Journal of Biotechnology and Biodiversity

journal homepage: *https://sistemas.uft.edu.br/periodicos/index.php/JBB/index*

Water as a factor modifying soil fertility in the Guamá River estuary

Sérgio Brazão e Silva [a], Marcondes Lima da Costa [b], Jessivaldo Rodrigues Galvão [a*], Mauro Junior Borges Pacheco [a], Matheus Vinícius da Costa Pantoja [a], Odete Kariny Souza Santos [a]

[a] Universidade Federal Rural da Amazônia, Brasil
[b] Universidade Federal do Pará, Brasil
[*] Autor correspondente (jessivaldo.galvao@ufra.edu.br)

INFO

Keywords
flooding
nutrients
gleysols
mineralogy
organic matter

ABSTRACT

The Guamá River estuary, in northern Brazil, has large fertile floodplain areas that have considerable potential for food production. In order to evaluate the effects of flooding on soil geochemistry, a prolonged flooding experiment was carried out on a Gleissolo Háplico of the Guamá River, while the mineralogy and fertility of the soil and the suspended river water were evaluated. The aim of the study was to investigate the geochemical processes that occur in the surface horizon of the Haplic Gleysols of the Guamá River. During the experiment, the soil was flooded with distilled water and samples were taken at regular intervals. There was a marked reduction from 322 mV on the first day to -337 mV by the 132nd day of flooding. The pH, which was initially 4.6, gradually increased until the 15th day of flooding, when it stabilized at around 6.5 to 6.7. The nutrients iron, phosphorus and manganese increased considerably in the exchange complex, with iron reaching high levels for plant nutrition. Potassium did not respond to the effect of flooding, and like calcium, its concentration changed little. Copper and zinc concentrations increased only slightly during flooding, but remained at adequate levels. The mineralogical characteristics of this soil indicated the presence of goethite, quartz, smectite, illite, kaolinite and anatase. The suspended material revealed high levels of exchangeable cations adsorbed to the sediment, with high CTC, low aluminum saturation and high base saturation. The frequent deposition of silt in the soil, together with the presence of organic matter and 2:1 clay minerals in the soil, contributes to maintaining the fertility of this environment.

Palavras-chaves
inundação
nutrientes
gleissolos
mineralogia
matéria orgânica

RESUMO

Água como fator modificador da fertilidade do solo no estuário do Rio Guamá.
O estuário do rio Guamá, no norte do Brasil, possui grandes áreas férteis de várzea com considerável potencial para a produção de alimentos. Com o objetivo de avaliar os efeitos da inundação na geoquímica do solo, foi realizado um experimento de inundação prolongada em um Gleissolo Háplico do Rio Guamá, enquanto foram avaliadas a mineralogia e a fertilidade do solo e da água do rio em suspensão. O objetivo do estudo foi investigar os processos geoquímicos que ocorrem no horizonte superficial dos Gleissolos Háplicos do Rio Guamá. Durante o experimento, o solo foi inundado com água destilada e amostras foram coletadas em intervalos regulares. Houve uma redução acentuada de 322 mV no primeiro dia para -337 mV no 132º dia de inundação. O pH, que inicialmente era 4,6, aumentou gradativamente até o 15º dia de cheia, quando se estabilizou em torno de 6,5 a 6,7. Os nutrientes ferro, fósforo e manganês aumentaram consideravelmente no complexo de trocas, com o ferro atingindo níveis elevados para a nutrição das plantas. O potássio não respondeu ao efeito das enchentes e, assim como o cálcio, sua concentração mudou pouco. As concentrações de cobre e zinco aumentaram apenas ligeiramente durante as cheias, mas permaneceram em níveis adequados. As características mineralógicas deste solo indicaram a presença de goethita, quartzo, esmectita, ilita, caulinita e anatásio. O material suspenso revelou altos níveis de cátions trocáveis adsorvidos ao sedimento, com alta CTC, baixa saturação por alumínio e alta saturação por bases. A frequente deposição de silte no solo, aliada à presença de matéria orgânica e argilominerais na proporção 2:1 no solo, contribui para a manutenção da fertilidade deste ambiente.

ISSN: 2179-4804
DOI: https://doi.org/10.20873/jbb.uft.cemaf.v13n1.18551

INTRODUCTION

In the Amazon region, much of the research that deals with the chemical characterization of soil is concentrated in the terra firme areas and, to date, there are significant gaps in understanding the effects of land use practices on floodplain soils. The coastal zone of northern Brazil, in the states of Amapá and Pará, includes around three million hectares of tidal floodplains, locally called floodplains, with medium to high fertility and high concentrations of calcium and magnesium (Lima et al. 2001). Floodplains are ecosystems that can be defined as a transition zone between terrestrial and aquatic environments, of continental or coastal origin, constantly or occasionally flooded by shallow waters, in addition to being composed of waterlogged soil (Junk et al., 2014).

The Guamá River, together with Guajará Bay, is part of the hydrographic system that surrounds Belém, the capital of the state of Pará. The floodplains of the Guamá River, located upstream of Belém, were occupied during the first centuries of European colonization, when sugar cane plantations were established to produce sugar, ethanol and liqueurs to supply Europe. Throughout history, the economic cycles in the Amazon have largely taken place in the areas of the floodplain estuaries (Tourinho et al., 2009; Norgaard, 2019).

To this day, these areas are used to extract natural resources such as cocoa (*Theobroma cacao* L.), andiroba (*Carapa guianensis* Aubl.), latex (*Hevea brasiliensis* Muell. Arg.) and açaí (*Euterpe oleracea* Mart.), as well as sawn wood from various tree species, such as macacaúba (*Platymiscium trinitatis* Benth.), virola (*Virola surinamensis* Warb.) and pau-mulato, *Calycophyllum spruceanum* Benth (Hiraoka, 1995; Tourinho et al., 2009). Currently, agricultural experiments have confirmed the possibility of productive plantations of cultivars such as açaí, rice and andiroba due to their adaptations to floodplain environments (Da Fontoura Júnior et al., 2020; Brito et al., 2020; Rodrigues e Medeiros, 2023). However, despite the viability of production, floodplain areas are rarely used for large-scale production. Many factors favor this scenario, such as the distance from production areas to consumer centers, the low inclusion of Amazonian food in national and global markets, and especially the lack of research that enables an understanding of the geochemical processes present in floodplain soils, as well as their proper management (Silva et al., 2023).

The Guamá alluvial plains, located in the Amazon region, are characterized by the predominant presence of Haplic Gleysols and, due to their dynamic processes, the chemical and physical characteristics of these soils are constantly changing. These changes promote the presence of greyish tones due to the reduction and solubilization of iron (Embrapa, 2018). Factors such as the low topography of floodplain rivers and seasonality interfere in the formation of soils of sedimentary origin, whose exposure is related to processes associated with the water cycle, such as removal, transportation and deposition (Silva et al., 2017). These effects, combined with the influence of the tide, contribute to changes in the fertility of the soil (Pereira, 2014). The fertility of floodplain soils is very high due to their origin from solid particles suspended in Amazonian rivers, with high cation exchange capacity and potassium release from montmorillonite and illite. The minerals of pre-Andean and Andean origin are deposited in layers of a few millimeters between the annual floods (Junk et al., 2011; Junk et al., 2020). These soils contrast considerably with those of the region's terra firme environments, which have low fertility. Lopes et al. (2006), however, found that although the soils of the Guamá floodplain offer excellent conditions for the production of a variety of crops, agriculture leads to a reduction in the concentrations of available elements, such as phosphorus and potassium, indicating the need for proper management and the replacement of nutrients removed by plantations. Low-altitude soils are permanently waterlogged and, as a result, have a horizon in which the products of redox reactions predominate over those of reduction. The characteristics of these soils are considerably altered when they contain water or are completely flooded (Ponnamperuma, 1972).

The main changes in wetlands that are flooded trigger changes in the physicochemical and biological properties of soils. The main transformations are: an increase in pH due to redox reactions, an increase in the concentrations of Mn^{2+} and Fe^{2+}, the reduction of S from sulphates to S^{4+}, the chemical reduction of nitrates and the accumulation of NH4+, as well as the oxidation of organic material (Pezeshki & Delaune, 2012). Otero et al. (2009) concluded that the decomposition of OHFe and OHMn minerals, with the consequent reduction of Fe and Mn, is one of the most important reactions in Gleysols. When these minerals are present in these soils in large quantities, they are released into solution and also produce hydroxyls, which contribute to raising the pH to values close to seven. An increase in the levels of available phosphorus is commonly observed during these redox reactions, which may be related to the structure of these oxyhydroxides. This may also be the result of the hydrolysis of iron and aluminum phosphates (Camargo et al., 1999). The release of adsorbed phosphorus through anion exchange in clays or unstable

ISSN: 2179-4804
DOI: https://doi.org/10.20873/jbb.uft.cemaf.v13n1.18551

iron and aluminum hydroxides under these physicochemical conditions may also represent another source of available phosphorus.

