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Phosphorus release from decomposing water hyacinth and effects of decomposition on water quality

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Abstract

Bench scale experiments were done to assess the effects of decomposition of water hyacinth on phosphorus release and water quality. Hyacinth plants from the lake were chopped to fine pieces. In replicate incubation tubes, 50 g of plant material was stocked to which 1.6 L of lake water was added. One set was aerated while the other was sealed with rubber stoppers to exclude airflow. Soluble phosphorus, pH, conductivity, and dissolved oxygen were measured daily for one month. In non-aerated set-ups, highest increase in phosphorus concentration occurred between the third and fourth days, but with a plateau after Day 5, and a peak (2,871.4 ± 771.2 mg L^{-1}) on Day 10. In the aerated trials with hyacinth, highest increase occurred between the fifth and ninth day, with a peak (2,041.1 ± 1,050.2 mg L^{-1}) on Day 9. Highly significant differences were attributed to time and aeration, with hypoxic conditions enhancing phosphorus release than well aerated ones. Significantly lower dissolved oxygen (range: 0.3 to 0.9 mg L^{1}) was in the non-aerated than the aerated (range: 3.6 to 7.9 mg L^{1}) set. Similarly, significantly lower pH (range: 5.9 to 6.7) was in the non-aerated than the aerated (range: 7.0 to 7.8) set. There were no significant differences in conductivity between the non-aerated (range: 318 to 501 µS cm^{1}) and the aerated (159 to 552 µS cm^{-1}) trials. Decomposition of water hyacinth releases phosphorus, with highest occurring during the initial 4 days. Enhanced nutrient release occurred under hypoxic than well aerated conditions. Decomposition of hyacinth resulted in depressed dissolved oxygen and pH. Effects of hyacinth decomposition on aquatic biota, especially fish, are not known hence need to be investigated.

Key words: water hyacinth, decomposition, phosphorus release, water quality

Introduction

Decomposition of aquatic macrophytes can influence carbon cycling and energy flow in shallow, aquatic ecosystems considerably (Battle and Mihuc, 2000). The breakdown of organic matter releases inorganic components including nutrients that were chemically incorporated in plant tissues. A few investigations have demonstrated the importance of internal processes for nutrient cycling in tropical lakes through decomposition of aquatic macrophytes (Pieczynska, 1990).

Decomposition studies of aquatic macrophytes such as *Salvinia* sp. indicated that nutrient release was rapid during the initial 4 days and was attributed to physical leaching (Ogwada *et al.*, 1984; Sharma and Goel, 1986). This was followed by slow nutrient release attributed to microbial decomposition. Under laboratory conditions, Reddy and Sacco (1981) found higher rates of soluble phosphorus (SRP) release under anaerobic than aerobic conditions. They also found that after herbicide application that resulted in death of water hyacinth in a canal, there were higher concentrations of soluble nitrogen and phosphorus in the canal drainage water than before herbicide application.

The objective of this study was to assess phosphorus release rates from decomposing water hyacinth plant material under aerobic and hypoxic conditions and to monitor influences of decomposition products on water quality.

Materials and methods

Laboratory incubation

Water hyacinth plants with minimal weevil infestation were collected from Lake Victoria and used for assessing phosphorus release rates during decomposition. Plants were washed with tap water to remove attached debris, cut into small pieces (1 cm^2) using a stainless steel knife and mixed thoroughly. Sub samples of 50 g were weighed on an electronic balance (precision of 0.01 g) and put in triplicate sets of Plexiglas tubes (83 cm x 6.7 cm) containing 1.6 L of lake water. Howard and Howard (1978) used a plant to water ratio of 1 g plant material to 30 mL water for *Typha domingensis* when investigating nutrient release via decomposition. The plant to water ratio used during this study (1 g plant to 32 ml water) was considered comparable to that of other investigations.

Control tests employed the same set-up but without water hyacinth. Both experimental and control set-ups were incubated at room temperature. One set was aerated to simulate turbulence in the absence of extensive water hyacinth mats on the lake, while in the other, incubation tubes were sealed with rubber stoppers and adhesive tape to eliminate gaseous exchange. The latter arrangement simulated conditions when extensive mats of water hyacinth cover the lake surface and depressed dissolved oxygen conditions develop in the water column beneath plant mats.

