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Application of Humus obtained from the Anaerobic Decomposition of Aquatic Plants in the Soil Fertilization of Traditional Cultures of the Amazon

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Authors' contributions

All authors contributed to the study, analytical proceeds, and wrote the first draft of the manuscript. All authors read and approved the final manuscript.

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ABSTRACT

This research aimed to develop a technique for the humus production from anaerobic decomposition of aquatic plants to improve soil fertility in traditional communities in the floodplain Amazon.

Texture and grain size analysis, pH, total organic matter, organic carbon, nitrogen and phosphorous, Na^{+},K^{+},Ca^{2+} and Mg^{2+} in the soils and humus were determined, and the productivity of the humus in suspended gardens was determined. A diagnosis of the riverside communities was performed.

The results confirmed that the biomass produced by aquatic plants has high nutrients concentrations. The productivity of crop tested was 240 % when using a mixture of humus-soil 1:1, and with others ratios (½:1 and ¼:1) the results were also satisfactory.

This technique of fertilization may be a good alternative, cheep, sustainable and affordable for the traditional communities of the Amazon floodplain.

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1. INTRODUCTION

Traditional or riverside communities in the Amazon region practicing family agriculture use rather rudimentary but efficient techniques, which cause low impact on the region. Riverside communities cultivate vast areas of the rainforest, and the economy of this population is often sustainable [1]. The communities always live on the banks of the rivers, and their form of economic organization is correlated to agriculture, extraction of resources, animal husbandry and hunting.

In the floodplain areas the riverside communities live in accordance with the flood pulse of the large rivers, especially the Amazon River, whose muddy waters during periods of high waters inundates most of the agricultural land. For a period of up to four months, the houses in the floodplain are inundated with water and the communities survive on stocked food, fishing and small suspended gardens or 'Jirau', often installed on the windowsill of the kitchen, During this period, the communities' productivity decreases not only in quantity but in quality since the diversity of crops grown in the suspended gardens is much less than that grown on the floodplains. Generally lettuce, chive, parsley, coriander, green-onions, cilantro, peppers and chicory are grown in the small suspended gardens. Periods of flooding are important for the fertilization and nutrient replenishment of the floodplains. During the floods there is increased production and decomposition of organic matter and sediment deposition, resulting in the maintenance of the high diversity of plant and animal species [2].

In general, floodplain soils do not need the incorporation of fertilizers [3]. However, in suspended gardens designed for family agriculture, a humic biomass increment has shown a significant improvement in productivity [4]. Studies conducted by the authors [4] demonstrated that the biomass produced by the decomposition of aquatic plants has high concentrations of C, N and P, minerals, vitamins and hormones. The process of controlled decomposition allows the incorporating of these nutrients to the soil, and produces good results in the production of fruit, vegetables and ornamental plants. The use of an anaerobic decomposition technique has demonstrated extremely viable for traditional communities, since the decomposition boxes installed on the terraces of the houses during the high waters periods does not occupy space and do not exude an unpleasant smell. Furthermore, this technique is easy to use and very low-cost, which is important considering that these communities are financially needy.

The main objectives of this study were: 1) to develop a technique for the production of humus using anaerobic decomposition of aquatic plants to improve soil fertility in traditional communities in the Amazon; 2) to develop sustainable and agro-ecological alternatives for restoration of degraded soils of the riverside communities; 3) to improve the productivity of traditional communities.

2. MATERIALS AND METHODS

2.1 Study Area

For this study was undertaken in the region between the cities of Manaus and Coari (State of Amazonas, Brazil), in the Middle Amazon River (Fig. 1), as part of the project PIATAM - Potential Impacts of Oil and Gas Transportation in the Amazon, coordinated by Federal

University of Amazonas in partnership with several foundations and institutes, and financed by Petrobras-Petróleo Brasileiro S.A. It is a region formed by floodplains and uplands, with many lotic and lentic ecosystems of white, black and clear waters. In this diverse mosaic there are many traditional communities that use the waters of Amazon River and tributaries directly for consumption. Riverside communities are mostly maintained by fishing activity and subsistence agriculture (family agriculture). Especially in the floodplain, the texture of the soil is quite variable, with soils ranging from clay-silt to silty-sandy, predominantly eutrophic, with a high cation exchange capacity (CEC), and a predominant exchangeable calcium ion. The soils of the floodplain also have a highly variable mineralogical composition, reflecting the diversity and nature of a recent origin, periodical hydromorphic conditions and a low degree of pedogenesis.