The dynamics of the nutritional chemical elements of the Gleysols of the Guamá River floodplains under intense redox conditions was investigated by Silva et al. (1996), Ferreira et al. (1998), Ferreira & Botelho (1999), Mattar et al. (2002) and Silva (2008). These studies, collected over a short period of time, recorded anomalous patterns, such as the levels of zinc and sulphur, which were supposed to decrease but were available in the soil throughout the study period. However, these studies did not consider the mineralogical content of the soils and the suspended material present in the river water that floods this habitat and plays a crucial role in the mobility, fixation and desorption of chemical elements, whether they are nutrients or not. The objective of this study is to investigate the geochemical processes that occur in the surface horizon of the Haplic Gleysols of the Guamá River, in the Amazon estuary, as a result of the entry of flood waters and redox reactions.

MATERIAL AND METHODS

The study was based on the analysis of soil samples collected in floodplains and samples of suspended material in the waters of the Guamá River in May 2018, located in the rural area of the municipality of Belém within the campus of the Brazilian Agricultural Research Corporation (EMBRAPA). The region's climate, according to Koppen, is of the Afi type, characterized by high humidity, with annual temperatures ranging from 23°C to 33°C and an altitude of 12 metres, as well as high rainfall, around 2,754.4 mm per year, which is made up of a rainy season, from December to May, and a less rainy season, from June to November.

Soil samples were taken to characterize the soil profile, with samples taken from the A1, AB and Bg horizons, and for flooding experiments, in which the samples were soaked in distilled water to test their ability to absorb and desorb chemical elements. The samples for soil characterization were designated according to soil horizon, A1 (depth 0 to 18 cm), AB (18 to 70 cm) and Bg (70 to 120 cm). The experimental sample was compiled from several separate sub-samples, collected with a Dutch auger at depths of up to 20 cm, which correspond to the A1 horizon, the stratum from which plants normally extract their nutrients. A total of 63 samples were collected at random from an area of approximately 10,000 m² and were mixed and homogenized to form a composite experimental sample, called EXP-01, which represents the A1 horizon (Embrapa, 2009).

The soil profile was collected at a point 500 m from the right bank of the Guamá River (1º27'32.50"S, 48º25'33.89"W), 10 km from the mouth of the river, where it flows into Guajará Bay (Figure 1). The vegetation is characteristic of arboreal forest, with trees such as acapurana (Campsiandra laurifolia Benth.), ubim (Baconiferous geonoma K.), mamorana (Pachira aquatica Aubl.), ananim (Symphonia globulifera L.), palha (Clitoria arbores Benth.) and ucuúba (Virola sebifera Aubl.). A sample of suspended material from the Guamá, a river with white (muddy) water, was collected in front of the area where the soil samples were used. The single sample of 3,000 liters of water was used in a polyethylene container, which was stored for natural decantation, i.e., without the addition of chemicals for application. After decanting, the supernatant was removed and the remainder was decanted into a smaller container (5 L) and then centrifuged, with the supernatant being recovered once again. The solid residue was stored in a desiccator for 24 hours. This sample was called SUS-01. The three thousand liters of water yielded 45.2 g of solid material.

1) Particle size analysis of the EXP-01 sample by sieving and the EMBRAPA pipette method (2009) at the UFRA laboratories;

2) Fertility analysis, according to EMBRAPA (2009), of the three soil profile samples and the suspended material, in the UFRA laboratories;

3) Mineralogical analysis of the EXP-01 and SUS-01 samples by X-ray diffraction (XRD) in the X-ray laboratories of the UFPA Geosciences Institute. The analyses were applied to the entire sample, using the powder method, as well as the clay fraction method, using angled slides for better diagnosis of the clay minerals. The samples analyzed with angled slides were also glycolated and heated for additional XRD, following the classic procedure for determining clay minerals. The measurements were obtained using an X'Pert Data Collector diffractometer (version 2.1a) and processed using the X'Pert HighScore software (version 2.1b);

4) Total chemical analyses (major, minor and trace elements) were carried out on the surface and lower horizons of the profile by Acme Analytical Laboratories Ltd. in Vancouver, Canada, using ICP-OES and ICP-MS;

The experimental procedure was carried out at the Chemical Analysis Laboratory of the Geosciences Institute of the Federal University of Pará. The EXP-01 sample, weighing 28 kg, was divided into four equal parts, which were stored in seven-liter polystyrene containers. These containers were filled with distilled water until the samples were covered to a depth of 2 cm, and the water was topped up whenever necessary. Samples of the

ISSN: 2179-4804
DOI: https://doi.org/10.20873/jbb.uft.cemaf.v13n1.18551

flooded soil from all four replicates were collected at irregular intervals, ranging from 1 to 15 days, but concentrating on the first few days and starting on the first day of flooding, since the most pronounced chemical transformations tend to occur during the first few days (Ponnamperuma, 1972). A total of 100 samples were collected. Samples were taken daily for the first five days, then every two days for the rest of the first month, and then at increasingly longer intervals of up to 15 days for the remainder of the experiment. A separate sampling protocol was followed for the determination of organic carbon, with a sample being taken every 15 days over a period of 276 days. All other elements and parameters were monitored over a period of 132 days. The pH and Eh values were recorded using a potentiometer, while the available P concentrations were determined by spectrophotometry. The concentrations of exchangeable Ca, K, Zn, Mn, Cu and Fe were determined by atomic absorption, while organic carbon was measured using the Walkley-Black method (EMBRAPA, 1997). The analyses were carried out at UFPA's Geosciences Institute. As the transformations are reversible, the samples were not dried, but the results were converted so that they could be interpreted in dry soil determinations, as usual. To convert the results, a sample of equal volume was taken from each replicate sample. One was kept moist, weighed and analyzed, while the other was dried in an oven at 105°C, weighed and stored in a desiccator for 24 hours. The ratio between the dry and wet samples was used to convert the results obtained to the wet sample, as usual, following the recommendations of Silva et al. (1996), Ferreira et al. (1998), Ferreira & Botelho (1999), Mattar et al. (2002) and Silva (2008).

The results were subjected to Analysis of Variance (ANOVA) using the coputational software SISVAR (Ferreira, 2019). They were compared using Tukey's test, presented in Scatter Diagrams, and Pearson's Correlation Coefficient. Phosphorus results were correlated with Ca, Fe and Mn

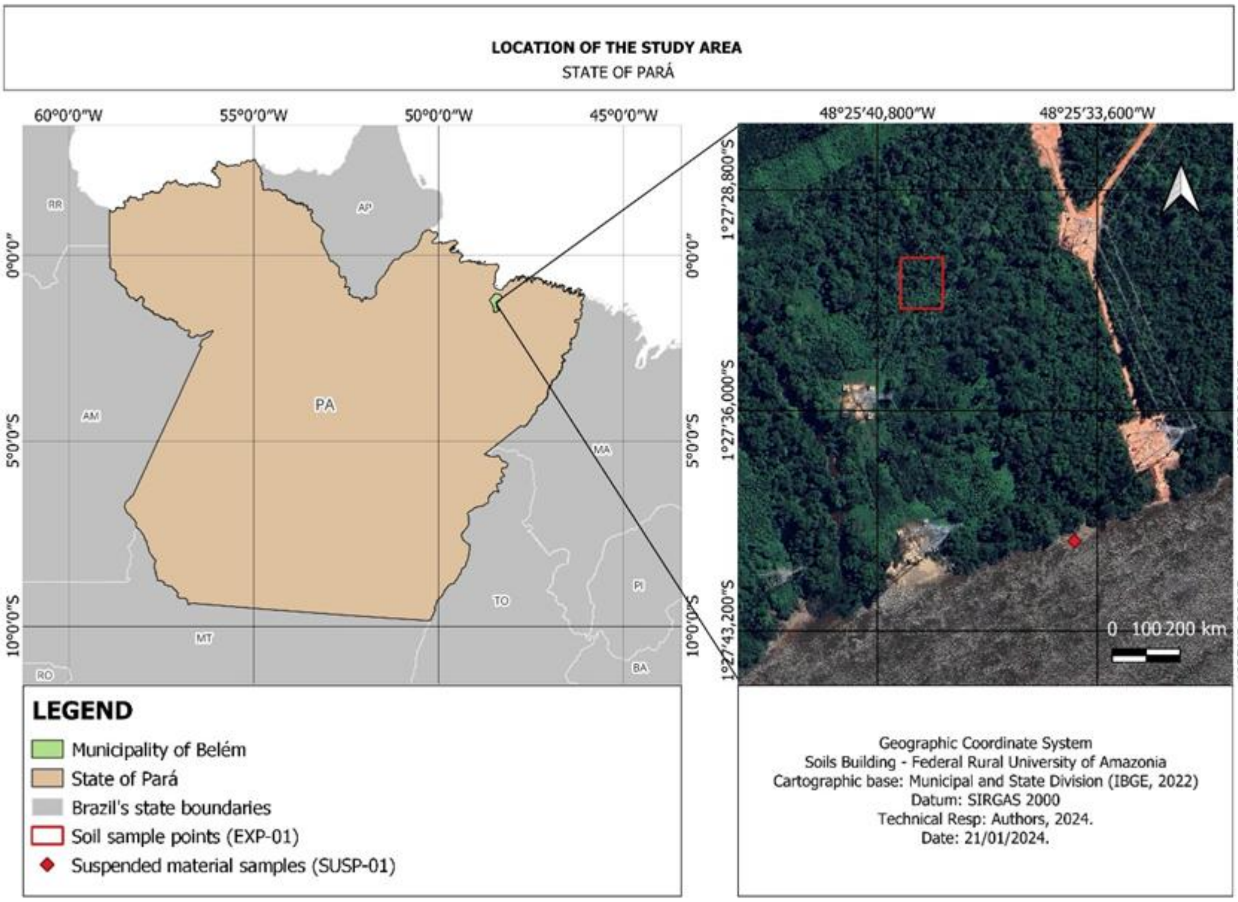

Figure 1 - Location of the study area in the floodplain of the Guamá River, in the rural area of the municipality of Belém, showing the collection points for the soil sample, EXP-01 (1º27'32.50"S, 48º25'33.89"W) and the suspended material sample, SUSP-01 (1º27'42.02"S, 48º25'32.35"W)

