a randomized block design. American oil palm accesses of Coari (RUB 1237), Manicoré (RUB 1195, RUB 1213, RUB 1225, RUB 1226, RUB 1227, RUB 1231, RUB 1232, RUB 1233, RUB 1234, RUB 1250, RUB 1271, RUB 1274, RUB 1277 and RUB 1283) and Manicoré x São Bartolomeu (RUB 1194) origin and African oil palm accesses of La Mé (LM 2T and LM 10T) origin were used as parents. The experimental plots consisted of 12 plants, with spacing of 9 m between the plants using an equilateral triangle design and 7.8 m between the rows and a plantation density of 143 palms ha^{-1}. Additional information regarding this plant breeding experiment is described in GOMES JUNIOR et al. (2014).

Plants were fertilized according to the follow rates (kg ha^{-1} year^{-1}): 46 of nitrogen (N); 35 of P_2O_5; 66 of K_2O; 19 of magnesium (Mg); 15 of sulfur (S); 0.9 of boron (B); 0.1 of cooper (Cu); 0.3 of manganese (Mn) and 0.5 of zinc (Zn), in 2009; 101 of N; 74 of P_2O_5; 135 of K_2O; 14 of Mg; 27 of S; 2.4 of B; 0.2 of Mn and 0.3 of Zn, in 2010; and 56 of N; 51 of P_2O_5; 120 of K_2O; 67 of calcium (Ca); 14 of Mg and 40 of S, in 2011.

Soil and leaf samples were collected in November 2011, in the dry season. The leaflets were sampled from the center of the leave number 17 (two pair of leaflets from each leaf) of 12 plants in each plot to obtain one composite leaf sample (48 leaflets). The leaflets were sampled in the field and prepared for analysis in the laboratory according to procedures described by RODRIGUES et al. (2002).

Leaflets samples were dried in an oven at 60℃ until constant mass, ground in a Willey type mill and submitted to procedures for macro and micronutrient analyses, as follows: leaf N concentration was determined by the semi-micro Kjeldahl method, after sulfuric digestion (EMBRAPA, 2009). The leaf P, K, Ca, Mg, Cu, iron (Fe), Mn and Zn concentrations were determined in extracts obtained through nitric-perchloric digestion. The P concentration was determined by colorimetry, K by flame photometry, Ca, Mg, Cu, Fe, Mn and Zn by atomic absorption spectrophotometry. The leaf B concentration was determined by spectrophotometry using dry ashing (oven digestion) and azomethine-H method (EMBRAPA, 2009).

The obtained data were submitted to analysis of variance (ANOVA), followed by the Scott & Knott clustering algorithm, at 5% probability. Statistical analyses were performed using SAS version 9.1 (SAS Institute Inc., Cary, NC, USA).

RESULTS AND DISCUSSION

The soil physicochemical characteristics are shown in Table 1. The concentration of P was higher in the topsoil (0 - 0.20 m layer), because of low mobility of phosphorus in the soil. This result is in agreement with the findings of ZAHARAH et al. (1985). In contrast, the sulfur concentration increased with depth in the soil, due to leaching of the sulfate. At both soil depths, low base saturation of the soil was observed, since liming is not a practice commonly used in oil palm plantations.

TABLE 1. Soil physicochemical characteristics of the experimental area.