Aeration was done using aquaria air pumps to which plastic tubes were attached and supplied air to the incubation tubes. Water loss due to evaporation was compensated for with distilled-deionized water after every sample event. Dissolved oxygen, pH, and electrical conductance were monitored using automated meters every 2 days just before taking water samples for nutrient analyses. This approach gives an indication of changes in water chemistry (Howard and Howard, 1978) during decomposition. At 2-day intervals, 50 mL of water were withdrawn from each tube using a 50 mL syringe fitted with a plastic tubing (87 cm long and 0.9 cm internal diameter) and analyzed immediately for soluble reactive phosphorus (SRP) following methods described in APHA (1989). The experiment was repeated two times, and each trial lasted 28 to 38 days. Phosphorus release rates were calculated from differences between SRP concentrations in the water column between successive sampling dates (Stephen et al.,1997; Holdren and Armstrong, 1980). Phosphorus release rates over time ("*P*/"*t*) were then calculated using Equation 1 adopted from Stephen et al. (1997).

Release Rates ($mgm^{-2}day^{-1}$) = $\left[C * H * 1000 * 24\right] \div i$

where C is change in phosphorus concentration ($mg\ L^{-1}$, i.e. concentration in overlying water at the end of incubation minus initial concentration); H is height of overlying water in meters; and *i* is incubation time in hours. Repeated Measures One-Way ANOVA was used to identify significant differences in physico-chemical parameters, and phosphorus release (Scheffe, 1953) through multiple comparisons of means. Data whose Mauchly's Test of Sphericity were significant ($P < 0.05$), were transformed using natural logarithm to homogenize variances.

Results

Physico-chemical parameters

Data for physico-chemical parameters in the water column are given in Figures 1-3. respectively. Significantly lower dissolved oxygen was in the non-aerated trials with hyacinth (range 0.3 to 0.9 $mg\ L^{-1}$), while the rest of the trials did not significantly differ (range 3.6 to 7.9 $mg\ L^{-1}$) from each other. Highly significant differences ($P < 0.01$) in dissolved oxygen (Figure 1) were due to time and aeration. Interactive effects between time and aeration were, however, not significant ($P > 0.05$) after data transformation (Table 1).

Highly significant time effects ($P < 0.01$, Table 1) resulted in low pH in non-aerated trials with hyacinth than in other trials (Figure 2), and interactive effects were as well significant ($P < 0.05$). Thus, pH was significantly lower in non-aerated trials with hyacinth (range: 5.9 to 6.7), compared to others (range: 7.0 to 8.1) with or without hyacinth (Figure 2).

Data on electrical conductance are given in Figure 3. There were highly significant ($P < 0.01$) time effects, particularly in trials with hyacinth. Conductance values in non-aerated trials were generally higher (range: 318 to 501 m*S* cm^{-1}) than in aerated trials (range: 159 to 366 m*S* cm^{-1}) but with no significant differences. Trials without hyacinth had significantly lower electrical conductance (range: 86 to 118 m*S* cm^{-1}) compared to those with hyacinth.

Concentrations of soluble reactive phosphorus (SRP) in the water column

Mean concentrations of SRP in the water column are given in Figure 4. In non-aerated trials with hyacinth, remarkable increases in mean concentrations were noted between the third and fourth day, with a peak on Day 10 (2,871.4 ± 771.2 $mg\ L^{-1}$). After Day 15, concentration declined remarkably to its lowest (1,063.9 ± 564.8) on Day 20. In the aerated setups, remarkable increases occurred between Days 5 and 9, with a peak (2,041.1 ± 1,050.2 $mg\ L^{-1}$) on Day 9. There after, concentration of SRP dropped down to 516.1 ± 51.0 $mg\ L^{-1}$. In both aerated and non-aerated trials without hyacinth, SRP concentration was less than 80 $mg\ L^{-1}$. Highly significant differences ($P < 0.01$) in SRP concentration were due to time and aeration, in addition to interactive effects between time and aeration (Tables 1).

