Aerobic and anaerobic decomposition of *Montrichardia arborescens* (L.) Schott.

BIANCHINI, I. JR.[1,2], PACOBAHYBA, L. D.[2] & CUNHA-SANTINO, M. B.[2]

[1] Departamento de Hidrobiologia, Universidade Federal de São Carlos. Via Washington Luiz, km 235. Cx. Postal 676. 13565-905. São Carlos, SP, Brasil. e-mail: irineu@power.ufscar.br

[2] Programa de Pós-Graduação em Ecologia e Recursos Naturais, Universidade Federal de São Carlos. Via Washington Luiz, km 235. Cx. Postal 676. 13565-905. São Carlos, SP, Brasil. e-mail: mbcunha@cosmo.com.br

ABSTRACT: Aerobic and anaerobic decomposition of *Montrichardia arborescens* (L.) Schott. This study is aimed at describing and comparing the kinetics of mineralization of *Montrichardia arborescens*. The samples of aquatic macrophyte and water were collected in the Cantá stream (02° 49' 11" N and 60° 40' 24" W), municipal district of Cantá, Roraima, Brazil. The plant material was oven-dried and triturated, and for each experimental condition (aerobic and anaerobic) 10 mineralization chambers were prepared with plant fragments and stream water. On sampling days the particulate (POM) and dissolved organic matter (DOM) were quantified. Additionally, two chambers were prepared with plant fragments and water to monitor the volume of produced gases in anaerobic mineralization. The results were fitted to first-order kinetics model. On average, POM comprised a labile/soluble ($POM_L \approx 30\%$) and a refractory fractions ($POM_R \approx 70\%$). The global decay rates (leachate/mineralization) of the labile/soluble POM of the anaerobic condition (1.34 day^{-1}) were 2.3 times higher than the aerobic ones. On the other hand, DOM mineralization rates for the aerobic process (0.0125 day^{-1}) were 3 times higher than the anaerobic one. For the oxidation of POM_R, the rates were similar ($\approx$ 0.0025 day^{-1}). For the anaerobic condition the formation of gases had three phases. Based on these results we conclude that during the decomposition of *M. arborescens* in the Cantá stream, the anaerobic process was faster in POM_L mineralization. On the other hand, the aerobic condition promotes a faster mineralization of DOM.

Key-words: aquatic macrophyte, detritus, decomposition, *Montrichardia arborescens*, Cantá stream.

RESUMO: Decomposição aeróbia e anaeróbia de *Montrichardia arborescens* (L.) Schott. Neste estudo objetivou-se descrever e comparar aspectos cinéticos da mineralização de *Montrichardia arborescens*. As amostras da macrófita aquática e de água foram coletadas no igarapé do Cantá (02° 49' 11" N e 60° 40' 24" W), município de Cantá, Roraima, Brasil. As plantas foram secas e trituradas e para cada condição experimental (aeróbia e anaeróbia) foram montadas 10 câmaras de decomposição contento fragmentos de plantas e água do igarapé. A cada dia de amostragem as frações particuladas (MOP) e dissolvidas (MOD) de matéria orgânica foram quantificadas. Adicionalmente, foram montadas duas câmaras para registrar, no caso da mineralização anaeróbia, os volumes de gases formados. Os resultados foram ajustados a um modelo cinético de 1ª ordem. Verificou-se que, em média, a MOP foi constituída por uma fração lábil/solúvel ($MOP_L \approx 30\%$) e uma refratária ($MOP_R \approx 70\%$). O coeficiente global de decaimento (lixiviação/mineralização) da MOP_L para a condição anaeróbia (1,34 dia^{-1}) foi 2,3 vezes maior que o da aeróbia. Em contrapartida, o coeficiente de mineralização da MOD do processo aeróbio (0,0125 dia^{-1}) foi 3 vezes mais elevado que o do anaeróbio. Para as oxidações da MOP_R, os coeficientes de oxidação apresentaram-se similares ($\approx$ 0,0025 dia^{-1}). Para a condição anaeróbia observou-se, ainda, que o processo de formação de gases se constituiu de três fases. Diante destes resultados inferiu-se que no igarapé do Cantá, durante a decomposi-

ção de *M. arborescens*, o processo anaeróbio é mais rápido no que se refere a mineralização da MOP_L. Por outro lado, a condição aeróbia deve promover uma mineralização mais rápida da MOD.

Palavras-chave: macrófitas aquáticas, detritos, decomposição, *Montrichardia arborescens*, igarapé do Cantá.