ISSN: 2179-4804
DOI: https://doi.org/10.20873/jbb.uft.cemaf.v13n1.18551

RESULTS AND DISCUSSION

Mineralogical and granulometric characteristics and fertility

According to the XRD analyses, the Gleysols of sample EXP-01 is composed of quartz, kaolinite, illite, smectite, goethite and anatase (Figure 2), in decreasing order of relative abundance. The composition of the suspended material is similar to that of the soil, except for the absence of goethite and anatase (Figure 3). Minerals such as quartz, kaolinite and goethite are also the main components of dryland soils in the area adjacent to the study area. The dryland soils may therefore have been the origin of these minerals in the floodplain, although illite and smectite, which are not found in the Amazonian dryland, must have been derived from the Guamá water or from neoformation. The presence of smectite in particular, but also illite, is of great importance, given the ability of these minerals to retain cations in the soil. These minerals are relatively rare in most terra firme soils in tropical Amazonia. The presence of smectite indicates environments with poorly drained soils, while the presence of kaolinite is characteristic of well-developed and leached soils, i.e. dryland soils, which are associated with tropical environments (Guyot et al., 2007).

Other studies on Amazonian soils have also mentioned the predominance of kaolinite in the clay fraction (Garcia et al., 2013; Barbosa, 2017). The predominant presence of kaolinite is the result of long periods of chemical and physical weathering, which makes it abundant and stable in Amazonian soils (Marques et al., 2010).

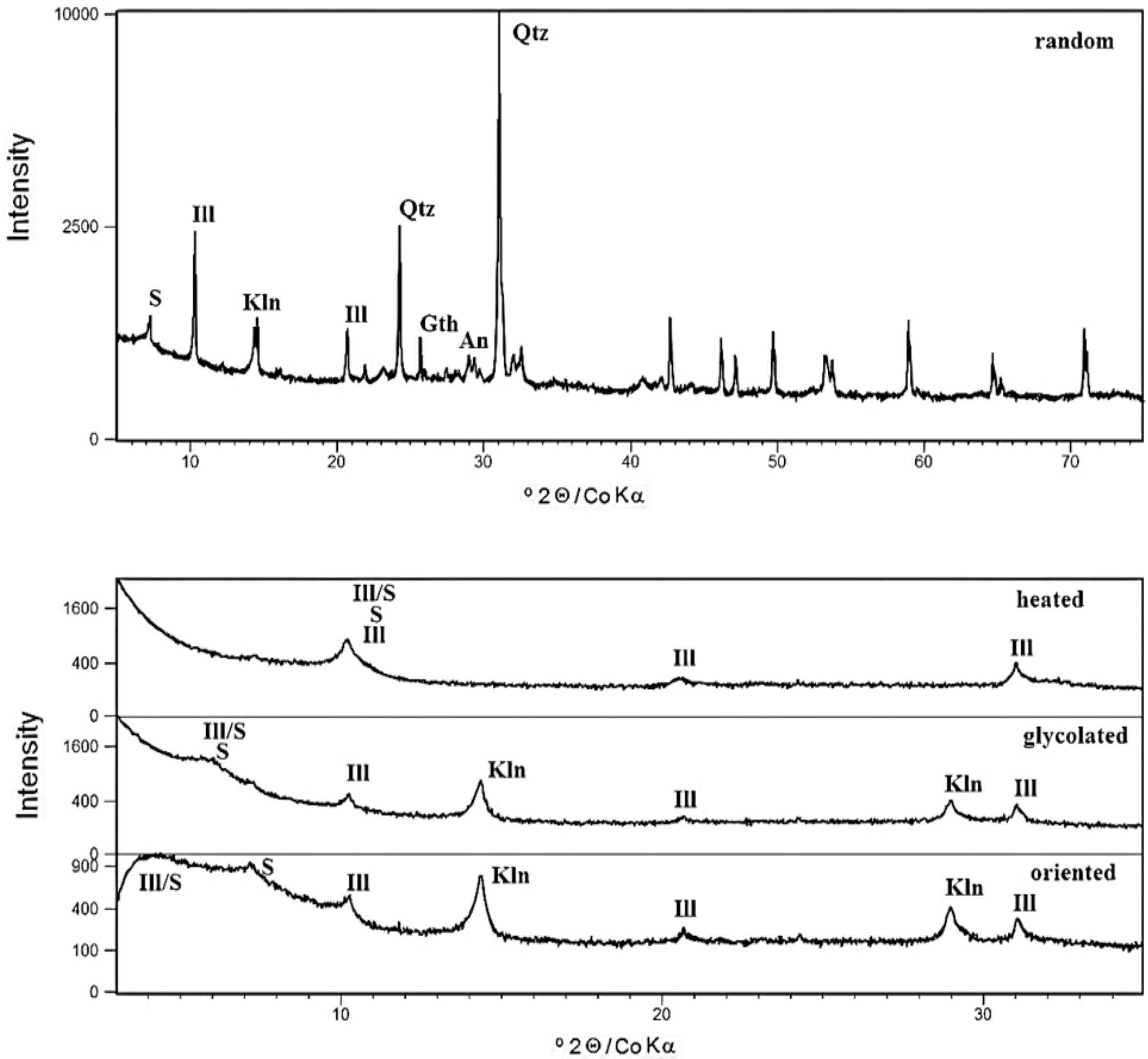

Figure 2 - Minerals identified by the XRD powder method for the consolidated sample EXP-01. Quartz (Qtz), kaolinite (kln), smectite (S), illite (ill), goethite (gth), and anatase (an)