One-Way ANOVA test indicated that SRP concentrations in both aerated and non-aerated trials without hyacinth were significantly lower ($P < 0.01$; range 18.1 to 75.0 $mg\ L^{1}$). No significant differences were noted in SRP concentration between the aerated (31.2 ± 2.3 $mg\ L^{1}$) and the non-aerated (29.5 ± 2.3 $mg\ L^{1}$) trials without hyacinth. In trials with hyacinth, cumulative mean SRP concentration in aerated setups (564.7 ± 76.4 $mg\ L^{-1}$) was significantly lower ($P < 0.01$) than the non-aerated (1,737.8 ± 166.0 $mg\ L^{1}$). There were highly significant effects ($P < 0.01$) of time, aeration, and interaction between the two, with hypoxic conditions enhancing phosphorus release more than well-oxygenated conditions. Additionally, treatments with hyacinth released more phosphorus than those without hyacinth.

Correlation between physico-chemical parameters and SRP concentration

Pearson's correlation coefficients between mean SRP concentrations and physico chemical parameters in the water column are given in Table 2. A negative significant ($P < 0.05$) correlation occurred only between dissolved oxygen and SRP ($r = -0.53$, $P = 0.05$) in non-aerated trials. Phosphorus concentration and other parameters other than dissolved oxygen, were weakly correlated.

Table1. Probabilities resulting from Repeated Measures Test on differences in treatment (aerated vs non-aerated) for water column physico-chemical parameters during P release from decaying water hyacinth using transformed data

Parameter	Within effects	Between effects	Interactive effects	Variance Test
Dissolved Oxygen	0.000	0.009	0.217	0.061
pH	0.000	0.480	0.025	0.078
Conductance	0.000	0.128	0.809	0.109
SRP	0.000	0.000	0.000	0.091

Table 2. Pearson's Correlation Coefficients (r) between water column physico-chemical parameters and SRP concentration

Parameter	r	Significance
(A) Aerated Trials		
Dissolved Oxygen & SRP	0.18	0.44
pH & SRP	0.05	0.83
Conductivity & SRP	0.03	0.89
(B) Non-aerated Trials		
Dissolved Oxygen & SRP	-0.53*	0.02
pH & SRP	-0.03	0.90
Conductivity & SRP	-0.13	0.60

*** Significant at P = 0.05 (2-Tailed)**

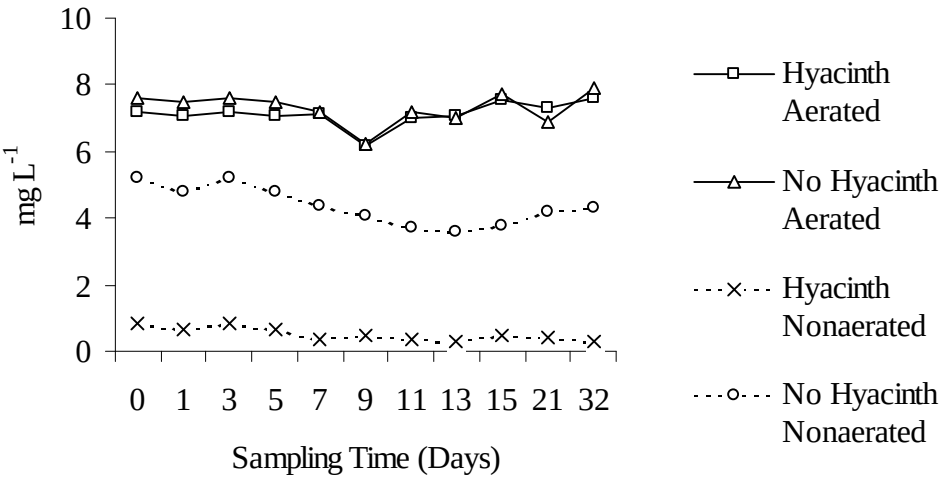

Figure 1. Dissolved oxygen concentration in the water column

Phosphorus release rates

Phosphorus release rates from decomposing hyacinth plant material are given in Figure 5. Maximum release rate in the non-aerated trials with hyacinth was 662.8 ± 91.9 mg m^{-2} day^{1} and occurred on Day 4, before reaching its lowest (-317.2 ± 111.8 mg m^{-2} day^{-1}) on Day 7. In non-aerated trials without hyacinth the range was –5.1 to 17.0 mg m^{2} day^{1}, with minimal variations compared to that with hyacinth.

