

Contribution of *Pueraria phaseoloides* L. in the Cycling of Macronutrients in oil Palm Plantations

Ismael de Jesus Matos Viégas, Milton Garcia Costa, Eric Victor de Oliveira Ferreira, Nilda Leonor Pezo Pérez, Henrique da Silva Barata, Jessivaldo Rodrigues Galvão, Heráclito Eugenio Oliveira da Conceição, Sérgio Dias do Espírito Santo

Universidade Federal Rural da Amazônia, Brazil

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Abstract

The use of cover crops has become a common practice in oil palm plantations, ensuring greater sustainability to agroecosystems, increasing nutrient cycling and providing greater savings in the use of mineral fertilizers. In this sense, the objective of this study was to evaluate the accumulation of macronutrients (N, P, K, Ca, Mg and S) in tropical kudzu plants (*Pueraria phaseoloides* L.) in oil palm plantations. The experiment was carried out in the municipality of Tailândia, Pará State, using a completely randomized experimental design, four replications and seven treatments (ages of oil palm). The accumulation of macronutrients was obtained through the product of nutrient concentrations and the dry matter of the aerial part of the living, dead and total cover of tropical kudzu. The order of total accumulation of cycled nutrients by legumes was Ca, N, K, Mg, P and S. Tropical kudzu cultivation, as a cover plant, contributes to nutrient cycling in oil palm plantations, but this benefit decreased with the age of palm oil trees.

Keywords: cover crops, legumes, nutritional diagnosis, oilseed, tropical kudzu

1. Introduction

Cover crops are important parts of sustainable agricultural systems in tropical regions. The use of cover crops produces several benefits; prevention of soil erosion, suppression of undesirable plants, improvement of microbial activity and soil quality, in addition to maintaining soil moisture (Fageria *et al.*, 2014a). The cover crops produce a large amount of biomass and have a pivoting root system that can extract nutrients from deeper soil layers, making them available after decomposition (Favero *et al.*, 2000).

The use of cover crops, mainly with tropical kudzu legumes (*Pueraria phaseoloides* L.), is common in the cultivation of palm trees, such as coconut palm (Lins and Viégas, 2020) and oil palm (Rodrigues *et al.*, 2002; Viégas *et al.*, 2019). For the conditions of Pará, there is the

recommendation of the intercropped planting of tropical kudzu and the oil palm (Viégas and Botelho, 2007). Legumes are known for their ability to increase the amount of soil organic matter (SOM) and their fertility due to symbiosis with rhizobacteria, which provides the fixation of atmospheric nitrogen (N_2) and decreased fertilizer costs in commercial plantations (Hutasoit *et al.*, 2017). In this sense, legumes become a possibility to increase the availability of N to oil palm (Agamuthu and Broughton, 1985), in addition to cycling other nutrients.

The intercropped cultivation of legumes and oil palm can change the dynamics of nutrient extraction and replacement in the agricultural ecosystem (Favero *et al.*, 2000). The understanding of nutrient concentrations in cover crops provides a better understanding of the dynamics of these nutrients in ecosystems (Viégas *et al.*, 2018), besides assisting in the nutritional management of the oil palm. In the conditions of cultivation of oil palm in Pará State, there are studies on the concentration of nutrients in tropical kudzu (Pérez and Viégas, 1997), but without the evaluation of their accumulation. For micronutrients, there is evaluation in *Pueraria phaseoloides* L. intercropped oil palm in Pará (Viégas *et al.*, 2018).

On the other hand, to be successful in the use of cover crops, it is necessary that the selected species tolerates high soil acidity and to be efficient in the use of nutrients (Fageria *et al.*, 2014a), mainly in oil palm plantations where the practice of liming is not common (Homma and Rebello, 2020) in acid soils of the Amazon (Franzini *et al.*, 2017). The efficiency of the use of nutrients by cover crops is based on the ability to acquire, transport, and remobilize nutrients in their tissues (Baligar *et al.*, 2001). The efficiency of nutrient use is influenced by the interaction of plants and environmental variables (solar radiation, temperature, and precipitation) and the interactions on legumes in tropical soils are limited (Fageria *et al.*, 2014a), making it essential to study this theme in specific edaphoclimatic conditions.