Soil characteristics	Depth cm	
	0-20	20-40
pH ($CaCl_2$)	4.5	4.2
OM (g dm^{-3})$^{(1)}$	14	6
P (mg dm^{-3})$^{(2)}$	16.4	1.7
P (mg dm^{-3})$^{(3)}$	18	3
K^+ ($cmol_c$ dm^{-3})$^{(2)}$	0.07	0.05
Ca^{2+} ($cmol_c$ dm^{-3})$^{(4)}$	1.3	0.6
Mg^{2+} ($cmol_c$ dm^{-3})$^{(4)}$	0.4	0.1
Al^{3+}($cmol_c$ dm^{-3})$^{(4)}$	0.3	0.5
H + Al ($cmol_c$ dm^{-3})$^{(5)}$	41.0	37.9
SB ($cmol_c$ dm^{-3})$^{(6)}$	1.7	0.8
CEC ($cmol_c$ dm^{-3})$^{(7)}$	5.8	4.6
Effective CEC ($cmol_c$ dm^{-3})	2.0	1.3
m (%)$^{(8)}$	13.6	38.0
V (%)$^{(9)}$	29.8	17.0
S (mg dm^{-3})$^{(10)}$	7	12
B (mg dm^{-3})$^{(11)}$	0.24	0.17
Cu (mg dm^{-3})$^{(2)}$	0.8	0.4
Fe (mg dm^{-3})$^{(2)}$	190	284
Mn (mg dm^{-3})$^{(2)}$	11	6
Zn (mg dm^{-3})$^{(2)}$	2.0	0.5
Clay (g kg^{-1})$^{(12)}$	205	310
Silt (g kg^{-1})$^{(12)}$	86	85
Sand (g kg^{-1})$^{(12)}$	709	605

$^{(1)}$OM: organic matter, wet oxidation with H_2SO_4 + $K_2Cr_2O_7$; $^{(2)}$extracted by Mehlich-1; $^{(3)}$extracted by Resin; $^{(4)}$extracted by KCl 1.0 mol L^{-1}; $^{(5)}$obtained by SMP index; $^{(6)}$SB: sum of base; $^{(7)}$CEC: cation exchange capacity; $^{(8)}$m: aluminum saturation; $^{(9)}$V: base saturation; $^{(10)}$sulfur extracted by calcium phosphate 0.01 mol L^{-1}; $^{(11)}$extracted by hot-water; $^{(12)}$pipette method.

The diagnostic leaf N, P, Ca, S, Fe and Zn concentrations showed no significant ($p>0.05$) differences among the HIE OxG progenies. The diagnostic leaf macronutrient concentrations of the HIE OxG progenies, on overall averages, were 22.1 g kg^{-1} (range=20.6-23.1 g kg^{-1}, p=0.4 and CV=5.8%) for N; 1.4 (range=1.3-1.6 g kg^{-1}, p=0.2 and CV=9.6%) for P; 10.6 g kg^{-1} (range=9.3-11.6 g kg^{-1}, p=0.2 and CV=9.3%) for Ca; 1.4 (range=1.3-2.4 g kg^{-1}, p=1 and CV=20.2%) for S.

The overall average of the diagnostic leaf Fe concentration of the HIE OxG progenies was 111.5 mg kg^{-1} (range= 101.3-126.3 mg kg^{-1}, p=0.1 and CV=10.4%) and 15.3 mg kg^{-1} (range=9.9-19.9 mg kg^{-1}, p=0.2 and CV = 20.3%) for Zn. In addition, there was no significant difference among HIE OxG progenies in relation to Al concentration, that ranged from 70 to 97.5 mg kg^{-1} (overall average of 83.9 mg kg^{-1}; p=0.4 and CV = 20.1%).

There were significant differences in diagnostic leaf K ($p\leq0.05$) and Mg ($p\leq0.05$) concentration among the interspecific hybrid of oil palm progenies as revealed through the F-test. According to the Scott-Knott test, two groups of progenies were observed in relation to the leaf K and Mg concentration (Table 2). The diagnostic leaf K concentration of the progenies ranged from 6.8 to 9.4 g kg^{-1} and Mg concentration ranged from 1.8 to 2.9 g kg^{-1}. Similar results were found for hybrids OxG of Coari x La Me origin in Ecuador and Colombia and it was observed that critical leaf K and Mg levels can be different among progenies (DUBOS et al., 2013).

Potassium and Mg have key roles in physiological and biochemical processes in the plant, such as enzyme activation, protein and chlorophyll synthesis, photosynthesis, osmoregulation, phosphorylation and carbohydrate partitioning, which greatly influence the growth of plants, crop yield and product quality (CAKMAK & SCHJOERRING, 2008; HAWKESFORD et al., 2012; OOSTERHUIS et al., 2014; ZÖRB et al., 2014). Furthermore, K also plays very important roles in human health, e.g. blood pressure (CAKMAK & SCHJOERRING, 2008; HE & MACGREGOR, 2008). Increasing dietary K intake by increasing K concentration of food crops is becoming an important challenge in plant research (CAKMAK & SCHJOERRING, 2008).