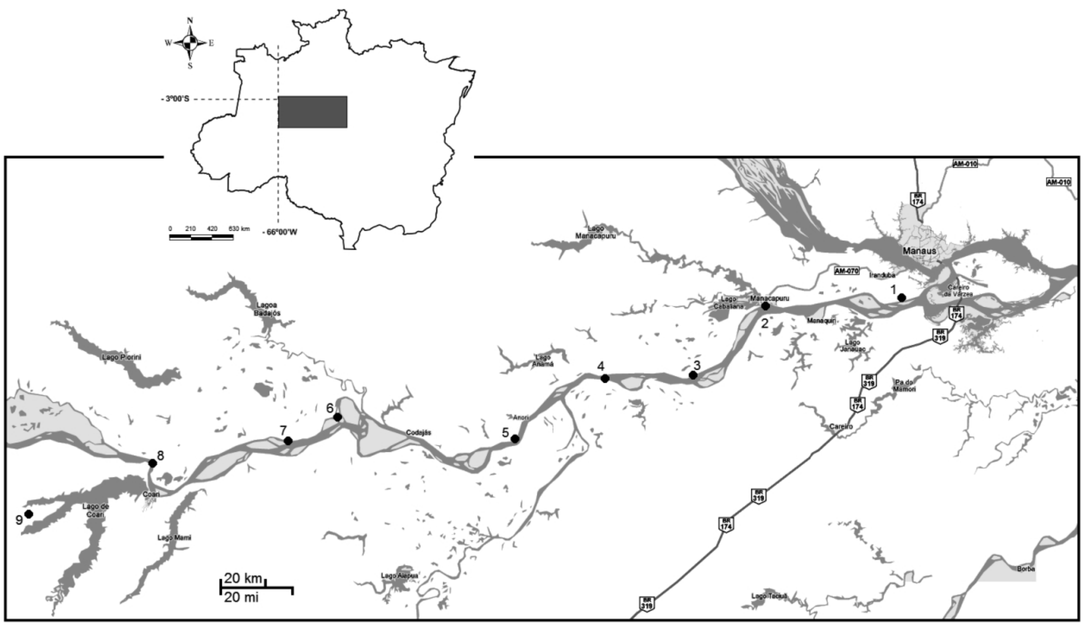

Fig. 1. Middle Amazon River with the location of the riverside communities where the program of humus production from aquatic plants was undertaken

In the study area, nine riverside communities were chosen for visits and capacity training and deployment of the boxes for anaerobic decomposition. The nine communities chosen were: 1) Sta. Luzia do Baixio, 2) Nossa Senhora das Graças, 3) Nossa Senhora de Nazaré, 4) Bom Jesus, 5) Sto. Antônio, 6) Matrinchã, 7) Lauro Sodré, 8) Esperança II and 9) Sta. Luzia do Buiçuzinho (Fig. 1). These communities were located at strategic points of the relief, usually in the high floodplain where there are lakes, which provides the families with fish. Most often, the buildings are built up on stilts, and the wooden floor can be moved above the maximum flood, during the high waters periods, as needed. In addition, the houses are usually built together on the highest shoal bordering the river. When the soil is not waterlogged, the planting areas are close to the houses. The plots are characterized by long and narrow strips of land, on areas of flooded forest, with little useful cultivation area.

2.2 Family Agriculture

The soil of the floodplain is fertile, however, the use of the land is limited due to the water level fluctuation of the rivers (Fig. 2A), which means that the communities have to produce as much as possible on these soils in a short period of time. Besides, the phenomenon of 'Fallen lands', which is the natural process of erosion of the banks of the Amazon River by the floodpulse, contributes annually according to [5] with significant loss of arable marginal lands. Therefore, it becomes more and more important to continue production of crops in suspended gardens (Fig. 2B) during the high waters periods.