In this sense, the objective of this work was to evaluate the accumulation of macronutrients in tropical kudzu plants intercropped with oil palm in northeastern Pará, Brazil.

2. Method

The study was carried out in Tailândia, region of Pará northeastern, Eastern Amazon, in the commercial oil palm plantations (hybrid Tenera) of the Royal Agroindustrial Company. The climate of the municipality is tropical rainy type without seasonal thermal variation, according to Köppen classification, with an average temperature of 26 °C, average relative humidity of 83 % and annual precipitation of 2,400 mm. During the conduction of the experiment, rainfall monitoring (Figure 1) of the research area was performed with the aid of a rain gauge.

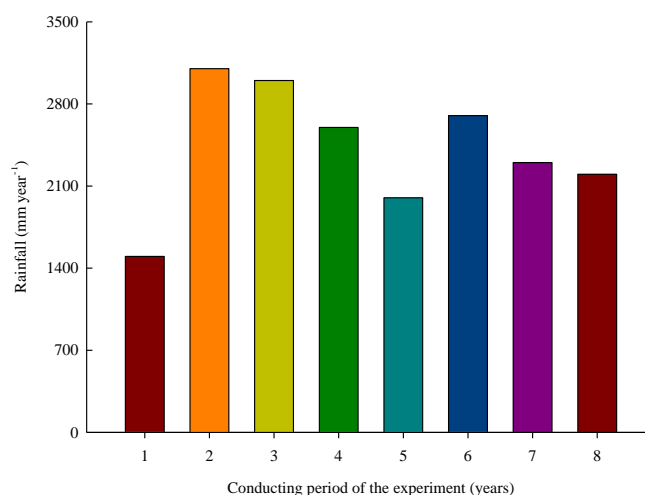


Figure 1. Annual rainfall occurred in the experimental area during the study period

The predominant soil in the region is the Yellow Oxisol, alic, leached and of low natural chemical fertility (Rodrigues *et al.*, 2005). A granulometric analysis of the soil of the experiment area was performed; 671.4 g kg⁻¹ of sand, 88.6 g kg⁻¹ of silt and 238.6 g kg⁻¹ of clay (sandy free texture). Also, chemical analyses of the soil (0.0 - 0.3 m) of the study area (Table 1) were performed. Both the particle size analysis and the soil chemical analyses were performed in the soil laboratory of Embrapa Amazônia Oriental.

Table 1. Chemical analysis of the soil (0.0- 0.3 m) of the experimental area as a function of the age of the oil palm plantations (Viégas *et al.*, 2018)

Age of planting Palm (years)	SOM*	pH	P**	K+**	Ca ²⁺ **	Mg ²⁺ **	Al ³⁺	H+Al***	SB	V
	g kg ⁻¹	(CaCl ₂)	mg dm ⁻³		-----	cmolc dm ⁻³	-----	-----		%
2	16.0	4.3	4.0	27.4	0.7	0.4	0.4	3.4	11.7	24
3	23.0	4.4	6.0	23.5	0.7	0.2	0.3	2.8	9.6	24
4	15.0	4.1	5.0	19.6	0.9	0.2	0.3	3.1	11.5	26
5	19.0	4.0	6.0	27.4	0.8	0.3	0.5	3.8	11.7	22
6	20.0	4.0	6.0	19.6	0.7	0.3	0.8	3.4	10.5	22
7	21.0	4.3	6.0	19.6	0.7	0.3	0.4	2.6	10.5	27
8	18.0	4.0	8.0	23.5	0.6	0.3	0.6	3.4	9.6	20

Note. * Colorimetric method; ** Extracted with ion exchange resin; ***. SMP method; Al³⁺ - extraction with KCl 1mol L⁻¹. SOM: soil organic matter, SB: Sum of the bases, V: Base saturation.