Potassium is the most abundant inorganic cation in plant cells (DREYER, 2014). Plant genotypes differ greatly in the uptake, translocation, accumulation and use of nutrients (CLARK, 1983). Genotypic variations in K concentration have also been reported in other crops such as wheat (GUOPING et al., 1999), cotton (YANG et al., 2011) and watermelon (FAN et al., 2013). Plants differ in their ability to take up K, which is attributed to variations in root structure, such as root density, rooting depth, root hair length and root exudates (ZÖRB et al., 2014).

CANIZELLA et al. (2015) also observed significant differences for Mg concentrations in diagnostic leaves among common bean varieties. Although Mg is one of the most important nutrients, its importance as a macronutrient has been overlooked in recent decades, and therefore, Mg deficiency in plants is becoming an increasingly severe problem (GUO et al., 2016). Sugar accumulation in source leaves is a major consequence of Mg shortage that can limit plant growth most probably by down regulation of photosynthesis activity (VERBRUGGEN & HERMANS, 2013).

The differences in leaf nutrient concentrations, both to K and Mg, observed among progenies resulted in different fertilization levels. According to the fertilizer recommendation based on foliar analysis (RODRIGUES et al., 2010), the recommended K rates can be 500, 750 and 1.000-2.000 g/plant, and the Mg rates recommended varied of 30, 60 and 80 g/plant, depending on the progeny.

On average, the foliar concentrations of Ca and Mg were within the appropriate levels, whereas N, P, K and S were less than the critical levels established for the oil palm according to FAIRHURST & MUTERT (1999) and RODRIGUES et al. (2010). The ranking of macronutrient leaf concentrations was N > Ca > K > Mg > P = S.

TABLE 2. Potassium (K) and magnesium (Mg) concentration in diagnostic leaflets (leaf number 17) of different progenies of interspecific hybrid between American oil palm - caiaué (Elaeis oleifera) and African oil palm (Elaeis guineensis).

Progeny	African oil palm Origin	K concentration	Mg concentration
		g kg^{-1}	
RUB 1213	LM 10 T	9.4 a	1.9 b
RUB 1250	LM 10 T	9.2 a	2.4 a
RUB 1277	LM 10 T	8.9 a	2.8 a
RUB 1225	LM 10 T	8.8 a	2.3 b
RUB 1233	LM 10 T	8.8 a	2.0 b
RUB 1234	LM 10 T	8.6 a	1.8 b
RUB 1194	LM 2 T	8.6 a	2.7 a
RUB 1195	LM 10 T	8.5 a	2.5 a
RUB 1283	LM 2 T	8.3 a	2.7 a
RUB 1232	LM 2 T	8.2 b	2.5 a
RUB 1226	LM 2 T	8.1 b	2.6 a
RUB 1274	LM 2 T	8.1 b	2.9 a
RUB 1231	LM 10 T	7.9 b	2.0 b
RUB 1227	LM 2 T	7.9 b	2.8 a
RUB 1271	LM 2 T	7.6 b	2.6 a
RUB 1237	LM 2 T	6.8 b	2.3 b
Overall average (g kg^{-1})		8.3	2.4
Variation between highest nutrient concentration and overall average (%)		13.1	20.9
Variation between lowest nutrient concentration and overall average (%)		19.0	27.0
Coefficient of variation (%)		10.0	12.8

Means followed by the same letter within a column do not differ according to the Scott-Knott test ($p \leq 0.05$).

The leaf B, Cu and Mn concentrations also showed significant differences among the progenies. Two groups of progenies were observed in relation to the leaf B, Cu and Mn concentration (Table 3), according to the Scott-Knott test, at 5% probability. The leaf micronutrient concentrations (mg kg^{-1}) of oil palm progenies ranged from 34.1 to 49, 4.9 to 6.6 and 163.8 to 301.3, respectively for B, Cu and Mn.