ISSN: 2179-4804
DOI: https://doi.org/10.20873/jbb.uft.cemaf.v13n1.18551

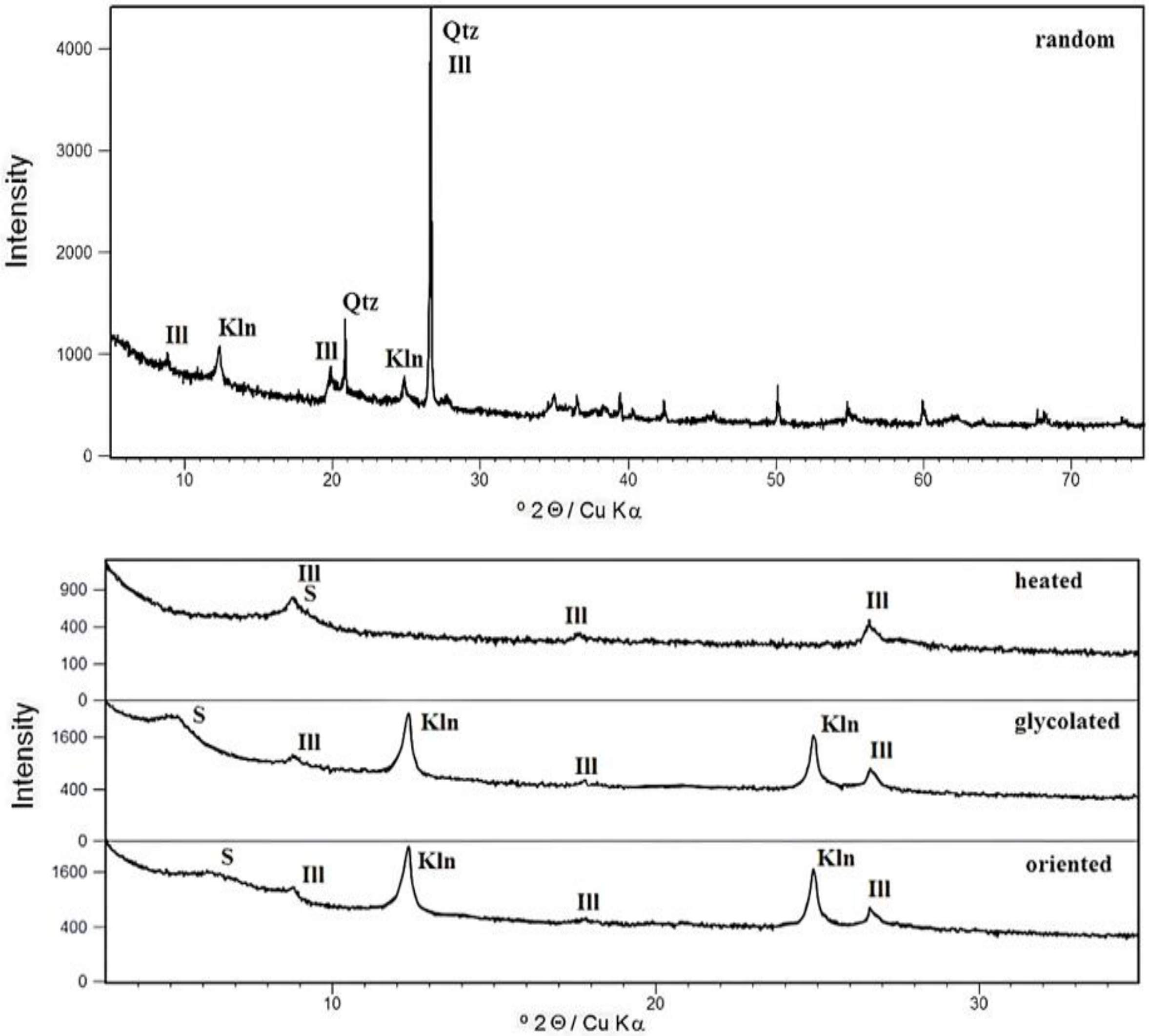

Figure 3 - Minerals identified by the XRD powder method and blades angled for the clay fraction for the suspended material (sample SUSP-01). Quartz (Qtz), kaolinite (kln), smectite (S), illite (ill), goethite (gth), and anatase (an).

The soil profile is typical of a Gleysol (Table 1), with average fertility increasing from the A1 to the Bg horizon. The pH is acidic, and the ΔpH indicates the predominance of negative charges throughout the horizon, which is characteristic of a Gleissolo Háplico. The cation exchange capacity (CEC) has relatively high values, and the granulometric analysis showed a soil with a slightly sandy texture (Dos Santos et al., 2018; Dal Cortivo, 2023). Organic carbon and other organic materials are relatively abundant, especially in the Bg horizon, which further emphasizes the Gleissolo configuration. Base saturation ≤ 50% indicates the presence of other ions occupying space in the exchange complex, such as aluminum, with 28.67%, which would be considered a high value by Lopes & Guilherme (2004). During the dry season, there was no water in the surface horizons, which made the environment aerobic, with an acidic pH in the water, which increases the solubilization of aluminium (Table 1). For vegetables, the Gleissolo analyzed is characterized by low levels of calcium and potassium, but high concentrations of magnesium and aluminum, forming an effective CEC of 5.68 cmolc/dm3, which can be considered average, but close to the potential CEC of this soil (Table 1).

ISSN: 2179-4804
DOI: https://doi.org/10.20873/jbb.uft.cemaf.v13n1.18551

Table 1 - The pH values and concentrations of the elements and compounds relevant to soil fertility found in the soil samples and suspended material from the Guamá River

Sample	pH		C	M.O	P	Ca	Mg	K	SB	H	Al	T	V	M
	H_2O	KCl	g kg^{-1}		mg.dm^3	cmol$_c$ dm^3							%	
A_1	4.69	3.59	3.9	6.72	2.52	1.52	2.48	0.08	4.08	3.94	1.60	9.62	42.41	28.67
AB	5.26	3.58	1.17	2.02	0.20	1.52	4.38	0.05	5.95	2.45	2.35	10.75	53.34	28.31
B_g	4.74	3.51	7.79	13.43	0.30	1.62	7.24	0.09	8.95	2.40	1.88	13.23	67.64	17.35
Suspended material					20.84	3.30	0.72	0.155	7.37	2.59	0.26	10.57	69.77	7.64

* Sample A1 (equivalent to EXP-01) returned the following granulometric composition: coarse sand = 2.90 g/kg; fine sand = 28.00 g/kg; silt = 743.00 g/kg; clay = 226.30 g/kg.

Phosphorus concentrations were relatively low compared to the saline Gleissolos typical of the Amazon estuary (Vieira, 1966; Ferreira & Botelho, 1999). Iron was distributed regularly throughout the profile, but once again with lower concentrations than in saline Gleissols. Although aluminum is present in the soil analyzed, it is not available as an exchangeable ion and therefore does not affect alkaline saturation. Similarly, potassium concentrations are low at the surface and in the lower horizons, indicating a reduced participation in the CEC of this soil.

Availability of chemicals during prolonged inundation

The experiment showed that flooding the Gleissolo (represented by the A1 horizon) with distilled water caused highly significant changes in all the parameters analyzed (Table 2). The pH, which was initially 4.6, gradually increased until the 15th day of flooding, when it stabilized at around 6.5 to 6.7 (Table 3 and Figure 4-A). These values provide favorable conditions for maintaining soil fertility by acting on the availability of macro and micronutrients essential for plant growth and development, while at the same time precipitating aluminum. High acidity conditions can promote levels of Al and Mn that are considered toxic, coupled with a lack of availability of Ca, Mg, P and K (Meurer et al., 2012).

Table 2 - Mean values recorded per day during the inundation experiment (inundation of gleysol from soil horizon A1 with distilled water) for pH, Eh and the concentrations of available P, Ca, K, Zn, Cu, and Fe

FV	pH	Eh	P	Ca	K	Cu	Zn	Fe	Mn
Days	**	**	**	**	NS	**	**	**	**
d.f./Days	24	24	24	24	24	24	24	24	24
CV%	0.71	7.86	49.20	12.63	71.77	35.56	15.96	14.08	8.34

** $p < 0.01$.; CV. - Coefficient of Variation.

ISSN: 2179-4804
DOI: https://doi.org/10.20873/jbb.uft.cemaf.v13n1.18551

Table 3 - Mean values recorded per day during the inundation experiment (inundation of gleysol from soil horizon A1 with distilled water) for pH, Eh and the concentrations of available P, Ca, K, Zn, Cu, and Fe

Day	pH	Eh mV	P mg/dm³	Ca mg/dm³	K mg/dm³	Zn mg/dm³	Mn mg/dm³	Cu mg/dm³	Fe mg/dm³	Day	C mg/dm³
1	4.69	322	7.77	225.25	1.28	6.75	151.5	1.25	1048	1	3.89
2	4.78	193	8.91	395.25	1.11	11.25	227	3.75	1179.25	14	3.01
3	5.1	103	10.58	346	0.71	12	226.75	1	1479.75	30	2.56
4	5.52	-36	13.15	249.25	0.13	11.25	309.25	1	1787.25	38	2.75
5	5.74	-85	11.102	243.75	0.37	13.75	340.75	2	2799.5	60	1.99
8	6.05	-208	20.63	270.25	1.39	13.25	373.75	2	2628	81	2.33
10	6.22	-246	15.42	285	1.06	16	367	2	2886.25	97	2.18
12	6.37	-251	16.46	496.75	0.17	14.5	324.75	2	5330	115	2.04
15	6.5	-270	23.12	456.5	0.18	14.5	360	1.25	5806.25	133	2.19
17	6.53	-293	20.96	404	0.48	15.25	316.25	1.75	6203.25	170	1.97
19	6.56	-303	18.6	446.25	1.01	18	355.75	2.25	6952	187	2.37
23	6.59	-311	38.62	434.75	1.24	14.75	334.5	2.25	7165	202	0.03
25	6.6	-336	48.06	426	1.04	14	346	0.75	6690.25	221	0.65
31	6.71	-352	119.15	390	0.15	10	365	3.75	2539	276	0.68
38	6.65	-354	72.32	338.5	0.15	15.25	343.75	1.75	3887.75		
45	6.67	-358	75.3	352.5	0.16	24.25	331.75	1.25	8136.25		
52	6.68	-371	111.47	353.5	0.16	20	526	5	7919.5		
59	6.68	-337	48.92	355.75	0.41	16.5	321.25	2.25	7703.75		
66	6.67	-333	57.94	385.75	0.58	17	335	1.5	8615.25		
73	6.69	-324	61.97	389.75	0.15	13	366.25	1	10245.5		
90	6.66	-329	67.62	456.25	0.14	18.75	392.75	1.5	9655		
97	6.64	-334	48.66	419.5	0.21	18.75	376.25	1	6941.5		
118	6.68	-332	63.08	408.25	0.14	21.75	350.75	1.25	5950.25		
125	6.63	-330	68.14	414.5	0.14	17.25	332.25	1.75	6145.75		
132	6.63	-337	75.78	472.5	0.14	22.5	338.5	1	6663.75		

(132 days) and organic carbon (276 days).

In contrast to pH, Eh decreased immediately during the first 25 days, when it dropped from +322 to -336 mV to stabilize at around -350 mV from day 31 onwards (Table 3 and Figure 4-B). This indicates a large reduction in redox potential, which subsequently remains constant during flooding.