The experimental design used was completely randomized, with four replications, and seven treatments: oil palm plantings from the second to the eighth year of age. Tropical kudzu

sowing was performed in the preparation of the oil palm field area, to sowing with 1 kg ha^{-1} of uninoculated seeds. The spacing used in the planting of the oil palm was of an equilateral triangle of nine meters in quincuncial (9 m between plants and 7.80 m between rows) for a total of $143 \text{ plants ha}^{-1}$.

Plant responses to treatments were evaluated based on the accumulation of macronutrients from the living, dead and total cover of tropical kudzu. The sampling was carried out between the lines of the oil palm plants by means of samples of the entire aerial part of the plants of living cover (green) and dead, using a wooden square of $0.5 \times 0.5 \text{ m}$ (0.25 m^2), all samplings in the seven treatments were carried out in the same period. The green and dead samples of tropical kudzu were cleaned with distilled water, packed in paper bags, and dried in a greenhouse ($70 \text{ }^\circ\text{C}$). After the determination of the dry matter of the samples, the plant material was grinding in a Wiley mill and, finally, the analyses of macronutrient concentrations (N, P, K, Ca, Mg and S). These were conducted in the soil and plant analysis laboratory of Embrapa Eastern Amazon, following the methodology of Carmo *et al.* (2000). Nutrients were extracted by sulfuric (N) and nitroperchloric (P, K, Ca, Mg and S) digestion methods and subsequently determined by semi-micro Kjeldahl (N), vanadate yellow spectrometry (P), flame photometry (K), atomic absorption spectrophotometry (Ca and Mg) and turbidimetry (S) methods.

The accumulation of macronutrients was obtained through the product of nutrient concentrations and the dry matter of the aerial part of the living and dead cover of tropical kudzu. The total accumulation of each nutrient was obtained by the sum of the accumulation in the living cover and in the dead cover. To extrapolate the dry matter production values of tropical kudzu to hectare, the clean areas around the oil palm (crowning) plants were subtracted, considering the radius of the crowning areas of 1.5 m in the first and second year, 2 m in the third year and 2.5 m in the fourth to eighth year of age of the plants.

Variance analysis ($p < 0.05$) was performed, and the data were adjusted to regression models according to the age of the oil palm plants using the Agroestast software (Barbosa and Maldonato Junior, 2015).

3. Results and Discussion

N accumulations in the living, dead and total cover of tropical kudzu decreased as a function of the age of the oil palm plantations (Figure 2a). This decrease in N accumulation is due to lower dry matter production of tropical kudzu plants due to the increase in the planting age of oil palm (Viégas *et al.*, 2018). In older oil palm plantations there is greater competition, mainly for light, causing greater shading from plants and lower dry matter production of tropical kudzu, with consequent lower accumulation of nutrients. Luna-Orea *et al.* (1996) also found that N accumulation in living tropical kudzu plants decreases as a function of time; obtaining 140 kg ha^{-1} of N in plants at the first month of age and 117 kg ha^{-1} of N in plants at the thirty-second month of age.

Table 2. Summary of the analysis of variance (coefficient of variance – CV, mean square and F test) of the variables evaluated (Nutrients accumulation)

Accumulation	Plant Cover	CV (%)	Medium Square	F test
N	Living	10.18	6701.19	282.52**
	Dead	10.51	55060.39	300.64**
	Total	9.38	99168.58	361.38**
P	Living	11.36	17.89	202.24**
	Dead	32.38	82.34	28.3**
	Total	22.67	172.84	54.09**
K	Living	8.50	6313.36	793.42**
	Dead	18.13	852.83	118.42**
	Total	5.18	11680.30	1887.53**
Ca	Living	8.89	2359.32	384.54**
	Dead	19.13	76715.91	94.01**
	Total	16.32	104951.56	125.51**
Mg	Living	10.02	42.34	236.86**
	Dead	19.34	914.28	93.94**
	Total	15.64	1335.86	131.85**
S	Living	20.48	3.91	73.48**
	Dead	51.05	76.47	9.28**
	Total	41.95	107.14	13.36**

Note. **, *, NS - significant at 1 %, at 5 % and no significant, respectively.