The uptake of micronutrients varies among plant species and genotypes within species (RENGEL, 2001; MARSCHNER, 2012). The rates of B fertilizer applied to oil palm interspecific hybrid is usually higher than to African oil palm (RINCÓN et al., 2012). Genotypic differences in leaf B concentration have been documented for other crops (GUPTA, 1979). For oil palm no results were found in available literature. Variability intraspecific for B in leaf is not well understood but may be related to differential requirement for stabilizing cell structure since high proportion of B is found on cell wall (BROADLEY et al., 2012). Most of the functions of Cu as a plant nutrient are based on enzymatically bound Cu which catalyses redox reactions (BROADLEY et al., 2012). Selecting genotypes which are highly efficient in Cu uptake, translocation from the roots to the shoots and re-translocation within the shoot is a promising approach to the prevention of Cu deficiency in crops (BROADLEY et al., 2012).Large number of enzymes is activated by Mn^{2+}, however there are only a small number of Mn-containing enzymes, such as superoxide dismutase and oxalate oxidase (BROADLEY et al., 2012). Manganese toxicity, which is affected by plant genotype, is probably more of a problem than Mn deficiency throughout the world (FAGERIA et al., 2002).

Although leaf B, Cu and Mn concentrations showed significant differences among the progenies, no differences were observed in the recommended rates of B, Cu and Mn among the progenies, according to the fertilizer recommendation based on foliar analysis (RODRIGUES et al., 2010). On average, the foliar concentrations of B, Cu, Fe, Mn and Zn were within the appropriate levels according to the nutrient sufficiency ranges derived from diagnosis and recommendation integrated system (DRIS) for mature oil palm (MATOS et al., 2016). The ranking of micronutrients and Al leaf concentrations was Mn > Fe > Al > B > Zn > Cu.

TABLE 3. Boron (B), cooper (Cu) and manganese (Mn) concentration in diagnostic leaflets (leaf number 17) of different progenies of interspecific hybrid between American oil palm - caiaué (Elaeis oleifera) and African oil palm (Elaeis guineensis).

Progeny	African oil palm	B concentration	Cu concentration	Mn concentration
	Origin		mg kg^{-1}	
RUB 1213	LM 10 T	48.5 a	6.0 a	163.8 b
RUB 1250	LM 10 T	47.4 a	5.6 b	262.5 a
RUB 1277	LM 10 T	49.0 a	6.3 a	265.0 a
RUB 1225	LM 10 T	34.1 b	5.6 b	248.8 a
RUB 1233	LM 10 T	35.7 b	5.0 b	297.5 a
RUB 1234	LM 10 T	37.5 b	5.1 b	200.0 b
RUB 1194	LM 2 T	36.8 b	5.9 a	178.8 b
RUB 1195	LM 10 T	40.8 b	5.9 a	215.0 b
RUB 1283	LM 2 T	45.0 a	5.9 a	248.8 a

RUB 1232	LM 2 T	35.8 b	4.9 b	301.3 a
RUB 1226	LM 2 T	36.2 b	5.5 b	235.0 b
RUB 1274	LM 2 T	42.8 a	6.6 a	283.8 a
RUB 1231	LM 10 T	38.8 b	5.1 b	298.8 a
RUB 1227	LM 2 T	37.8 b	5.5 b	283.8 a
RUB 1271	LM 2 T	45.2 a	6.3 a	196.8 b
RUB 1237	LM 2 T	38.7 b	5.8 a	235.0 b
Overall average (g kg^{-1})		40.6	5.7	244.6
Variation between highest nutrient concentration and overall average (%)		20.7	16.5	23.1
Variation between lowest nutrient concentration and overall average (%)		16.2	14.3	33.1
Coefficient of variation (%)		10.5	9.6	23.1

Means followed by the same letter within a column do not differ according to the Scott-Knott test ($p \leq 0.05$).

Additional studies will be required to evaluate the genetic variability and the nutritional behavior of HIE OxG in the Brazilian Amazon. In addition, it is important to follow strictly the procedures recommended to ensure obtainment of representative leaf samples, e.g. using a zigzag sampling pattern, in order to avoid problems in the sampling and fertilization recommendation.