Family agriculture in the Amazon floodplain region is predominantly based on an diversified agro-forestry system, which establish conditions and characterizes the form of production and consumption of goods by the traditional family units. This is an alternative system, facing the agro-ecological production with a sustainable management of the forest. This way of managing the land has a strong socioeconomic appeal, and according to [6], contributes to property and work and closely linked family ties.

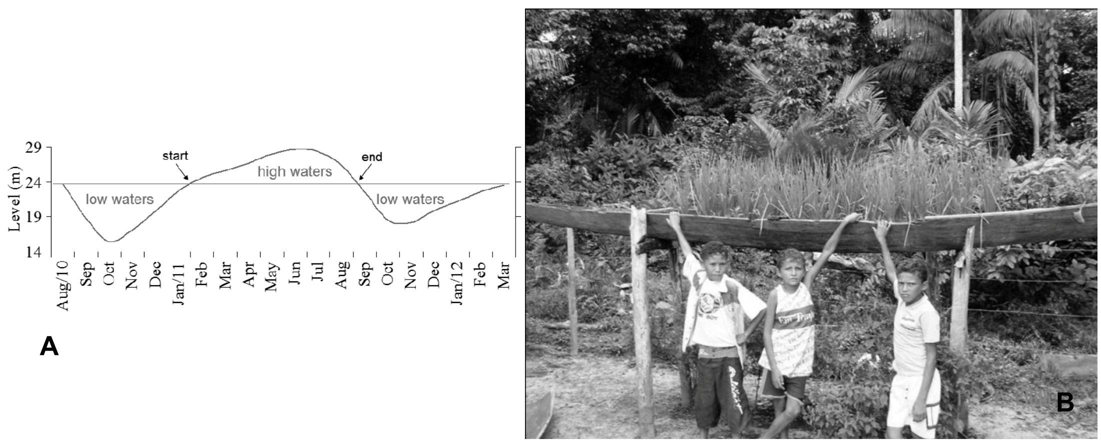

Fig. 2. A) Floodpulse in Middle Amazon River upstream Manaus city measured between August 2010 and March 2012, indicating the period of cultivation in suspended gardens (start and end); B) suspended garden at 1.6 m from ground level cultivated during the high water periods

2.3 Physical and Chemical Analysis of Soils and Plants

2.3.1 Sampling

In all nine riverside communities samples of 500g of soil (0.0 to 0.3m) and 1000g of aquatic plants for chemical analysis were collected. Sampling occurred at the beginning of the flood (October and November), before the flood waters of the Amazon River reached the areas. Soil was stored in plastic bags and refrigerated at -4ºC. The plants were washed with water from the river itself to remove insects and fishes, and were then partially dried and pressed. Aquatic plants were collected randomly, forming a consortium of *Eichhornia crassipes, Ludwigia natans, Pistia stratiotes, Utricularia foliosa, Azolla caroliniana* and *Ceratopteris pteridoides*.