The maximum accumulation of N in the living cover of tropical kudzu was observed at two years (125 kg ha^{-1}) and, in the dead cover, also at two years (330 kg ha^{-1}) totaling the accumulation of 455 kg ha^{-1} of N (Figure 2a), corresponding to $1,011 \text{ kg ha}^{-1}$ of urea (45 % of N). Thus, there was a decrease in N accumulation in relation to the age of oil palm, with lower accumulation in the eighth year in the living cover (7.2 kg ha^{-1}) and in the dead cover (23.5 kg ha^{-1}), performing the total cycling of 30.7 kg ha^{-1} of N, corresponding to only 68.2 kg ha^{-1} of urea, being 14.8 times lower than obtained in the second year. The lower accumulation of N in tropical kudzu in intercropping with older oil palm is expected, since when the root system of oil palm grows between the lines, competition for nutrients leads to a gradual decline in the yield of cover crops (Agamuthu and Broughton, 1984). The decrease in N accumulation in the dead cover of kudzu plants as a function of the age of oil palm plants observed in the present study may also be related to the increase in N demand for oil palm plants, since it increases from 86 to 113 kg ha^{-1} of N from the fourth to the fifth year of crop plantations (Franzini *et al.*, 2020), considering $143 \text{ plants ha}^{-1}$ and a productivity of 17 t ha^{-1} .

Espindola *et al.* (2006), evaluating the dead cover of tropical kudzu in banana plantations, verified accumulation of 126 kg ha^{-1} of N. In coffee plantations, research conducted with cover crops concluded that biological fixation is responsible for 80 % of N accumulation in legumes (Partelli *et al.*, 2011). In Europe, the evaluation of nineteen legume species indicated that all plants were able to perform N fixation above 100 kg ha^{-1} (Buchi *et al.*, 2015). In this sense, it is verified that the use of legumes such as tropical kudzu contributes to an increase in the supply of N in the agroecosystem, increasing its availability for oil palm and promoting savings in the use of mineral N fertilizers.

In oil palm plantation where the legume *Pueraria phaseoloides* L. is used as a soil cover plant, N fertilization is dispensed from the first year of planting (Viégas and Botelho, 2007). There was no positive response to N fertilization (urea), compared to the absence of N supply, with *Pueraria phaseoloides* as soil cover (Viégas *et al.*, 2019). In cultivation of coconut plants, is suggested the reduction of mineral N fertilization when in intercropping with *Pueraria phaseoloides* L. (Lins and Viégas, 2020).

For the average productivity of the oil palm in Pará (17 t ha^{-1} ; Homma and Rebello, 2020), the current recommendation (Franzini *et al.*, 2020) is 113 kg ha^{-1} of N, a quantity lower than the N cycled (128 kg ha^{-1}) in the dead cover of tropical kudzu in the average of eight years. In the living cover of kudzu, the average amount of cycled N represents 42 % (47.9 kg ha^{-1}) of the demand for this nutrient from oil palm (Figure 2a).