Introduction

The aquatic macrophytes represent an important ecological group among the plants growing in aquatic environments (Pieczynska, 1993; Rea et al., 1998; Rooney & Kalff, 2000). In general, aquatic macrophytes are Phanerogamae belonging to the group of vascular plants. However, it is usual to include species of macroalgae, Pteridophyta and Bryophyta among these hydrophytes. These plants differ themselves from terrestrial ones for their anatomical, physiologic and ecological particularities (Rizzini, 1976). Based on attachment and their position on the water surface, the aquatic macrophytes can be classified into three types: submergent (fixed on substrate or free-floating), emergent (rooted or free-floating) and freely floating. The primary production of the littoral zones is frequently attributed to these plants, which support the operation of trophic chains (Wetzel, 1992). Essentially, the dynamics of the detritus chain is due to decomposition, a process in which the resources are modified continually through mass losses and structural alterations. Thus, the particulate and dissolved detritus in the littoral zone may arise from senescence and death of aquatic plants and be responsible for up to 50% of the adduction of organic carbon in these systems (Godshalk & Wetzel, 1978; Wetzel, 1995; Cunha & Bianchini Jr., 1998). The organic matter is decomposed and mineralized through the metabolisms of several aquatic organisms (Zozaya & Neiff, 1991; Wetzel & Likens, 1991).

In the Amazonian area the aquatic macrophytes are found in large quantities and wide diversity (Rodrigues, 1989), which make them important for the energy and matter fluxes. Although several studies on decomposition of aquatic macrophytes exist in Brazil, only scant data can be found for the Amazonian area. This work is aimed at describing and discussing the kinetics of decomposition of an emergent aquatic macrophyte, *Montrichardia arborescens*, under laboratory conditions. The processes are modeled mathematically in an interactive procedure that associates aspects of natural systems with appropriate equations (Characklis, 1990). Here we exploit models dealing with decomposition of aquatic macrophytes, which consider abiotic variables from the environment, the chemical composition of the detritus and the metabolic routes used by heterotrophic microorganisms. In such models the velocity with which nutrients and carbon are cycled depends, basically, on the balance between the immobilization processes (assimilation) and mineralization (Swift et al., 1979).

Materials and Methods

Samples of water and plants (adults samples) were collected in the Cantá stream, municipal district of Cantá (02° 49' 11 " N and 60° 40' 24" W), State of Roraima, Brazil. The plants were washed within the stream; in laboratory, these plants were washed with tap water to remove the periphyton, sediment particles and coarse material. After being washed the plant material was oven-dried (45 °C) and triturated; the fragments of leaves, stems and stalks were homogeneized. In the laboratory 20 decomposition chambers were prepared; 10 were incubated under aerobic conditions with continuous air bubbling and 10 were incubated under anaerobic conditions. In each chamber 4.0 g (DW) of plant fragments were added to 400.0 ml of stream water that was previously filtered in glass wool. The flasks were maintained in the dark at a room temperature of 26.3 ± 0.3°C. Based on the kinetics of oxygen consumption described for this resource (Cunha-Santino et al., submitted) and on the maximum amount of available dissolved oxygen in each chamber (≈ 3.25 mg = $(OD)_{sat}$ × 0.4 l; where $(OD)_{sat}$ at 26.3 °C ≈ 8.11 $mg.L^{-1}$), the mixtures were considered to become anaerobic 2h after adding the plant fragments at the latest. The chambers used for investigation of anaerobic processes were maintained closed and were opened only on the respective sampling days.

On sampling days (1, 3, 5, 10, 15, 20, 30, 60, 90 and 120) the material of a flask for each condition studied was fractionated into particulate organic matter (POM) and dissolved (DOM) by pre-filtration and centrifugation (1 hour; 978 g). POM samples were oven-dried (45 °C) until constant weight, and their final masses were determined by gravimetry. Aliquots of DOM (250.0 ml) were dehydrated (45 °C) and their final masses were also determined by gravimetry (Wetzel & Likens, 1991). The consumed organic matter (COM) was calculated by the difference between the initial content of the plant fragments (TOM = total organic material » 4.0 g DW) and the remaining organic matter determined on the sampling days (POM + DOM).

In parallel, two chambers were prepared to monitor the formation of gases inherent in the anaerobic decomposition processes, according to the manometric method proposed by Sorokin & Kadota (1972). These incubations were prepared by the addition of 10.0 g (DW) of plant fragment in one liter of stream water. The chambers were maintained for 127 days at 25.7 ± 1.6 °C, in the dark and under anaerobic conditions. In these chambers, the temperature and the volumes of gases were recorded daily, with a mercury thermometer and a manometer of low pressure (coupled to the flasks). After each measurement the flasks were depressurized.