CONCLUSIONS

Potassium, Mg, B, Cu and Mn concentrations in leaflets in diagnostic leaf varied among HIE OxG progenies.

Potassium and Mg fertilizers recommendations, based on the criterion of concentrations of these nutrients in leaflets, were different among interspecific hybrid of palm oil progenies.

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REFERENCES

BARCELOS, E.; RIOS, S. de A.; CUNHA, R. N.; LOPES, R.; MOTOIKE, S. Y.; BABIYCHUK, E.; SKIRYCZ, A.; KUSHNIR, S. Oil palm natural diversity and the potential for yield improvement. **Frontiers in Plant Science**, v. 6, n. 1, p. 1-16, 2015. Disponível em: <http://dx.doi.org/10.3389/fpls.2015.00190>. doi: 10.3389/fpls.2015.00190

BROADLEY, M.; BROWN, P.; CAKMAK, I.; RENGEL, Z.; ZHAO, F. Function of nutrients: micronutrients. In: MARSCHNER, H. **Mineral nutrition of higher plants**. 3.ed London: Elsevier, 2012. p. 191-248.

CAKMAK, I.; SCHJOERRING, J. K. Special topics in potassium and magnesium research. **Physiologia Plantarum**, v. 133, n. 4, p. 623, 2008. Disponível em: http://dx.doi.org/10.1111/j.1399-3054.2008.01146.x. doi: 10.1111/j.1399-3054.2008.01146.x

CANIZELLA, B. T.; MOREIRA, A.; MORAES, L. A. C.; FAGERIA, N. K. Efficiency of Magnesium Use by Common Bean Varieties Regarding Yield, Physiological Components, and Nutritional Status of Plants. **Communications in Soil Science and Plant Analysis**, v. 46, n. 11, p. 1376-1390, 2015. Disponível em: http://dx.doi.org/10.1080/00103624.2015.1043452. doi: 10.1080/00103624.2015.1043452

CLARK, R. B. Plant genotype differences in the uptake, translocation, accumulation, and use of mineral elements required for plant growth. **Plant and Soil**, v. 72, n. 2, p. 175-196, 1983. Disponível em: <http://dx.doi.org/10.1007/978-94-009-6836-3_5>. doi: 10.1007/978-94-009-6836-3_5

COMTE, I.; COLIN, F.; WHALEN, J.; GRÜNBERGER, O.; CALIMAN, J. P. Agricultural practices in oil palm plantations and their impact on hydrological changes, nutrient fluxes and water quality in Indonesia: a review. **Advances in Agronomy**, v. 116, n. 1, p. 71-124, 2012. Disponível em: <http://dx.doi.org/10.1016/B978-0-12-394277-7.00003-8>. doi: 10.1016/B978-0-12-394277-7.00003-8

CORLEY, R. H. V. How much palm oil do we need? **Environmental Science & Policy**, v. 12, n. 2, p. 134-139, 2009. Disponível em: <http://dx.doi.org/10.1016/j.envsci.2008.10.011>. doi: 10.1016/j.envsci.2008.10.011

CRISTANCHO, J. A. R.; HANAFI, M. M.; OMAR, S. R. S.; RAFII, Y. M.; MARTÍNEZ, F. M.; CAMPOS, C. E. C. Alleviation of aluminum in acidic soils and its effect on growth of hybrid and clonal oil palm seedlings. **Journal of Plant Nutrition**, v. 34, n. 3, p. 387-401, 2011a. Disponível em: <http://dx.doi.org/10.1080/01904167.2011.536880>. doi: 10.1080/01904167.2011.536880

CRISTANCHO, R. J. A.; HANAFI, M. M.; SYED OMAR, S. R.; RAFII, M. Y. Variations in oil palm (*Elaeis guineensis* Jacq.) progeny response to high aluminium concentrations in solution culture. **Plant Biology**, v. 13, n. 2, p. 333-342, 2011b. Disponível em: <http://dx.doi.org/10.1111/j.1438-8677.2010.00378.x>. doi: 10.1111/j.1438-8677.2010.00378.x

CUNHA, R.N.V.; LOPES, R.; GOMES JÚNIOR, R.A.; RODRIGUES, M.R.L.; TEIXEIRA, P.C.; ROCHA, R.N.C.; LIMA, W.A.A. Material genético utilizado para a produção sustentável da cultura da palma de óleo na Amazônia. In: Ramalho Filho, A.; Motta, P.E.F. da, Freitas, P.L. de; Teixeira, W.G. **Zoneamento Agroecológico, Produção e Manejo para a Cultura da Palma de Óleo na Amazônia**. Rio de Janeiro: Embrapa Solos, 2010. p.93-100.