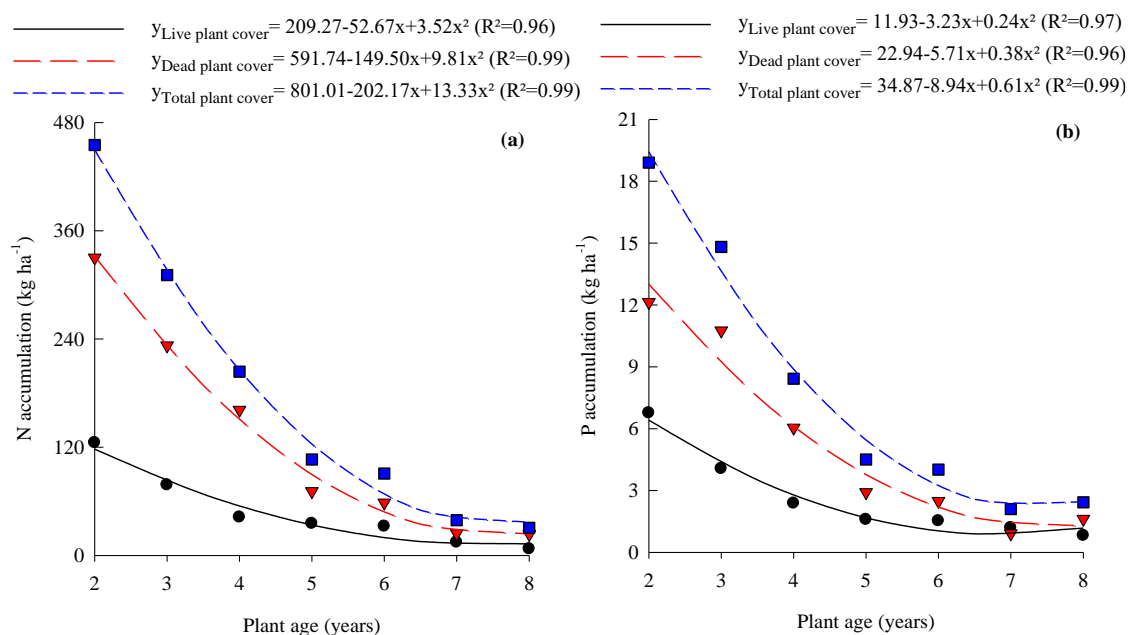


Figure 2. Accumulation of N (a) and P (b) in living, dead, and total cover of tropical kudzu as a function of the age of the oil palm plantations

For P accumulations, there was a decrease in their values in the living, dead and total cover of tropical kudzu as a function of the age of the oil palm plantations (Figure 2b). This fact is due to the decrease in dry matter production of tropical kudzu plants intercropped with older oil palms (Viégas *et al.*, 2018), since the concentration of P in this cover plant is higher at older ages of palm oil plantations (Peréz and Viégas, 1997). In a study conducted in the Bolivian Amazon, a decrease in P accumulation was observed due to the age of tropical kudzu; 13 kg ha⁻¹ of P at the first month of age and 10 kg ha⁻¹ of P at the thirty-second month of plant age (Luna Orea *et al.*, 1996). Espindola *et al.* (2006), evaluating the effect of dead cover of tropical kudzu in banana plantations, verified accumulation of 9.8 to 10.3 kg ha⁻¹ of P. Under the conditions of Pará State, the demand of oil palm is estimated at 38 kg ha⁻¹ of P in plantations with 143 plants ha⁻¹ and productivity of 17 t ha⁻¹ of bunches (Franzini *et al.*, 2020). Thus, there is the potential of tropical kudzu to contribute to the supply of the nutrient; on the average of the eight years evaluated up to 7 % (2.6 kg ha⁻¹ of P) in living cover and 14 % (5.3 kg ha⁻¹ of P) in dead cover, totaling 21 % (7.9 kg ha⁻¹ of P). On average for eight years, the 7.9 kg ha⁻¹ of P is equivalent to 41 kg ha⁻¹ of triple superphosphate (44 % of P₂O₅).