2.3.2 Analytical proceeds

A brief description of the normal procedures will be done. In the chemistry lab, the soils and plants samples were dried at 45˚C for a period of 48 h, then homogenized, sieved and pulverized, and the very fine fraction (125–63 µm) was used to determine organic content, macronutrients and ion (Na^+,K^+,$Ca^{2+}$and Mg^{2+}) concentrations. Grain-size analysis was determined by the mechanical – gravimetric method using sodium hexametaphosphate solution. The sand fractions (2000vcs – 63vfs µm) were obtained by sieving with a water jet. The clay fraction (<4µm) was determined in a test tube via separation of suspended material [7], silt was determined by mass difference and the results expressed as percentage (%). pH was determined in the dried soil and plant samples by using H_2O and KCl solutions and specific probes [7]. Total organic matter (TOM) content was determined by hot acidic extraction, using 100g of sample with excess hydrogen peroxide (30%) on a heater plate at 100˚C, followed by drying in an incubator at 60˚C, with calculation of the weight difference before and after dry digestion. Total organic carbon (TOC) and total nitrogen (TN) were determined with the use of an LECO CNS-2000 analyzer model. After, a correlation between TOM and TOC was made for the soils and aquatic plants. The analysis followed protocols for sample preparation described by the EMBRAPA Manual of Soil Analyzes [7]. Total phosphorous (TP) in the soils and aquatic plants was determined by method of extraction of ascorbic acid with a spectrophotometer at 725ηm, according to the methodological adjustment developed by [8]. Concentrations of Na^+,K^+,Ca^{2+} and Mg^{2+} were measured by flame atomic absorption spectrophotometry according to Standard Method proceeds [9]. All the nutrients results were expressed as % and the ions as $cmol_c\ kg^{-1}$. The determination of the cation exchange capacity ($mmol_c\ kg^{-1}$ CEC) in the soils and aquatic plants was done by the method of adsorption of methylene blue ($C_{16}H_{18}N_3SCl.3H_2O$ - hydrochloride metiltiamina) on Millipore filter paper according to [10]. All analytical proceeds followed international protocols, and soil and vegetal material analyses were made at the Instituto Nacional de Pesquisas da Amazônia (INPA) laboratories.

2.3.3 Anaerobium decomposition and productivity test

For this study the humus production method by anaerobic decomposition of aquatic plants was adopted using 200 liter plastic boxes with lids, for easy handling and transportation (Fig. 3). The goal was to use a simple and rapid technique so that the communities could repeat the procedure several times in the absence of researchers. Approximately 50kg of fresh aquatic plant material was collected on the banks of the Amazon River close to the communities. Before storing the plants in boxes, the excess water was drained with a sieve. The vegetal material was then pressed into boxes and stored with a pestle, and at the end of the procedure the excess water was again removed from the boxes by tilting them. After, the boxes were sealed and labeled with the date and place of sampling, and allowed to rest for 120 days. Tests were made with 90, 120 and 160 days and the preliminary results showed that 120 days was the ideal time for a complete breakdown. After this period, the humus was spread on the dry floors of the houses to evaporate the excess moisture (Fig. 4). The humus was then crushed and mixed with the soil of the suspended gardens in a ratio of 1:1 (50%); ½:1 (25%); ¼:1 (12.5%) and 0:1 (0% humus-control). To the productivity test, was choose the specie *Allium fistulosum* L. (Liliaceae), an herb of fast crop, native to regions from Southern Europe and North Africa, usually named of chive, and generally commercialized in association with coriander and parsley. The suspended gardens productivity was determined by considering the chive biomass produced ($kg\ m^{-2}$) as a function of the humus/soil ratio used in each suspended garden.

Fig. 3. Model of the plastic boxes used in the anaerobic decomposition project in riverside communities

Fig. 4. Dried humus produced from aquatic plants of the Middle Amazon River

3. RESULTS AND DISCUSSION

In each community the general characteristics of the soils and the techniques used by the residents in the production and harvesting of annual crops were observed. A diagnosis was performed in the upland and floodplain communities, with direct monitoring of residents, and the following characteristics were identified:

a) Predominance of silt-clay and medium clay soils, with variation in nutrient and organic matter content;
b) Medium-low fertility of the soils interferes with the development of crops, especially annual crops in the low waters periods;
c) The continuous practice of clearing and burning of forests has caused soil erosion, contributing to low productivity of family agriculture;
d) In the floodplain the deforestation and burning in association to rains and action of river currents, during high waters, have accelerated the process of erosion of the river banks.