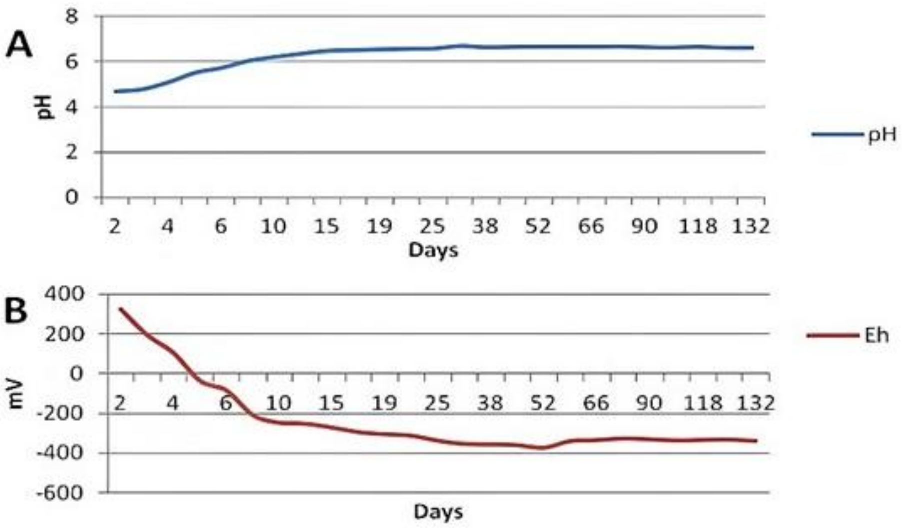

Figure 4 - Variation in mean pH (A) and Eh (B) values during the 132 days of inundation

ISSN: 2179-4804
DOI: https://doi.org/10.20873/jbb.uft.cemaf.v13n1.18551

Organic carbon, plotted at 132 days, was determined at 276 days, demonstrating its consumption. During the first 132 days, organic carbon levels followed a pattern of variation similar to that of Eh (Table 3 and Figure 5). During the first 38 days, organic carbon decreased from 3.89 g/dm³ to 2.56-2.75 g/dm³ and, from the 60th day onwards, it remained at around 2.00 g/dm³, decreasing abruptly after the 202nd day. These decreasing values indicate the intense oxidation of the organic material, as suggested by the Eh values, which are related to the presence of oxygen in the samples and dissolved in the water. The consistency of the values recorded over the course of the experiment indicates that the redox reactions ceased, as shown by the Eh values and, indirectly, by the pH levels, i.e. the environment was reducing over the experimental flooding period. On the 202nd day, however, a large additional consumption of organic carbon began, followed by considerable bacterial activity, represented by the slight increase in organic material.

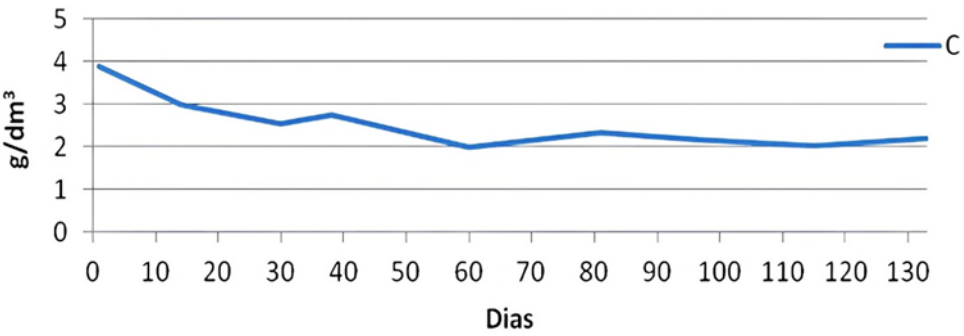

Figure 5 - Variation in mean organic carbon concentrations during the 132 days of inundation

Iron was among the most available elements in the samples, increasing irregularly until it reached 10,245.5 mg/dm3 on the 73rd day (Table 3 and Figure 6-A). In general, these changes seem to be related to changes in redox potential, although the distribution curve suggests that some of the dissolved iron is being immobilized in some of the time intervals as the experiment progresses, probably by being precipitated as ferrous minerals such as siderite or pyrite, which are expected to occur in these environments through diagenesis (Ferreira et al., 2007; Kristensen et al., 2008; Otero et al., 2009).

The values obtained for iron may represent toxic levels for some crops, such as rice, although native cultivars, such as açaí (Euterpe oleracea Mart.), bacaba (Oenocarpus bacaba Mart.) and buriti (Mauritia flexuosa L.), easily tolerate the levels recorded, which is confirmed by the exuberance of the floodplain forest in the study area. According to Junk (2020), floodplain soils have high iron concentrations. However, Lima et al. (2005) concluded that this was directly related to the higher levels of total iron in these horizons, possibly as destabilized and dissolved ferrous oxides and hydroxides, associated with an increase in phosphorus availability. However, Malepfane (2022) observed that the release is more intense in the topsoil, with a lower effect in subsequent horizons.

ISSN: 2179-4804
DOI: https://doi.org/10.20873/jbb.uft.cemaf.v13n1.18551

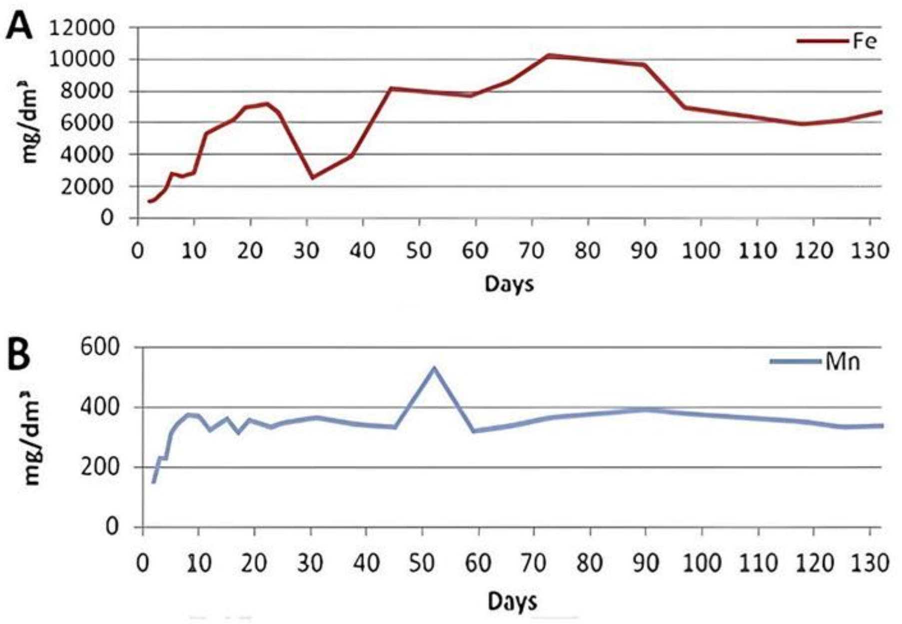

Figure 6 - Variation in the mean concentrations of available iron (A) and manganese (B) during the 132 days of inundation

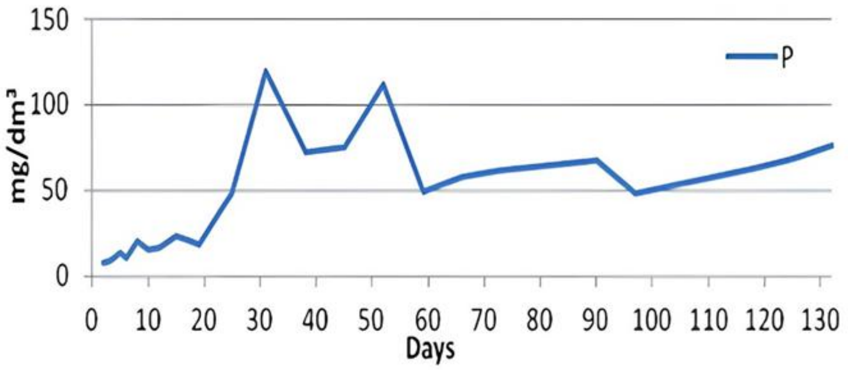

Figure 7 - Variation in the mean concentrations of available phosphorus during the 132 days of inundation

Available phosphorus also increased over time (Table 4 and Figure 7), although the highest values (119.15 and 111.47 mg/dm³) were recorded between the 31st and 52nd days, with a slight increase from the 118th day onwards. This pattern is directly related to the levels of available Fe (Table 3 and Figure 7-A), as would normally be expected, when phosphorus bound to OHFe minerals is released through its decomposition and the subsequent reduction of Fe, as well as available Mn and Ca, among other elements (Mello et al., 1992; Ferrando et al., 2002). A slight correlation can be observed with Mn.

Goethite, lepidocrocite and ferrihydrite (the most common forms of OHFe in soils), particularly goethite, which was identified in the Gleissolo, have a significant specific surface area as well as chemical reactivity for phosphorus adsorption and are therefore important for the release of this element under reductive conditions (Schwertmann & Taylor, 1989). The levels of available phosphorus in the soil, which were initially very low, reached relatively high values towards the end of the experiment. This increase occurs shortly after the oxidation of organic carbon, as indicated by the abrupt decline in levels of this carbon, from 389 mg/dm³ to around 200 mg/dm³ during the first few days (Table 3 and Figure 5), which results in the formation of carbon dioxide or bicarbonate ions, which contribute to the formation of carbonates, such as siderite-rhodochrosite or isolated siderite.