For the accumulations of K in the living, dead and total cover of tropical kudzu, there were quadratic responses, decreasing according to the age of the oil palm plantations (Figure 3a). In a research conducted with tropical kudzu also indicated a decrease in K accumulation as a function of time; in the first month of age of the plants the accumulation of K was 74 kg ha⁻¹ and at the twenty-second month of age it was 70 kg ha⁻¹ (Luna Orea *et al.*, 1996). On the other hand, a research carried out with dead cover of tropical kudzu in banana cultivation verified the accumulation of 44 to 47 kg ha⁻¹ of K (Espindola *et al.*, 2006). In the current research, in the living cover, the maximum cycling of K (116.4 kg ha⁻¹) occurred at 2 years of planting and, the minimum (5.5 kg ha⁻¹), at the eighth year (Figure 3a). In this sense, the

potential of tropical kudzu is verified in supplying K to oil palm plants, contributing to the sustainability of the consortium.

A study evaluating nutrient cycling in tropical kudzu dead cover residue in rainy season indicated that K is the fastest-released nutrient (Espindola *et al.*, 2006). This fact justifies the lower accumulation of K in the dead cover of tropical kudzu in relation to the living cover, indicating the rapid release of the nutrient (Figure 3a). For an average yield of 17 t ha⁻¹, the recommendation of K fertilization for oil palm in Pará is 169 kg ha⁻¹ (Franzini *et al.*, 2020). Thus, the supply of K due to its cycling by tropical kudzu can contribute to the reduction of the applied level of the nutrient in mineral fertilizers. K cycling in tropical kudzu was 33.2 kg ha⁻¹ in living cover, 13.4 kg ha⁻¹ in dead cover and 46.6 kg ha⁻¹ in total, indicating a decrease of 27.6 % in the application of K fertilizers. The low cycled values of K verified in the tropical kudzu of the present study are the result of the low absorption of the nutrient by the cover plant (Pérez and Viégas, 1997) due to its low availability in the soil of oil palm plantations (Table 1; Brasil and Cravo, 2020).

Ca accumulations in the living, dead and total cover of tropical kudzu decreased with the age of the oil palm plantations (Figure 3b). A decrease in Ca accumulation in tropical kudzu was also observed in the Bolivian Amazon from 14 to 11 kg ha⁻¹ from first to the thirty-second month of plant age (Luna Orea *et al.*, 1996). Research with dead cover of tropical kudzu indicated, in the dry period, accumulation of 38 kg ha⁻¹ of Ca and, in rainy season, of 63 kg ha⁻¹ of Ca (Espindola *et al.*, 2006).

In the present study, the accumulation of Ca in the living cover ranged from 3.8 to 70.6 kg ha⁻¹, providing an average cycling of 27.9 kg ha⁻¹ of Ca (Figure 3b). Oil palm plantations, with productivity of 17 t ha⁻¹ and density of 143 plants ha⁻¹, present a demand of 68 kg ha⁻¹ of Ca (Franzini *et al.*, 2020), indicating that tropical kudzu can supply 41 % of the nutrient. In this sense, tropical kudzu can contribute to increased nutrient availability, since, according to Matos *et al.* (2016), Ca is among the nutrients with the highest frequency of deficiency in oil palm plantations in Pará. Espindola *et al.* (2006) report that Ca is the nutrient with slower release in tropical kudzu.