The results of the analyses of grain size and soil texture sampled in the nine riverside communities are shown in Table 1. In general, the soils are grouped in the Gleysoil class, which are typical soils of wetlands or periodically flooded areas as in Amazonian floodplains. The Gleysoil soils have varied coloration, alternating between tones of gray and blue, depending on the degree of hydromorphism. Fertility is also quite varied, but in the case of soils of the Amazon floodplain, these tend to be naturally fertile with high levels of ions resulting from river banks erosion, sediments transported from the Andes, and high load of vegetal material produced (litter). The major limitation of these soils is the low drainage capacity, which ensures a prolonged period of flooding in the Amazonian floodplain. The silt fractions predominated with percentages ranging between 65 and 72%, followed by clay fractions with percentages between 22 and 28%. These results are confirmed by studies developed by [11], who described floodplain soils to be typically with a high silt and fine sand content. Plinthosols Haplic were found in patches of soil near the communities in higher areas where the water of the Amazon River, even during the maximum flood, does not reach. Examples are the communities Sta. Luzia do Baixio, Nossa Senhora de Nazaré, Esperança II and Sta. Luzia do Buiçuzinho. These soils are also quite common in the Amazon region, especially bordering the river channels. Plinthosols are soils from floodplains generally used for extensive grazing, with a restricted drainage and varying in color from red to various shades of gray. In these soils the silt and clay fractions showed closer concentrations, with a texture ranging from silt-clay to medium clay.

Table 1. Texture and particle size of soils sampled from riverside communities of the Middle Amazon River

Community	Soil	Texture	Sand	Silt	Clay
				(%)	
Sta. Luzia do Baixio	FXd4	Medium clay	2	55	43
Nossa Sa. das Graças	GXve4	Franco clay-silt	8	65	27
Nossa Sa. de Nazaré	FXd1	Clay-silt	2	58	40
Bom Jesus	GXve4	Franco clay-silt	6	66	28
Sto. Antônio	GXve4	Franco clay-silt	5	68	27
Matrinchã	GXve4	Franco clay-silt	6	72	22
Lauro Sodré	GXve4	Franco clay-silt	5	70	25
Esperança II	FXd4	Medium clay	3	51	46
Sta. Luzia do Buiçuzinho	FXd13	Medium clay	3	52	45

Legend: FXd4=Plinthosol Haplic Dystrophic+Podzolic Red-Yellow Dystrophic; FXd1=Plinthosol Haplic Dystrophic; GXve4= Gleysoil Haplic Ta Eutrophic+Gleysoil Haplic Ta Dystrophic+Newsoil Fluvic Ta Eutrophic; FXd13= Plinthosol Haplic Dystrophic+Podzolic Red-Yellow Dystrophic+Planosol Haplic Distrophic.

The pH values in the soil ranged from 4.7 to 5.4 (H_2O) and 3.4 to 4.0 (KCl). In general, the periodically flooded soils showed a more acidic pH. This phenomenon can be due to the transport and deposition of sediments riche in nutrients and ions to the banks of the Amazon River, interfering with the decomposition rate that alters the pH of the soil. The floodplain comprises an area of diverse channels and deposits sites, where flows the Amazon River vary [12]. This complex system of channels, with anastomosis or meanders, allows a high sedimentation of nutrients from the highest regions (Andes), especially during the high waters periods, which facilitated by the vegetation cover, difficult the erosion process and favors fine sediments deposition [13]. It is during periods of high waters that the transport processes, leaching and deposition are intensified. Total organic matter (TOM) and total organic carbon (TOC) concentrations varied from 1.0 to 2.3% and from 0.5 to 1.3%. Studies of soils in the Middle and Upper Amazon River, including areas near riverside communities, confirmed that the floodplain soils have low levels of TOC, with values generally below 1% [3,14]. According to these authors, the levels of TOC are relatively low, even in soils with slow decomposition, such as the hydromorphic soils. Despite the low TOC values found, in general, a trend of higher concentration of nutrients in soils with a higher degree of hydromorphism was observed to the C, N and P. Gleysoils eutrophic (GXve) and plinthosoils (FXd) found in the study area are among soils with a lower organic matter content [15]. The carbon content in the soil depends on several factors such as temperature, pH, humidity, drainage capacity, aeration, texture and degree of leaching [16,17,18] and concentration of litter. Another factor influencing the concentration and residence time of carbon in soils, especially organic carbon, is the culture adopted in the region. There is a loss in the carbon content of 40% in the case of land use with crops, and a loss of 20% for land use with pastures [19]. The total nitrogen (TN) ranged from 0.1 to 0.3 % and the concentrations of total phosphorus (TP) ranged from 0.001 to 0.005 % (Table 2). The average ratio of proportionality between the macronutrients (C:N:P) was 308:70:1, while the average ratio of proportionality in the hydromorphic soils was 301:68:1.