ISSN: 2179-4804
DOI: https://doi.org/10.20873/jbb.uft.cemaf.v13n1.18551

Table 4 - Pearson correlation coefficient (n = 40) for P, Ca, Mn, and Fe in the inundated gleysol

	Ca	Mn	Fe	P
Ca	1	0.2735**	0.6213**	0.3129**
Mn	O.2735**	1	0.5512**	0.6650**
Fe	0.6213**	0.5512**	1	0.7811**
P	0.3129**	0.6650**	0.7811**	1

Phosphorus release is influenced by seasonality, with the highest concentrations observed during the rainy season. Prolonged flooding provides conditions that are characterized by greater movement of materials in the watershed that contribute to the accumulation of organic matter and, consequently, to the elevation of soil carbon levels (Gomes et al., 2015; Hatje et al., 2017).

The high concentration of available phosphorus in Gleissolos can be attributed to the reductive condition characteristic of these soils. In this context, phosphorus is retained in the oxides present, and the dissolution of these oxides occurs in the reducing environment, thus releasing the previously retained phosphorus (Dal Cortivo, 2023).

In short periods, on the other hand, phosphorus release was associated with the mineralization of organic phosphorus, while total phosphorus was also present in significantly greater quantities after the soil dried out. Willet (1989) confirmed the organic and mineral contributions to the release of phosphorus in the soil and, in particular, the existence of conditions in some soils that allow part of this phosphorus to be reabsorbed, which may have occurred in the Gleissolo studied here.

Therefore, factors linked to the presence of organic material and the flood cycle are important for the release of this element, as well as the mineral constituents formed, which can reabsorb the phosphorus released. This was confirmed by Nguyen and Marschner (2005), who observed a relatively rapid increase in the availability of organic phosphorus, but a gradual increase in inorganic phosphorus in seasonally flooded systems, compared to constantly waterlogged or dry soils

ISSN: 2179-4804
DOI: https://doi.org/10.20873/jbb.uft.cemaf.v13n1.18551

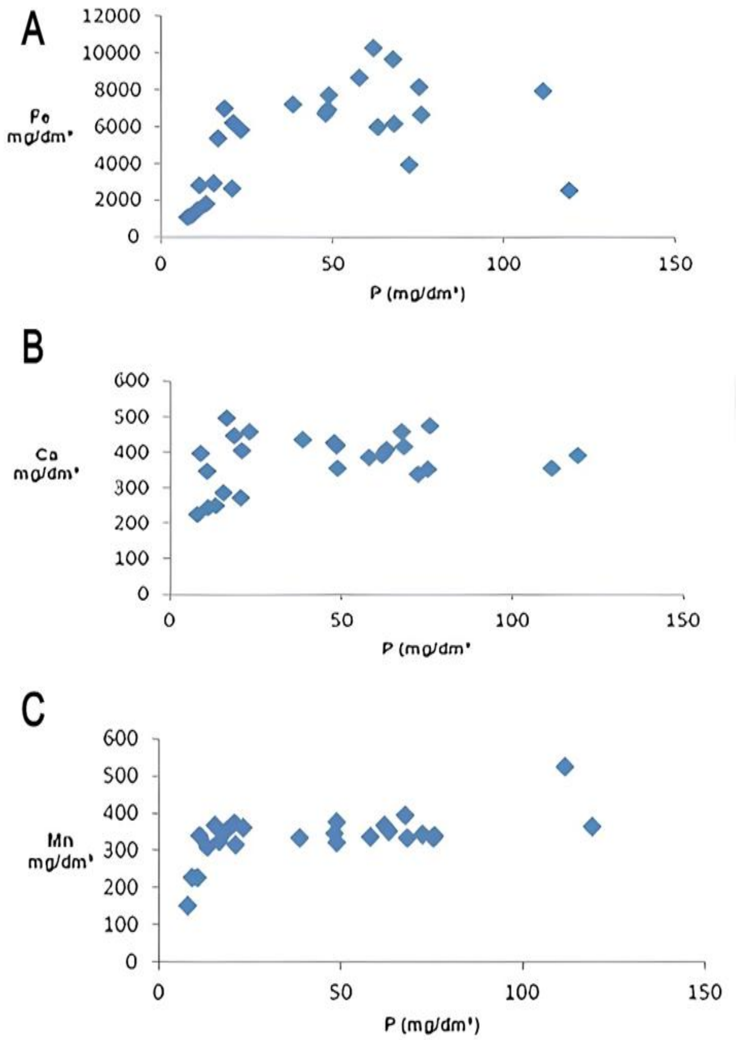

Figure 8 - Diagrams of linear dispersion for the correlations between P and Fe (A), P and Ca (B), P and Mn (C)

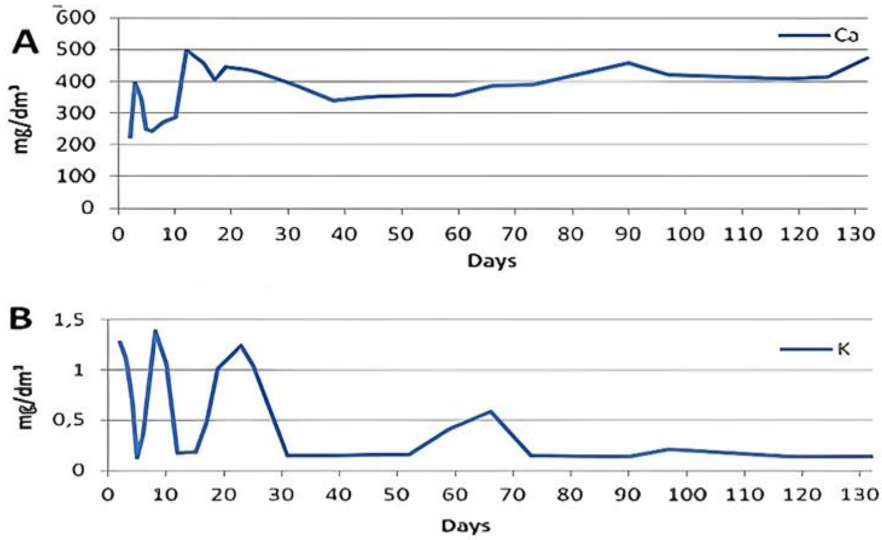

Figure 9 - Variation in the mean concentrations of available calcium (A) and potassium (B) during the 132-day flood period

ISSN: 2179-4804
DOI: https://doi.org/10.20873/jbb.uft.cemaf.v13n1.18551

Calcium and potassium are elements that undergo reduction processes in the soil and are present in reduced form.. They had low levels of availability throughout the soil profile, and low values predominated in the experiment. The change in concentration is due to the exchange of cations that occurs due to the production of excess Fe and Mn ions. Calcium increased considerably and irregularly during the first 12 days before reaching a plateau between 350 and 470 mg/dm³ (Table 3 and Figure 9-A), which are average values, although they tend to increase over time. The high variation in potassium meant that the results were not significant. Potassium showed a similar pattern to calcium, although with much lower values, reflecting its much lower levels in the soil, with considerable oscillation during the first 25 days, between 0.2 and 1.2 g/dm³, and then between 0.14 and 0.20 g/dm³ from the 31st day onwards, with the exception of the interval between the 59th and 66th days, when it increased to 0.50 g/dm³ (Table 3 and Figure 9-B), suggesting stability with a slight downward trend. These oscillations, particularly during the first 12 days, probably reflect the intense cation exchange that takes place between illite and smectite in the soil over a short period of time.

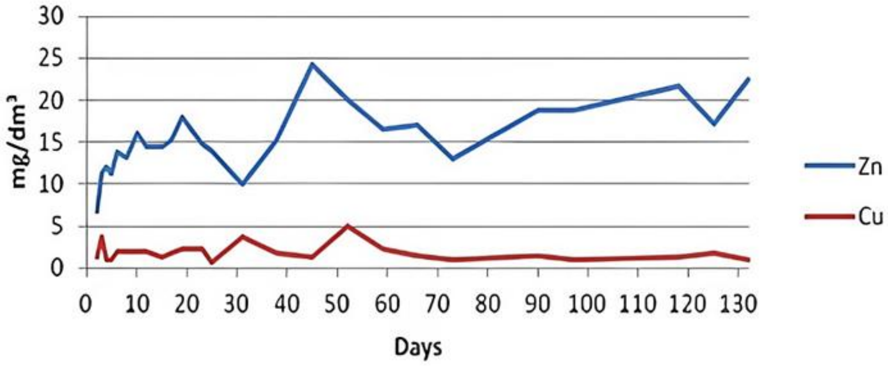

Figure 10 - Variations in the mean concentrations of available zinc and copper during the 132 days of inundation

Zinc solubilization also increased during the flooding of the Gleissolo, from 6.75 to 24.5 mg/dm³ up to the 45th day, with average values observed up to the 19th day and large fluctuations between 13.0 and 22.5 mg/dm³ (Table 3 and Figure 10), as observed for the other elements, with a tendency to increase over the course of the experiment, from the 70th day onwards. This pattern is opposite to that recorded by Ferreira et al. (1998), Sanches (1981), Ferreira & Botelho (1999), who found that zinc availability tended to decrease during long periods of flooding. However, the results of the short-term studies by Mattar et al. (2002) and Silva (2008) were consistent with those of the present study. Copper was relatively similar to zinc (Table 3 and Figure 10), but with much lower values, ranging from 1.25 to 5.00 mg/dm³, although the highest value was recorded on day 52, while levels fluctuated between 1.00 and 2.25 mg/dm³ throughout the rest of the experiment. The release of Zn and Cu was equivalent, at a ratio of four to one.