In the aerated trials with hyacinth, highest release rate (217.7 ± 92.9 mg m^{2} day^{1}) occurred on Day 7, and by Day 9, the rate had reached its lowest value (-635.6 ± 413.7 mg m^{2} day^{-1}). In aerated trials without hyacinth, the rates were in the range –4.6 to 0.8 mg m^{2} day^{-1} and with minimal variations (Figure 5). Highly significant differences ($P < 0.01$) in release rates were due to time effects, while aeration was just significant ($P < 0.05$), with higher rates occurring in the non-aerated trials with hyacinth. Interactive effects between time and aeration were, however, not significant ($P > 0.01$, Table 1). Effects of decomposition and its products on water quality were reflected in depressed dissolved oxygen, low pH and high electrical conductance in the non-aerated setups, and an increase in water column SRP in both setups with hyacinth.

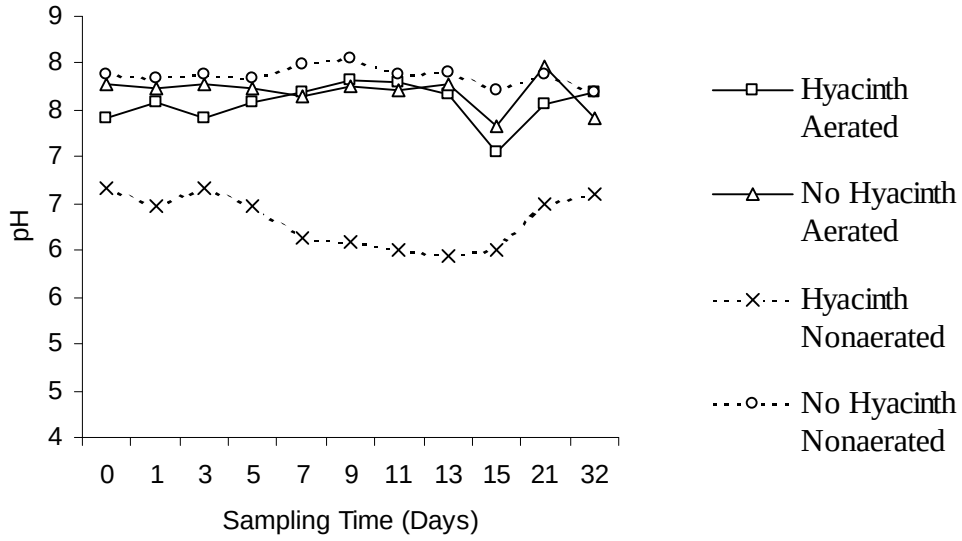

Figure 2. pH in the water column

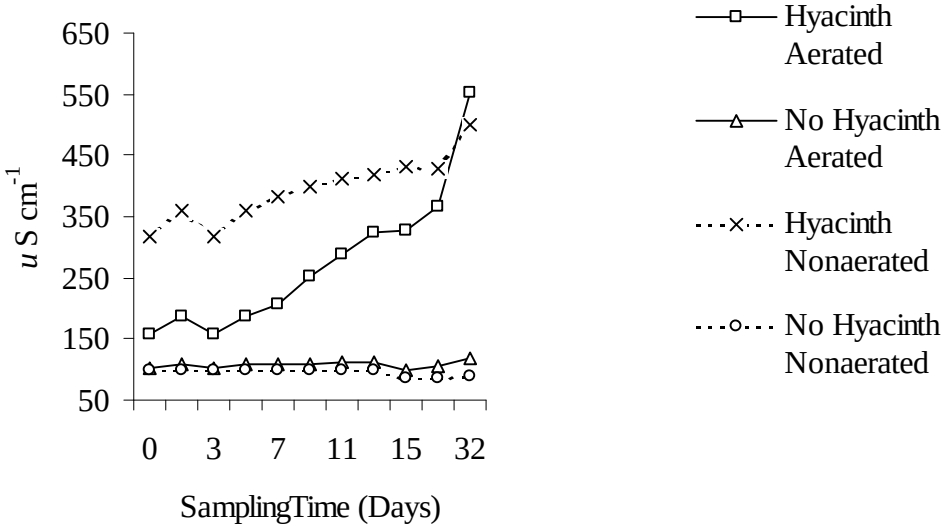

Figure 3. Electrical conductance in the water column

Discussion

Role of decomposition of macrophytes in aquatic ecosystems

Decomposition of aquatic plants in general and water hyacinth in particular, is essential for recycling organic and inorganic components in aquatic ecosystems and is influenced by several environmental factors especially dissolved oxygen (Acharya 1935). Most plant tissue eventually enters the detritus pool, and microbes (both bacteria and fungi) become involved in the mineralization processes. Suberkropp (1997) considered tropical aquatic ecosystems detritus based, with decaying plant matter acting as an important energy source.

Influence of decomposition on water quality and phosphorus concentration

During decomposition of water hyacinth and other macrophytes, nutrients and other chemical constituents are released into the water with both direct and indirect effects on water quality and other ecosystem components. In this study, decomposition resulted in a significant decrease in dissolved oxygen over time, leading to hypoxic conditions. A decrease in pH that resulted in acidic conditions, with an increase in conductivity was, however, unexpected although this may occur in natural waters with poor buffering capacity, high concentrations of salts, high inorganic loading, or with heavy metal contamination. In related studies on Lake Kivu, Central Africa (Jannasch, 1975), and