Results and Discussion

The temporal variations of POM, DOM and COM during the aerobic (1A) and anaerobic mineralization (1B) of *M. arborescens* are shown in Fig. 1. For the two

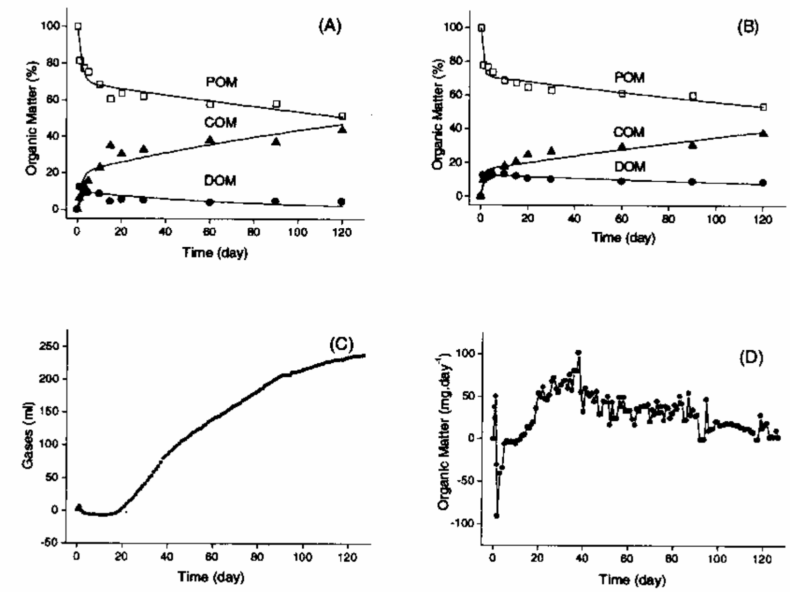

Figure 1: Temporal variations of POM, DOM and COM during aerobic (A) and anaerobic (B) decomposition processes of *Montrichardia arborescens*; accumulated gases volume (C) and daily rate variations of anaerobic mineralization of de *M. arborescens* (D).

experimental conditions, the mass loss recorded for POM indicates that the leachate is important for the degradation of this species of aquatic macrophyte. This process prevailed in the first days, being responsible for the intense mass loss and, consequently, for the chemical alterations of the detritus. These fast processes of mass loss are associated with the oxidation of labile compounds and with the solubilization of protoplasmatic fractions and hydrosoluble structural compounds (Canhoto & Grace, 1996). Based on the work by Wetzel (1995), it is suggested that the soluble compounds during this stage of decomposition are predominantly organic and inorganic substances that are highly susceptible to microbial metabolism.

It is assumed that the reactions involved in the *M. arborescens* mineralization are described by first-order kinetics (Bianchini Jr., 2000), which is represented by Equations 1 through 4.

$$IN_1 = \frac{k_M}{k_1} POM_L \left(1 - e^{k_1 t}\right) \quad \text{(Eq. 1)}$$

$$IN_2 = \frac{k_L}{k_1} POM_L \left(1 + \frac{k_2}{k_1 - k_2} e^{-k_1 t} + \frac{k_1}{k_2 - k_1} e^{-k_2 t}\right) \quad \text{(Eq. 2)}$$

$$IN_3 = POM_R \left(1 - e^{-k_3 t}\right) \quad \text{(Eq. 3)}$$

$$COM = \sum_{i=1}^{3} IN_i \quad \text{(Eq. 4)}$$

where:

POM_L	=	Labile/soluble particulate organic matter;
POM_R	=	Refractory particulate organic matter;
DOM	=	Dissolved organic matter; $DOM = \frac{k_L}{k_1} POM_L$
COM	=	Consumed organic matter (mineralized);
T	=	Time;
k_L	=	POM_L leachate coefficient from the soluble fractions;
k_M	=	POM_L mineralization coefficient;
k_1	=	POM_L global decay coefficient ($k_L + k_M$);
k_2	=	DOM mineralization coefficient;
k_3	=	POM_R mineralization coefficient;
$IN_{1\ a\ 3}$	=	Inorganic compounds produced from the three mineralization routes.