Raising the pH tends to decrease the availability of Zn and Cu. The availability of zinc and copper is more significant in a pH range between 5.0 and 6.5. Elements such as Zn and Cu are required in smaller quantities by plants, and in most soils the amount contained meets the need (Dias Dos Santos, 2021; Batista et al., 2018).

However, the pH values recorded in this experiment were not high enough to make these elements unavailable. Thus, the amounts of exchangeable zinc and copper in the exchange complex were adequate for plant growth until the end of the experiment.

CONCLUSIONS

The study carried out on the soils of the Guamá River floodplain confirmed the existence of favorable conditions for plant development and food production resulting from factors inherent to the environment in which it is found. High CTC and high carbon concentration were found in the Bg horizon and, as well as, an increase in the pH value with the consequent low saturation of aluminum equivalent to Haplic Gleysols.

Three conditions were demonstrated, existing in this environment that favors the existence of high fertility in this region of chemically impoverished soils.

1. The flooding experiment carried out demonstrates the beneficial effect that flooding has on the nutritional characteristics of the soil, especially in relation to macronutrients, with the exception of

ISSN: 2179-4804
DOI: https://doi.org/10.20873/jbb.uft.cemaf.v13n1.18551

potassium. While the levels of zinc and copper varied slightly during the experiment, they persisted in the soil exchange complex, maintaining satisfactory conditions for plant nutrition. The very high values found for iron and manganese reached levels that would be toxic for some cultivars, but have no visible effects on the local native vegetation. While the experiment demonstrated the consumption of carbon in the soil through redox reactions, in the natural environment, there is a constant renewal of this material through litter deposits, which promotes the accumulation of humidified organic material throughout the soil profile.
2. There is a daily flooding of the floodplain soil caused by the tide. This flooding is associated with the constant deposition of sediments, leading to soil formation. The study of this sediment that is suspended in the river water has shown that it also contributes to the maintenance of the soil fertility, as it has high fertility, with high CTC and high P.
3. The mineralogical determination in this soil and in the sediment suspended in the river water was also different from other soils in the Amazon. Among the minerals found, the presence of 2:1 clay minerals such as illite and smectite contribute to the high CTC results presented.

These conditions, of course, are related to the conditions of lowland soils, quite abundant in this region, contribute to the existence of soil that is easily vegetated, with the possibility of being used in food production.

ACKNOWLEDGMENTS

We are grateful to the Chemical Analyses and XRD laboratories of the UFPA Geosciences Institute, and the UFRA Soil Analysis Laboratory, and to their respective teams for their support during the experiment and analysis of samples. We also thank the graduate program in Geosciences for providing the material necessary for the analyses and UFRA for logistic support for the collection of the samples.

BIBLIOGRAPHICAL REFERENCES

Barbosa, T. M. B. Mineralogia e disponibilidade de fósforo em solos de terra firme da Amazônia Central. Tese (Doutorado em Agronomia Tropical). Universidade Federal do Amazonas, Manaus, 2017, 85p.

Batista, M.A., Inoue, T.T., Esper Neto, M., and Muniz, A.S. Princípios de fertilidade do solo, adubação e nutrição mineral. Hortaliças-fruto [online]. Maringá: EDUEM, 2018, pp. 113-162. ISBN: 978-65-86383-01-0.

Bertoni, J. C.; Holanda, F. S. R.; Carvalho, J. G. De; Paula, M. B. De; Assis, M. P. De 1999. Efeito Do Cobre Na Nutrição Do Arroz Irrigado Por Inundação - Teores E Acúmulo De Nutrientes. Ciênc. Agrotec., Lavras, V. 23, N.3, P. 547-550.

Brito, Aline Dias et al. Saberes e práticas tradicionais da extração do óleo de Carapa guianenses Abul.(andiroba) em área de várzea do município de Igarapé-Miri, PA. Revista Brasileira de Agroecologia, v. 15, n. 3, p. 13-13, 2020.

Camargo, F.A. de O., Santos, G. de A., Zonta, E., 1999. Alterações eletroquímicas em solos inundados. Ciência Rural 29, 171–180. https://doi.org/10.1590/S0103-84781999000100032

Da Fontoura Júnior, José Acélio Silveria et al. Simulação de diferentes arranjos de sistemas integrados em áreas de várzea. Brazilian Journal of Development, v. 6, n. 8, p. 63059-63077, 2020.

Dal Cortivo, Nelsi Santos; Júnior, Ismael Laurindo Costa; Pletsch, Adelmo Lowe. Parâmetros Físico-Químicos Em Diferentes Frações E Classes De Solos Florestais E Agrícolas, No Entorno Do Parque Nacional Do Iguaçu-PR. Geoambiente On-line, n. 47, 2023.

Dias Dos Santos, Fernanda et al. Fatores que afetam a disponibilidade de micronutrientes no solo. Tecno-Lógica, v. 25, n. 2, 2021.

Dos Santos, Gisele Barbosa et al. Gleissolo em ambiente de vereda no chapadão do urucuia, oeste da bahia/gleysol in vereda's environment at the chapadão do urucuia's plateau, western Bahia. Geographia Meridionalis, v. 4, n. 1, p. 44-56, 2018.

Embrapa, 2009. Manual De Análises Químicas De Solos, Plantas E Fertilizantes. Silva, F. C. Da (Editor Técnico). 2. Ed. Ver. Ampl. – Brasília, Df: Embrapa Informação Tecnológica, 627 P.

Embrapa. Centro Nacional de Pesquisa de Solos. Manual de Métodos de Análise de Solo. 2 ed. Rio de Janeiro: Embrapa Solos, 212 p., 1997.

Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA). (2018). Sistema Brasileiro de Classificação dos Solos.Ed.5, Brasília.

Ferrando, M., Mercado,G.; Hernandez, J. 2002. Dinámica Del Hierro E Do Fósforo Durante Período Cortos De Anaerobiosis In Los Suelos. Agrociencia. V. Vi, 1:1-9.

Ferreira, D. F. 2007 Sisvar: Sistema De Análise De Variância. Versão 5.0. Lavras: Ufla/Dex.

Ferreira, D. F. SISVAR: A Computer analysis system to fixed effects split plot type designs; Sisvar. Brazilian Journal of Biometrics, v. 37, n.4, p.529–535, 2019.

Ferreira, T. O.; Vidal-Torrado, P., Otero, X. L., Macias, F. 2007. Are Mangrove Forest Substrates Sediments Or Soil? A Case Study In Southeastern Brazil. Catena 70:79-91.

Ferreira, W. De A.; Botelho, S. M. 1999. Efeito Da Inundação Sobre As Propriedades De Um Gleissolo Sálico Sódico De Várzea Do Rio Dos Morcegos, No Município De Primavera, Pará. Belém: Embrapa Amazônia Orienta. Boletim de Pesquisa, 21. 24 P.

Ferreira, W. De A.; Modesto Júnior, M. De S.; Botelho, S. M.; Mascarenhas, R. E. B. 1998. Efeito Da Inundação Sobre As Propriedades De Um Glei Pouco Húmico De Vár-

ISSN: 2179-4804
DOI: https://doi.org/10.20873/jbb.uft.cemaf.v13n1.18551

zea do Rio Guamá, Nos Municípios De Belém E Santa Isabel, Pa. Belém: Embrapa-Cpapu, Boletim De Pesquisa, 207. 29 P.

Garcia, C. H. P.; Lima, H. N.; Silva, F. W. R.; Junior, N.; Ferreira, A.; Teixeira, W. G.; Macedo, R. S.; Tavares, S. G. Chemical properties and mineralogy of soils with plinthite and petroplinthite in Iranduba (AM), Brazil. Revista Brasileira de Ciência do Solo, Viçosa, v. 37, p. 936-946, 2013.

Gomes, Mariano et al. Atributos físicos e químicos do solo e uso das terras das ilhas do rio São Francisco. Caderno de Ciências Agrárias, v. 7, n. 1, p. 34-45, 2015.

Guyot, J. L,; Jouanneau, J. M.; Soares, L.; Boaventura, G. R.; Maillet, N.; Lagane, C. 2007. Clay Mineral Composition Of River Sediments In The Amazon Basin. Catena. 71:340-356.

Hatje, V., Pedreira, R.M.A., DE Rezende, C.E., Schettini, C.A.F., DE Souza, G.C., Marin, D.C., Hackspacher, P.C.. The environmental impacts of one of the largest tailing dam failures worldwide. Scientific reports, v. 7, n. 1, p. 10706, 2017.

Hiraoka, M. 1995. Land Use Changes In The Amazon Estuary. Global Environmental Change, (5) 4:323-333.