DENDÊ. In: AGRIANUAL 2014: Anuário Estatístico da Agricultura Brasileira. São Paulo: Informa Economics FNP, 2014. p. 29.

DREYER, I. Potassium (K^+) in plants. **Journal of Plant Physiology**, v. 171, n. 9, p. 655, 2014. Disponível em: <http://dx.doi.org/10.1016/j.jplph.2014.03.001>. doi: j.jplph.2014.03.001

DUBOS, B.; GALLARDO, C.; ZAMBRANO, J. E. Comportamiento nutricional de los híbridos interespecíficos *Elaeis oleifera* x *Elaeis guineensis* (OxG) en el oriente ecuatoriano y colombiano. **Palmas**, v. 34, n. especial, p. 337-344, 2013.

EMPRESA BRASILEIRA DE PESQUISA AGROPECUÁRIA - EMBRAPA. **Sistema brasileiro de classificação de solos**. 3.ed. Brasília, 2013. 353 p.

EMPRESA BRASILEIRA DE PESQUISA AGROPECUÁRIA - EMBRAPA. **Manual de análises químicas de solos, plantas e fertilizantes**. 2.ed. Brasília, Informação Tecnológica, 2009. 627 p.

FAGERIA, N. K.; BALIGAR, V. C.; CLARK, R. B. Micronutrients in crop production. **Advances in Agronomy**, v. 77, n. 1, p. 185-268, 2002. Disponível em: <http://dx.doi.org/10.1016/S0065-2113(02)77015-6>. doi: 10.1016/S0065-2113(02)77015-6

FAIRHURST, T. H.; MUTERT, E. Interpretation and Management of Oil Palm Leaf Analysis Data. **Better Crops International**, v. 13, n. 1, p. 48-51, 1999.

FAN, M.; BIE, Z.; XIE, H.; ZHANG, F.; ZHAO, S.; ZHANG, H. Genotypic variation for potassium efficiency in wild and domesticated watermelons under ample and limited potassium supply. **Journal of Plant Nutrition and Soil Science**, v. 176, n. 3, p. 466-473, 2013. Disponível em: <http://dx.doi.org/10.1002/jpln.201200007>. doi: 10.1002/jpln.201200007

GOH, K. J.; HÄRDTER, R. General oil palm nutrition. In: FAIRHURST, T.; HARDTER, R. (Eds.). **Oil Palm: Management for Large and Sustainable Yields**. Singapore: Potash & Phosphate Institute and International Potash Institute, 2003. p. 191-230.

GOMES JUNIOR, R. A.; GURGEL, F. de L.; PEIXOTO, L. de A.; BHERING, L. L.; CUNHA, R. N. V.; RICARDO, R.; PINA, A. J. A.; VEIGA, A. S. Evaluation of interspecific hybrids of palm oil reveals great genetic variability and potential selection gain. **Industrial Crops and Products**, v. 52, n. 1, p. 512-518, 2014. Disponível em: <http://dx.doi.org/10.1016/j.indcrop.2013.10.036>. doi: 10.1016/j.indcrop.2013.10.036

GUO, W.; NAZIM, H.; LIANG, Z.; YANG, D. Magnesium deficiency in plants: An urgent problem. **The Crop Journal**, v. 4, n. 2, p. 83-91, 2016. Disponível em: <http://dx.doi.org/10.1016/j.cj.2015.11.003>. doi: 10.1016/j.cj.2015.11.003

GUOPING, Z.; JINGXING, C.; TIRORE, E. A. Genotypic variation for potassium uptake and utilization efficiency in wheat. **Nutrient Cycling in Agroecosystems**, v. 54, n. 1, p. 41-48, 1999. Disponível em: <http://dx.doi.org/10.1023/A:1009708012381>. doi: 10.1023/A:1009708012381