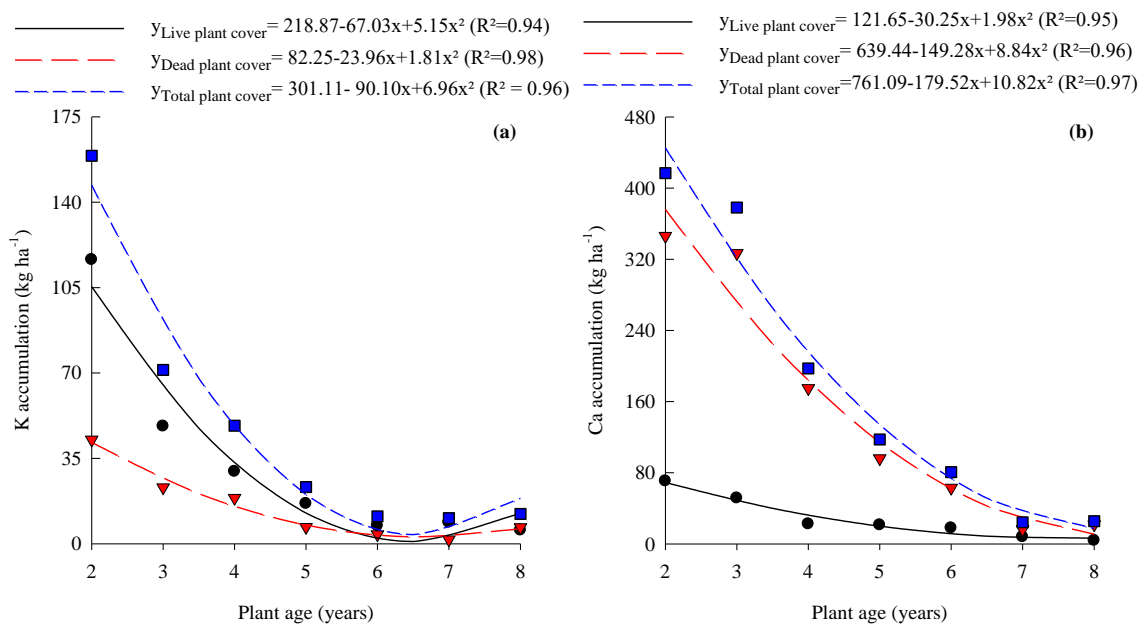


Figure 3. Accumulation of K (a) and Ca (b) in living, dead, and total cover of tropical kudzu as a function of the age of the oil palm plantations

The accumulation of Mg in the living, dead and total cover of tropical kudzu also decreased as a function of the age of the oil palm (Figure 4a). A similar result was observed by Luna Orea *et al.* (1996) in living cover of tropical kudzu; Mg accumulation decreased from 8 kg ha⁻¹ in the first month to 6 kg ha⁻¹ at thirty-second month of plant age. The use of dead cover of tropical kudzu in banana plantation indicated higher accumulation of Mg (25 kg ha⁻¹) in rainy season compared to dry period (15 kg ha⁻¹) (Espindola *et al.*, 2006). The data of the present study indicate an average cycling of 4.2 and 16.1 kg ha⁻¹ of Mg in living and dead cover, respectively, totaling 20.3 kg ha⁻¹ of cycled Mg (Figure 4a). The recommendation of Mg fertilization for a productivity of 17 t ha⁻¹ of the oil palm in Pará is 34 kg ha⁻¹ (Franzini *et al.*, 2020). There is an indication of positive response in the production of oil palm plants to Mg fertilization in the region (Oliveira *et al.*, 2019).

For S accumulation in the living, dead and total covers of tropical kudzu, there was also a decrease in the values as a function of the age of the oil palm (Figure 4b). Research evaluating other legumes as cover plants found that the crotalaria accumulated 13.8 kg ha⁻¹ of S (Silva *et al.*, 2010). The decrease in S accumulation in tropical kudzu as a function of oil palm age may also be related to the export of the nutrient by bunches. Franzini *et al.* (2020) estimate that there is export of 8.5 kg ha⁻¹ of S in planting with 17 t ha⁻¹ of bunches of fresh fruits. Thus, for this productivity, the same authors recommend applying 20 kg ha⁻¹ of S in oil palm plantation. The total cycling of S in the tropical kudzu ranged from 1.2 to 13.2 kg ha⁻¹ at the eighth and second year, respectively (Figure 4b). Thus, there is the contribution in the nutrition of the oil palm in cultivation intercropped with tropical kudzu by the cycling of S. This fact becomes relevant since the S was pointed out as one of the nutrients with the highest incidence of deficiency in the planting of oil palm in Pará (Matos *et al.*, 2019).