Table 2. pH and average contents of TOM, TOC, TN and TP in surface soils (0.0-0.3 m) of the communities of the Middle Amazon River

Community	pH		TOM*	TOC	TN	TP
	H_2O	KCl	(% dw)			
Santa Luzia do Baixio	5.2	3.9	1.2	0.7	0.1	0.001
Nossa Sa. das Graças	4.7	3.5	1.9	1.1	0.3	0.003
Nossa Senhora de Nazaré	5.4	4.0	1.0	0.6	0.1	0.001
Bom Jesus	4.7	3.4	2.1	1.2	0.2	0.004
Sto. Antônio	4.8	3.5	1.9	1.1	0.3	0.004
Matrinchã	4.7	3.4	2.1	1.3	0.3	0.005
Lauro Sodré	4.8	3.5	2.3	1.3	0.3	0.004
Esperança II	5.2	3.9	1.1	0.6	0.2	0.002
Sta. Luzia do Buiçuzinho	5.3	4.0	1.1	0.5	0.1	0.002

**Pearson correlation between TOM and TOC values r= 0.9860*

In the floodplain, soils are predominantly eutrophic and with high CEC and high soil exchangeable, especially of calcium and magnesium ions, and in some cases sodium and aluminum [11,20]. Average ionic concentrations determined in this study varied little between the soils sampled, and the effect of landscape unit on the determined values was not observed. The sodium concentrations ranged from 0.22 to 0.39 $cmol_c\ kg^{-1}$ and were considerably larger than the values determined in other hydromorphic soils. The same behavior was recorded for magnesium, which showed concentrations ranging from 2.49 to 3.15 $cmol_c\ kg^{-1}$. Potassium and calcium ions showed higher concentrations in Plinthosols ranging from 0.19 to 0.26 and 7.73 to 8.44 $cmol_c\ kg^{-1}$, respectively (Table 3). The results obtained in this study are within the range of levels determined by [21] for floodplain soils under different land use systems in the Middle Amazon River. The authors obtained values between 6.8 and 12.2 for calcium, 1.4 and 5.9 for magnesium and between 0.15 and 1.24 $cmol_c\ kg^{-1}$ for potassium. The CEC of marginal soils in the Amazon River ranged from 21.36 to 23.41 $mmol_c\ kg^{-1}$, with an average 22.55+/- 0.54 $cmol_c\ kg^{-1}$.

According to the criteria established by [22], the ionic concentrations determined in the soils of the Amazonian communities were classified as low to intermediate. Aquatic plants, especially the plants with floating roots, are known for their high-capacity to absorb ions, incorporating them into their biomass. In this sense, care should be taken when using this material as raw material for production of humus, because these plants can be contaminated with trace elements or oil and grease from the water and land nearby, and as result can contaminate the humus and the vegetable production.

Table 3. Average ion concentration in surface soils (0.0-0.3 m) of the communities of the Middle Amazon River

Community	Na^+	K^+	Ca^{2+}	Mg^{2+}	CEC
		($cmol_c$ kg^{-1})			($mmol_c$ kg^{-1})
Sta. Luzia do Baixio	0.25	0.25	8.44	2.60	22.40
Nossa Sa. das Graças	0.33	0.21	7.87	2.83	22.45
Nossa Sa. de Nazaré	0.23	0.23	8.03	2.51	21.36
Bom Jesus	0.36	0.22	7.85	2.86	22.50
Sto. Antônio	0.33	0.20	7.95	2.77	22.53
Matrinchã	0.39	0.23	7.73	3.15	22.81
Lauro Sodré	0.38	0.19	7.92	3.11	22.92
Esperança II	0.24	0.26	8.41	2.66	23.41
Sta. Luzia do Buiçuzinho	0.22	0.23	7.89	2.49	21.99