The mineralization of *M. arborescens* was then assumed to occur via three simultaneous processes. The first comprised two parallel events, viz. the leaching and the mineralization of labile compounds (IN_1). The second route includes leaching and mineràlization of DOM (IN_2). The third pathway contemplates the catabolism of refractory fractions in inorganic compounds (IN_3). The temporal variations of POM and DOM were used to determine the coefficients of the mathematical model, for which a method of non linear regression, the iterative algorithm of Levenberg-Marquardt, was used (Press et al., 1993).

The data in Fig. 1 were fitted to the kinetics model described above, from which parameters depicting the various processes were obtained. For the anaerobic condition, the fast process of mass loss (solubilization + oxidation of the labile compounds) involved about 30.2% of the detritus, while for the aerobic condition 28.3% were involved. The mass losses for the two experimental conditions have the same order of magnitude, because the main mechanisms involved, i.e. leaching and chemical oxidation, depend on the origin and quality of the detritus and not on biotic variables (microbial community) or abiotic variables (pH, temperature and dissolved oxygen). An accentuated mass loss was observed for the two experimental conditions until approximately the 15th day, after which the loss decreased. The rate of mass loss basically depends on the heterogeneity of the resources and define two possible routes for POM mineralization: one for the labile/soluble (POM_L) and another for the refractory (POM_R) fractions. The labile fraction of organic matter, IN_1 in Eq. 1, was 20.4% and 15.5% for the aerobic and anaerobic conditions, respectively. A compilation made by Bianchini Jr. (2000) including degradation studies of several types of detritus identified these resources as heterogeneous, with an average refractory fraction 2.8 times higher than the labile fraction. In this study the average of POM_R:POM_L ratio was 2.4.

The fittings to the kinetics model for POM mass loss had coefficients (r^2) of 0.93 and 0.95 for the aerobic and anaerobic conditions, respectively. For the formation and decay of DOM r^2 was 0.93 and 0.88 for the aerobic and anaerobic conditions.

The global coefficient of POM_L decay (leachate/mineralization, k_1) for the anaerobic condition (1.34 day^{-1} ± 0; $t_{1/2}$ = 0.5 day) was 2.3 times the value for the aerobic condition (0.59 day^{-1} ± 0.16; $t_{1/2}$ = 1.2 days). Even though k_1 is higher for the anaerobic condition, in practice the effects of these coefficients on the decomposition process of *M. arborescens* are almost the same because their half-times are of the order of hours/days, much shorter than the half-time of the resistant fractions, which is of the order of months/years. Also, these coefficients are related to the decomposition reactions that act in the smallest fraction of the detritus (≈ 30%). The content of refractory fraction (POM_R - Eq. 3) was 69.8% and 71.7% for the aerobic and anaerobic conditions, respectively. The mineralization coefficients of refractory fractions had the same order of magnitude: 0.0026 day^{-1} ± 0.0004 ($t_{1/2}$ = 263 days) for the aerobic condition and 0.0024 day^{-1} ± 0.0005 ($t_{1/2}$ = 288 days) for the anaerobic condition. These coefficients reflect the recalcitrant nature of the detritus, since this fraction is basically comprised by fibers: lignin and cellulose (Newell et al., 1995). The composition and density of the microorganisms community may also have influenced the velocity of mineralization of the refractory fractions. The mineralization coefficients (k_3) for POM_R suggest that regardless of the redox condition of the medium, the microorganisms involved presented similar potentials of heterotrophy, as indicated by the similar coefficients.

Due to the mass loss of POM_L, from the leachate and oxidation processes, formation of dissolved fractions of organic matter occurred. The maximum values determined for DOM indicate that small amounts of detritus of *M. arborescens* were solubilized. DOM corresponded to 9.8 and 12.8% for the aerobic and anaerobic conditions, respectively. The similarity of such values suggests that the composition of the detritus was the principal factor to define the solubilization potential (Fig. 1A and 1B). After the stage in which the appearance of leachate prevailed, the concentrations of dissolved organic compounds tended to decrease, regardless of the experimental condition. The decrease is basically due to chemical oxidation, mineralization (respiratory process) and immobilization (assimilation) of dissolved compounds. Gupta et al. (1996) and Best et al. (1996) also observed a similar pattern of decay of DOM for the decomposition of aquatic macrophytes.