Junk W.J.; Piedade,,M.T.F.; Wittmann F.; Schongart J. 2020. Várzeas Amazônicas: Desafios para um Manejo Sustentável. - Manaus: Editora do INPA.

Junk, W. J. Condições físico-químicas dos solos na várzea da Amazônia Central. Desafios para um Manejo Sustentável, p. 77, 2020.

Junk, W. J. et al. Brazilian wetlands: Their definition, delineation, and classification for research, sustainable management, and protection. Aquatic Conservation: Marine and Freshwater Ecosystems, [s. l.], v. 24, n. 1, p. 5–22, 2014.

Junk, W.J.; Piedade, M.T.F.; Schöngart, J.; Cohn-Haft, M.; Adeney, J.M.; Wittmann. A classification of major naturally-occurring Amazonian lowland wetlands. Wetlands, v. 31, p. 623-640, 2011.

Kristensen, E.; Bouillon, S.; Dittmar, T.; Marchand, C. 2008. Organic Carbon Dynamics In Mangrove Ecosystems: A Review. Aquatic Botany 89:201-219.

Lima, H. N.; Mello, J. W. V. De; Schaefer, C. E. G. R.; Ker, J. C. 2005. Dinâmica Da Mobilização De Elementos Em Solos Da Amazônia Submetidos À Inundação. Acta Amazonica, V. 35(3), P. 317-330.

Lima, R. R.; Tourinho, M. M.; Costa, J. P. C. Da. 2001. Várzeas Flúvio-Marinhas Da Amazônia Brasileira: Características E Possibilidades Agropecuárias. Belém: Fcap. Serviço De Documentação E Informação, 342 P.

Lopes, E. L. N.; Fernandes, A. R.; Grimaldi, C.; Ruivo, M. De L. P.; Rodrigues, T. E.; Sarrazin, M. 2006. Características Químicas De Um Gleissolo Sob Diferentes Sistemas De Uso, Nas Margens Do Rio Guamá, Belém, Pará. Bol. Mus. Par. Emílo Goeldi. Belém, V. 1, 1:127-137.

Lopes; A. S.; Guilherme, L. R. G. 2004. Interpretação De Análise De Solo: Conceitos E Aplicações. Anda - Boletim Técnico, Nº 2. Edição Revisada. São Paulo. 50 P.

Malepfane, Ntwanano Moirah et al. Land use and site effects on the distribution of carbon in some humic soil profiles of KwaZulu-Natal, South Africa. Heliyon, v. 8, n. 1, 2022.

Marques, J. D. O.; Teixeira, W. G.; Reis, A. M.; Junior, O. F. C.; Batista, S. M.; Afonso, M. A. C. B. Atributos químicos, físico-hídricos e mineralogia da fração argila em solos do Baixo Amazonas: Serra de Parintins. Acta Amazonica, v. 40, p. 1-12, 2010.

Mattar, R. M. V. C.; Vieira, L. S.; Silva, G. R. 2002. Efeito Da Inundação Sobre O Ph E A Disponibilidade De Fósforo, Sódio, Ferro E Manganês Em Um Gley Pouco Húmico Coletado Na Várrzea Do Rio Guamá, Belém (Pa). Revista De Ciências Agrárias, N. 37, P.113-121.

Melo, J. W. V.; Fontes, M. P. F.; Ribeiro, A. C.; Alvarez, V. V. H. 1992. Inundação E Calagem Em Solos De Várzea: I. Alterações Em Ph, Eh, E Teores De Fe2+ E Mn2+ Em Solução. R. Bras. Ci. Solo. Campinas, V.16, P. 309-317.

Meurer, E. J. Fundamentos da química do solo. Ed. Porto Alegre: Evangraf, 5ªed. 280p. 2012.

Muner, L. H. D.; Ruiz, H. A.; Venegas, V. H.; Neves, J. C.; Freire, F. J.; Freire, M. B. D. S. Disponibilidade de zinco para milho em resposta à localização de fósforo no solo. Revista Brasileira de Engenharia Agrícola e Ambiental, v. 15, n. 1, p. 29-38, 2011.

Nguyen, B. T.; Marschner, P. 2005. Effect Of Drying And Rewetting On Phosphorus Transformations In Red Brown Soils With Different Soil Organic Matter Content. Soil Biology And Biochemistry. 37 1573-1576 P.

Norgaard, R. B. (2019). Significação do potencial para produzir arroz com irrigação controlada na várzea amazônica. Revista de Economia e Sociologia Rural, 19(2), 287-313.

Otero, X. L.; Ferreira, T. O., Huerta-Diaz, M. A., Partiti, C. S. M.; Souza J. R., V.; Vidal-Torrado, P.; Macias, F. 2009. Geochemistry Of Iron And Manganese In Soils And Sediments Of A Mangrove System, Island Of Pai Matos (Cananéia-Sp, Brazil). Geoderma, 148, P. 318-335.

Pereira, Denison da Silva. Dinâmica socioespacial em comunidades ribeirinhas das ilhas de Abaetetuba-PA. 2014. Tese de Doutorado. Dissertação (Mestrado). Universidade Federal do Pará, Instituto de Filosofia e Ciências Humanas, Programa de Pós-Graduação em Geografia Belém.

Pezeshki, S.R. & Delaune, R.D. Soil Oxidation-Reduction in Wetlands and Its Impact on Plant Functioning. Biology, v.1, p: 196-221. 2012.

Ponnamperuma, F. N. 1972. The Chemistry Of Submerged Soils. Advances In Agronomy, New York, N.24, P29-96.

Rodrigues, Renato dos Prazeres; Medeiros, Monique. Atividades socioprodutivas e tipologias de Unidades de Produção Familiar de camponeses-ribeirinhos em várzea do Baixo Tocantins. Revista de Economia e Sociologia Rural, v. 62, p. e264420, 2023.

Sanches, P. A. 1981. Suelos Del Tropico:Caracteristicas Y Manejo. San Jose, Costa Rica: Iica, P. 430-446.

Schwertmann, U.; Taylor, R. R. 1989. Iron Oxides. In: Dixon, J.B.; Weed, S.B. (Eds.) Mineral In Soils Environments. Madson, Soil Science Society Of America, P. 379-438.

ISSN: 2179-4804
DOI: https://doi.org/10.20873/jbb.uft.cemaf.v13n1.18551

Silva GJ, Neves SMAS, De Paula WCS, Da Silva VN (2017). Relação da cobertura vegetal e uso do solo com o ndvi e a temperatura superficial da área não inundável do pantanal de Cáceres/MT. Simpósio Brasileiro de Geografia Física Aplicada.v1i.

Silva, P. A. L. Da; 2008. Efeito Da Inundação Sobre O Enxofre E Outros Atributos Químicos De Um Gleissolo Háplico Da Várzea Do Rio Guamá, Belém-Pa. Dissertação Mestrado. Universidade Federal Rural Da Amazônia. 60p.

Silva, S. B. E. 2010. Belém E O Ambiente Insular. Belém: Universidade Federal Da Amazônia. 165 P.

Silva, S. B. E; Vieira, L. S.; Ferreira, W. De A. 1996. Avaliação Da Disponibilidade De Nutrientes Em Várzea Inundada Do Rio Guamá. Belém: Fcap. Serviço De Documentação E Informação. Fcap, Informe Técnico, 18. 18 P.

Silva, Sérgio Brazão et al. Interações geoquímicas na superfície de gleissolos no Estuário Amazônico. 2023. Tese (Doutorado em Geologia e Geoquímica) – Universidade Federal Rural da Amazônia.

Smanhotto, A.; Sousa, A. D. P.; Sampaio, S. C.; Nóbrega, L. H.; Prior, M. Cobre e zinco no material percolado e no solo com a aplicação de água residuária de suinocultura em solo cultivado com soja. Engenharia Agrícola, v. 30, n. 2, p. 347-357, 2010.

Tourinho, M. M.; Gama, J. R. V.; Bentes-Gama, M. De M.; Santos, S. R. M. Dos Várzeas Do Estuário Do Rio Amazonas: Características E Possibilidades Agronômicas. In: Gama, J. R. V.; Palha, M. Das D. C.; Santos, S. R. M. Dos (Organizadores) A Natureza E Os Ribeirinhos. . Belém: Universidade Federal Rural Da Amazônia. 2009. P. 269-293.

Vieira, L. S. 1966. Ocorrência E Formas De Fósforo Em Solos Da Amazônia, Brasil. Dissertação Mestrado. Costa Rica. Turrialba, Iica, Mg. Sci. T. 110 P.

Vilhena, M. Do P. S. P.; Costa, M. L. Da; Berredo, J. F. 2010. Continental And Marine Contributions To Formation Of Mangrove Sediments In Eastern Amazônia Mudplain: The Case Of Marapanim Estuary. Jornal Of South America Earth Science, Elsevier Ltd.. p. 427-438.

Willet, I. R. 1989, Causes And Prediction Of Changes In Extractable Phosphorus During Flooding. Aust. J. Soil Res. 27 45-54 P.

ISSN: 2179-4804
DOI: https://doi.org/10.20873/jbb.uft.cemaf.v13n1.18551