Total carbon, nitrogen and phosphorus in humus of aquatic plants are presented in Table 4, and are expressed as percentage values of the dry mass (dw). The pH (H_2O) of the humus stabilized after 120 days of anaerobic decomposition was higher than the pH measured in marginal soils of the Amazon River. The pH of the humus varied between 5.84 and 6.02, with average of 5.93+/-0.05. Nutritional levels ranged from 15.7 to 40.3% for carbon; from 0.5 to 2.8% for nitrogen, and 0.1 to 0.4% for total phosphorus. The average ratio of proportionality of macronutrients C:N:P in the humus was 131:11:1, which is a ratio very close to the standard model of proportionality 100:10:1, indicating a better balance in nutrient concentrations. In percentage, the macronutrient values in aquatic plants were higher than the concentrations observed in marginal soils. Pearson correlations between total C, N and P concentrations (Table 4) were moderates, showing some independence of the results. The explication for this includes different soils and variation in the nutrients concentration in the consortium of plants.

Table 4. Minimum and maximum levels of nutrients (% dw) of humus from aquatic plants in the Middle Amazon River

Community	pH	TC		TN		TP	
	(H_2O)	Min	Max	Min	Max	Min	Max
Sta. Luzia do Baixio	5.89	18.3	21.6	1.0	1.6	0.18	0.21
Nossa Sa. das Graças	5.94	16.8	38.9	1.2	1.7	0.10	0.13
Nossa Sa. de Nazaré	6.02	15.7	18.7	1.1	1.9	0.12	0.19
Bom Jesus	5.89	21.5	32.0	1.6	2.1	0.21	0.27
Sto. Antônio	5.93	28.7	38.8	1.6	2.6	0.30	0.36
Matrinchã	5.84	27.7	40.3	2.6	2.8	0.20	0.23
Lauro Sodré	5.93	26.2	39.5	0.5	1.6	0.20	0.24
Esperança II	5.96	25.2	33.0	1.2	1.4	0.21	0.22
Sta. Luzia do Buiçuzinho	5.98	22.1	32.5	2.0	2.1	0.21	0.23

**Pearson correlation TC-TN values r=0.5254; TC-TP r=0.5360; and TN-TP r=0.4808.*

The results of ion analysis demonstrated a significant enrichment of the concentrations of K^+, Ca^{2+} and Mg^{2+} in aquatic plants, in particular K^+, in comparison with the average values found in the floodplain soils (Fig. 5). In the consortium of plants, K^+ varied between 398 and 575 with average 497 $cmol_c\ kg^{-1}$; Ca^{2+} ranged between 203 and 277 with average 236 $cmol_c\ kg^{-1}$; and Mg^{2+} ranged between 99 and 128 with average 114 $cmol_c\ kg^{-1}$. Taking into consideration in particular total N and K, the values found in the humus samples suggest that these elements have high potential for agricultural production in floodplain areas, and in particular for use in suspended gardens.