GUPTA, U. C. Boron nutrition of crops. **Advances in Agronomy**, v. 31, n. 1, p. 273-307, 1979. Disponível em: <http://dx.doi.org/10.1016/S0065-2113(08)60142-X>. doi: 10.1016/S0065-2113(08)60142-X

HÄRDTER, R.; FAIRHURST, T. Introduction: Oil palm: Management for large and sustainable yields. In: FAIRHURST, T.; HARDTER, R. (Eds.). **Oil Palm: Management for Large and Sustainable Yields**. Singapore: Potash & Phosphate Institute and International Potash Institute, p. 1-12.2003.

HAWKESFORD, M.; HORST, W.; KICHEY, T.; LAMBERS, H.; SCHJOERRING, J.; MOLLER, I. S.; WHITE, P. Functions of macronutrients. In: MARSCHNER, P., ed. **Mineral nutrition of higher plants**, 3.ed. New York, Elsevier, 2012. p.171-178.

HE, F. J.; MACGREGOR, G. A. Beneficial effects of potassium on human health. **Physiologia Plantarum**, v. 133, n. 4, p. 725-735, 2008. Disponível em: http://dx.doi.org/10.1111/j.1399-3054.2007.01033.x. doi: 10.1111/j.1399-3054.2007.01033.x

HORMAZA, P.; MESA-FUQUEN, E.; ROMERO, H. M. Phenology of the oil palm interspecific hybrid *Elaeis oleifera* x *Elaeis guineensis*. **Scientia Agricola**, v. 69, n. 4, p. 275-280, 2012. Disponível em: <http://dx.doi.org/10.1590/S0103-90162012000400007>. doi: 10.1590/S0103-90162012000400007

LEE, C. T.; RAHMAN, Z. A.; MUSA, M. H.; NORIZAN, M. S.; TAN, C. C. Leaf nutrient concentrations in oil palm as affected by genotypes, irrigation and terrain. **Journal of Oil Palm & The Environment**, v. 2, n. 1, p. 38-47, 2011. Disponível em: <http://dx.doi.org/10.5366/jope.2011.05>. doi: 10.5366/jope.2011.05

MARSCHNER, H. **Mineral nutrition of higher plants**. 3.ed London: Elsevier, 2012. 643p.

MATOS, G. S. B. de; FERNANDES, A. R.; WADT, P. G. S. Níveis críticos e faixas de suficiência de nutrientes derivados de métodos de avaliação do estado nutricional da palma-de-óleo. **Pesquisa Agropecuária Brasileira**, v. 51, n. 9, p. 1557-1567, 2016. Disponível em: <http://dx.doi.org/10.1590/S0100-204X2016000900055>. doi: 10.1590/S0100-204X2016000900055

OLLIVIER, J.; LAMADE, E.; DUBOS, B.; ERWANDA, S.; PERMADI, P.; SURYANA, E.; FLORI, A.; COCHARD, B.; JACQUEMARD, J. C. Hacia um diagnóstico nutricional preciso para la palma de aceite, teniendo en cuenta el origen del material de siembra. **Palmas**, v. 34, n. especial, p. 203-220, 2013.

OOSTERHUIS, D. M.; LOKA, D. A.; KAWAKAMI, E. M.; PETTIGREW, W. T. The physiology of potassium in crop production. **Advances in Agronomy**, v. 126, n. 1, 203-233, 2014. Disponível em: <http://dx.doi.org/10.1016/B978-0-12-800132-5.00003-1>. doi: 10.1016/B978-0-12-800132-5.00003-1

RAMALHO FILHO, A.; MOTTA, P. E. F. da; FREITAS, P. L. de; TEIXEIRA, W. G. (Ed.). **Zoneamento agroecológico, produção e manejo para a cultura da palma de óleo na Amazônia.** Rio de Janeiro: Embrapa Solos, 2010. 216p.