As for the mineralization coefficients of DOM (k_2), the aerobic process was three times faster than the anaerobic one (0.00403 day^{-1} ± 0.002; $t_{1/2}$ = 172 day). These results agree with cycling studies of degradation of organic compounds (Best et al., 1990; Moore et al., 1992), in which aerobic processes were usually faster. Since aerobic oxidations release larger amounts of energy, the microorganisms involved in this process tend to present larger growth coefficients and number of cells (Davis & Cornwell, 1991). The smaller mineralization coefficients for DOM (k_2), compared to those for POM_L (k_1), were probably related to the quality of DOM. In this context, one has to consider the possible conversion of these dissolved compounds into humic substances that possess a refractory nature.

The evolutions of the mineralization of *M. arborescens* in Fig. 1 indicate, for both aerobic and anaerobic conditions, that up to ca. the 10th day COM increased considerably, and this increase had a lower rate later on. It is concluded that COM increases due to the oxidation processes of the labile fractions of DOM and POM, since these fractions generate in a short period of time the organic supplies for the respiratory processes. For the aerobic condition, COM is usually associated with formation of CO_2. In the anaerobic condition, in addition to CO_2, CH_4 may also have been formed, as observed in similar experiments by Bianchini et al. (1998) and Roura-Carol & Freeman (1999). Part of the detritus supported the formation of microorganism biomass, which in addition to its excretion products and re-synthesis products were mineralized. This contributes to the increase in COM. Here, such contributions were considered in the mineralization pathway of POM_R - IN_3.

Fig. 1C shows the accumulated volume of gases generated during the anaerobic process of degradation of *M. arborescens*. The time evolution of COM (Fig. 1B) was associated with the formed gases. Through this relation a methodological equivalence between the two experimental procedures could be established. The relation between the results of oxidation of the consumed organic matter and the formation of gases presented a high determination coefficient (r^2: 0.89). From the potential function the daily rates of mineralization of organic matter could be estimated in terms of mass (Fig. 1D). The equivalence between the two procedures to assess anaerobic mineralization became clear after the 20th day when the gases probably reached their saturation concentrations and the processes of gas formation supplanted the generation of dissolved inorganic compounds (e. g. carbonates).

Fig. 1D shows the anaerobic mineralization of *M. arborescens*, which had three phases. In the first, from the beginning to the 12th day, daily rates of gas formation oscillated strongly, including negative rates. This indicates that gas consumption through assimilation or solubilization prevails over gas formation via mineralization. The second phase, from the 13th until the 38th day, was characterized by intense release of gases with strong increases in daily rates. These higher rates probably are due to the mineralization of labile dissolved compounds, of the formation of CH_4, the denitrification, the formation of H_2S and the adaptation of the heterotrophic community. In the third stage, from the 39th to the 127th day, labile fractions are exhausted and the mineralization rates decrease, suggesting: i) a larger refratability of the remaining organic matter (lignocellulosic compounds and formation of humic substances); ii) the alteration in the microbial community; iii) a larger competition for the detritus by the processes of biological assimilation and iv) a smaller availability of the intermediary products, causing the rates of consumption of organic matter to decrease.

The results indicate that in the Cantá stream, the process of anaerobic decomposition of *M. arborescens* is more efficient with regard to mass loss of POM_L (leachate and oxidation of the labile organic matter). On the other hand, the aerobic condition promotes a faster mineralization of dissolved organic matter, contributing to cycling of the detritus of *M. arborescens* in this environment. It is still possible that in this system, the efficiency of mineralization of the particulate detritus is not affected due to the availability of dissolved oxygen.

Conclusions

From the analysis of the data, particularly using first-order kinetics model, several conclusions can be drawn: i) The detritus of *M. arborescens* is a heterogeneous substratum from the structural point of view (chemical composition of the detritus), presenting two fractions: a labile/soluble (POM_L » 30%) and a refractory one (POM_R » 70%); ii) In the aerobic process the global decay coefficient (oxidation/leachate) of POM_L (0.59 day^{-1}) was 224 times the mineralization coefficient of POM_R (0.0026 day^{-1}). In the anaerobic process these values corresponded to 1.34 day^{-1} (global decay coefficient) and 0.0024 day^{-1} (mineralization coefficient); iii) For both experimental conditions, POM_L generated DOM that was mineralized with half-time of 55 days for the aerobic and 167 days for the anaerobic condition; iv) For the *M. arborescens* detritus, both aerobic and anaerobic mineralizations were processed via three routes: oxidation of POM_L, of DOM and POM_R and v) For the anaerobic condition, the equivalence of the two experimental procedures, i.e. kinetics of mass loss and formation of gases, was more prominent in the late phase of the degradation process, after the 20^{th} day.

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