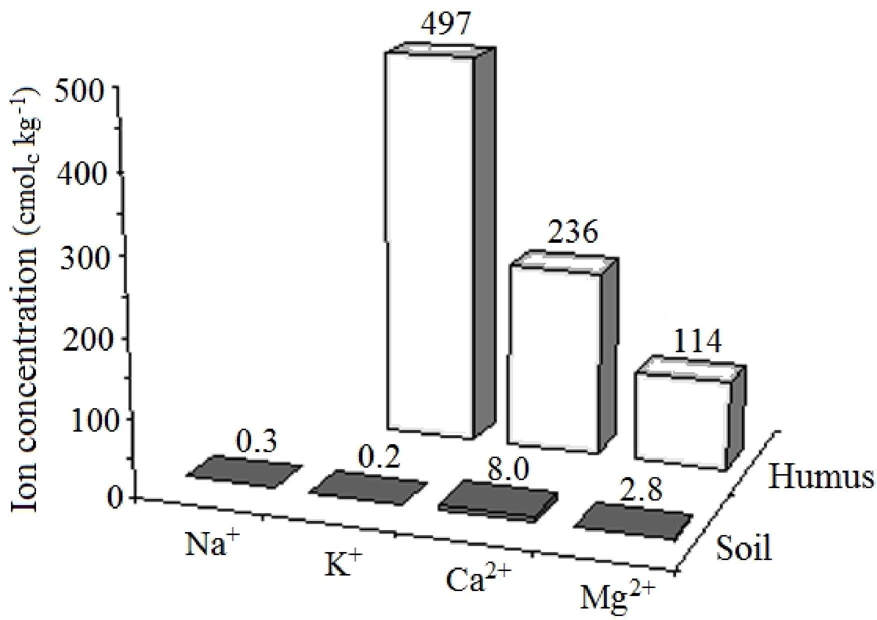

Fig. 5. Contrast between the average ionic concentration in soil and humus of aquatic plants in the Middle Amazon River

In recent decades the Amazon River floodplain occupation has intensified, especially with agricultural activities of short cycle crops (e.g., rice, corn, several varieties of beans etc.), and various vegetables. It is believed that this region of the floodplain will become an important future area of cultivation due to high soil fertility. From this perspective, studies on the floodplain productivity with agroecological concepts application should be encouraged.

The productivity results of the suspended gardens in the proportion humus/soil used show an enrichment of more than 240% to the mixture 1:1 of humus and soil. It was observed that the performance was also satisfactory in ratios ½:1 with increased productivity of 175 % and ¼:1 with increased productivity of 90% (Fig. 6). The results are optimistic and may represent a major ecological and economic alternative for family agriculture in the Amazon region, with the potential to be used with success in the activities of agriculture, horticulture and forestry.

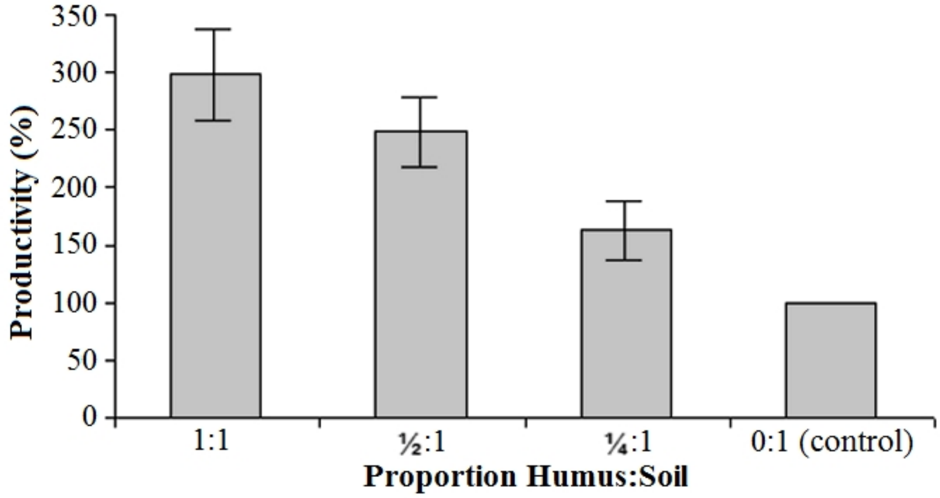

Fig. 6. Productivity of chive (*A. fistulosum* L.) using different ratios of humus from aquatic plants of the Middle Amazon River (gray bars = average with maximum and minimum values)

4. CONCLUSION

Studies have confirmed that the biomass produced by aquatic plants has high concentrations of C, N and P and ions K^+, $Ca^{2+}$and Mg^{2+}. The use of an anaerobic decomposition technique was well suited to the conditions of life of the populations, since the decomposition boxes installed on the rooftops of homes during the high waters periods did not occupy space, and did not exude an unpleasant smell to the residents. Furthermore, this technique is easy to use and has a very low-cost, and can be repeated several times by the residents. The productivity of the crops tested was 240 % when using a mixture of humus and soil 1:1. The other mixing results also showed satisfactory results in comparison to production control, showing that this technique of fertilization may be a good, sustainable and affordable alternative for the traditional communities of the region of the Amazon floodplain.

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