It is note point that lower S cycled values by tropical kudzu are also due to low concentrations of the nutrient in the tissue of these plants (Peréz and Viégas, 1997), due to the low concentration of soil organic matter (Table 1), the main source of S in the soil (Vitti *et al.*, 2018). The high rate of mineralization and the high leaching of S favors the occurrence of nutrient deficiency in the planting of oil palm in Pará (Matos *et al.*, 2016), factors favored by the climate of the current study (Figure 1). Thus, it is observed that for all macronutrients cycled by kudzu plants there is a decrease in their accumulations according to the increase in the age of oil palm plantations. The kudzu is a heliophilous legume that needs sun exposure with low luminous composition point, which when shaded by palms trees over the years reduces the accumulation of macronutrients.

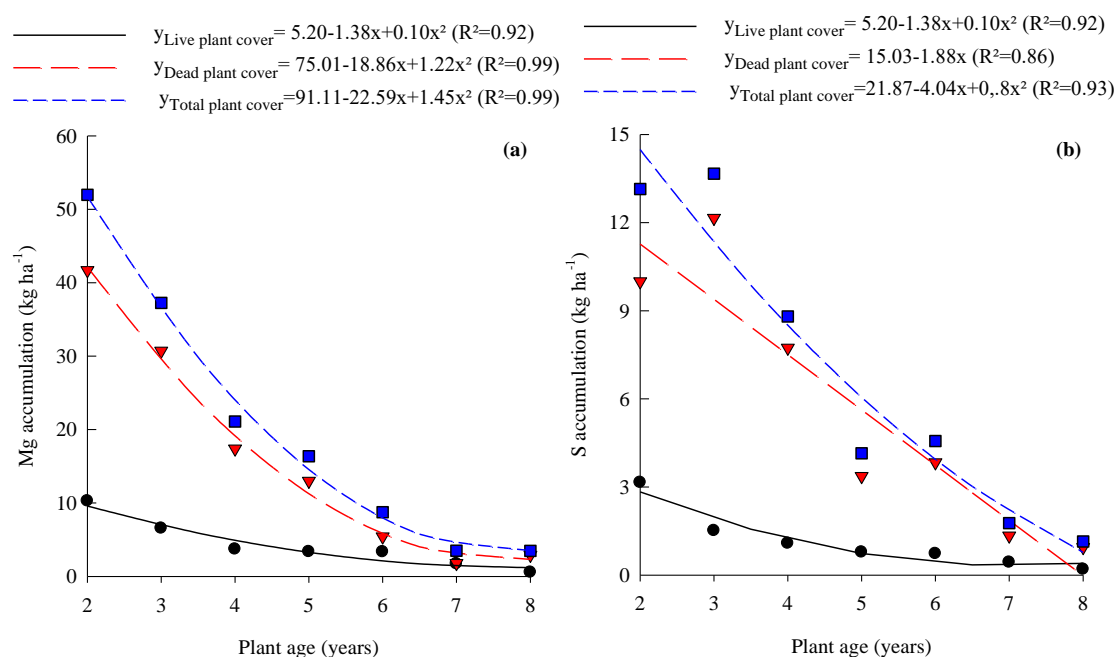


Figure 4. Accumulation of Mg (a) and S (b) in living, dead, and total cover of tropical kudzu as a function of the age of the oil palm plantations

4. Conclusions

- The accumulation of macronutrients in cover of tropical kudzu decreases as a function of the age of the oil palm, being in the order: $N > K > Ca > Mg > P > S$ in the living, $Ca > N > Mg > K > S > P$ in the dead and $Ca > N > K > Mg > P > S$ in total.
- *Pueraria phaseoloides* L. contributes to macronutrients cycling and become an option of sustainable management to cultivation of palm oil trees, with potential reduction in the use of mineral fertilizers. However, the macronutrients cycling by kudzu plants decreases with their ages.

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