RENGEL, Z. Genotypic differences in micronutrient use efficiency in crops. **Communications in Soil Science and Plant Analysis**, v. 32, n. 7-8, p. 1163-1186. Disponível em: <http://dx.doi.org/10.1081/CSS-100104107>. doi: 10.1081/CSS-100104107

RINCÓN, A. H. N.; GARZÓN, E. M. G.; CRISTANCHO, J. A. R. Contenidos de nutrimentos en diferentes estructuras de palmas híbridas O× G bajo condiciones comerciales de viveros. **Revista Palmas**, v. 33, n. 1, p. 11-21, 2012.

RODRIGUES, M. R. L.; AMBLARD, P.; SILVA, E. B.; MACEDO, J. L V.; CUNHA, R. N. V. TAVARES, A. M. **Avaliação do estado nutricional do dendezeiro: análise foliar**. Manaus: Embrapa Amazônia Ocidental, 2002. 9p. (Circular Técnica, 11).

RODRIGUES, M. R. L.; TEIXEIRA, P. C.; MACÊDO, J. L. V. de; CUNHA, R. N. V.; LOPES, R.; ROCHA, R. N. C.; TEIXEIRA, W. G. Avaliação do estado nutricional e manejo da fertilidade do solo para a produção sustentável da cultura da palma de óleo na Amazônia. In: RAMALHO FILHO, A.; MOTTA, P. E. F. da; FREITAS, P. L. de; TEIXEIRA, W. G. (Ed.). **Zoneamento agroecológico, produção e manejo para a cultura da palma de óleo na Amazônia.** Rio de Janeiro: Embrapa Solos, 2010. p.115-126.

SANTOS, J.C. dos; HOMMA, A.K.O.; SENA, A.L.S.; GOMES JÚNIOR, R.A.; MENEZES, A.J.E.A. de; MONTEIRO, K.F.G. **Desempenho socioeconômico do sistema produtivo familiar de dendê em Moju, estado do Pará**. Belém: Embrapa Amazônia Oriental, 2014. 36p. (Boletim de pesquisa e desenvolvimento, 94).

SAYER, J.; GHAZOUL, J.; NELSON, P.; BOEDHIHARTONO, A. K. Oil palm expansion transforms tropical landscapes and livelihoods. **Global Food Security**, v. 1, n. 2, p. 114-119, 2012. Disponível em: <http://dx.doi.org/10.1016/j.gfs.2012.10.003>. doi: 10.1016/j.gfs.2012.10.003

TAN, N. P.; ZAHARAH, A. R.; SITI NOR AKMA, A.; JAMALUDDIN, N. Evaluating the variability of Gafsa phosphate rock uptake by oil palm genotypes at nursery stage. **Pertanika Journal of Tropical Agricultural Science**, v. 33, n. 2, p. 223-231, 2010.

VERBRUGGEN, N.; HERMANS, C. Physiological and molecular responses to magnesium nutritional imbalance in plants. **Plant and Soil**, v. 368, n. 1-2, p. 87-99, 2013. Disponível em: <http://dx.doi.org/10.1007/s11104-013-1589-0>. doi: 10.1007/s11104-013-1589-0

YANG, F. Q.; WANG, G. W.; ZHANG, Z. Y.; ENEJI, A. E.; DUAN, L. S.; LI, Z.H.; TIAN, X. L. Genotypic variations in potassium uptake and utilization in cotton. **Journal of Plant Nutrition**, v. 34, n. 1, p. 83-97, 2011. Disponível em: <http://dx.doi.org/10.1080/01904167.2011.531361>. doi: 10.1080/01904167.2011.531361

ZAHARAH, A. R.; HAWA, J.; SHARIFUDDIN, H. A. H. Accumulation and migration of phosphate applied as rock phosphate in an oil palm plantation. **Pertanika**, v. 8, n. 3, p. 317-321, 1985.

ZÖRB, C.; SENBAYRAM, M.; PEITER, E. Potassium in agriculture – status and perspectives. **Journal of Plant Physiology**, v. 171, n. 9, p. 656-669, 2014. Disponível em: <http://dx.doi.org/10.1016/j.jplph.2013.08.008>. doi: 10.1016/j.jplph.2013.08.008