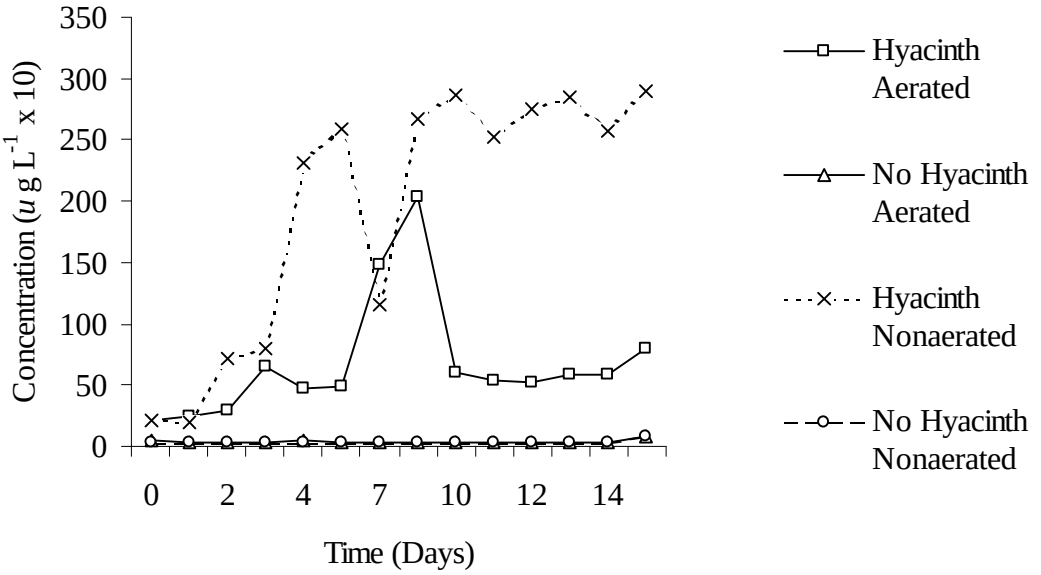

Figure 4. Mean concentrations of SRP in the water column

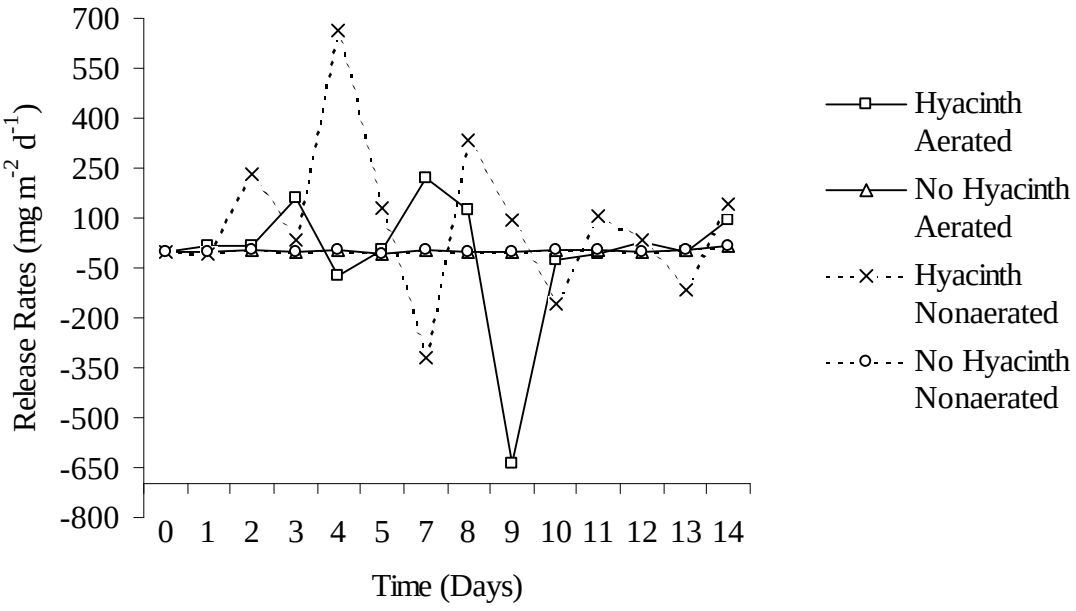

Figure 5. Phosphorus release rates from decomposing hyacinths

Lakes Nyos and Monoun, Cameroon (Kusakabe *et al.*, 2000), it was noted that decomposition of organic matter raised partial pressure of CO_2, thereby lowering pH, accompanied by accumulation of mineral salts that lead to increased electrical conductance. Low pH due to high CO_2 partial pressure and high conductivity due to presence of salts (e.g., NaCl.) were also reported by Lahav *et al.* (2001) when investigating pH, alkalinity and acidity in ultra soft waters. Manyala *et al.* (1996) also reported low pH and high electrical conductance in areas of industrial discharges in the Kenyan part of Lake Victoria, East Africa.

Depending on the amount of biomass undergoing decomposition, hydrological conditions, and lake morphometry, decomposition of aquatic macrophytes can have important effects on an aquatic ecosystem. Examples include reduction or total elimination of fishes (e.g. Nile perch) and other aquatic organisms that cannot tolerate hypoxic conditions. Consequences of these passed unrecorded in Lake Victoria when massive water hyacinth biomass sank in late 1998. Coupled with the increasing anoxic hypolimnion of Lake Victoria (Mugidde, 1993), sinking and subsequent decomposition of water hyacinth may have aggravated the problem of anoxia and internal nutrient loading, especially in deeper portions of the lake where a persistent anoxic hypolimnion enhances phosphorus release, or in sheltered shallow bays where turnover rates of biotic and abiotic components are high (Lehman and Bronstrator, 1994).

It is probable that low dissolved oxygen in the non-aerated trials limited formation of chemically bound phosphorus with oxidized cation species (Fe, Ca and Al); this may have accounted for significantly higher concentrations of SRP in non-aerated trials with hyacinth than aerated ones. The Kagera River continuously transports huge chunks of water hyacinth mats, most of which are fragmented by strong waves and sink to the sediment surface and may have negative effects on the water quality and fish species abundance and distribution of nearby bays.

Release of soluble phosphorus was significantly higher under non-aerated than aerated conditions and was highest during the first 3 to 6 days. Decomposition experiments have demonstrated that non-microbial processes (physical leaching) dominate the first 4 days of decomposition; thereafter, the contribution of microbial processes increases exponentially and those of non-microbial processes decline exponentially at fairly similar rates (Gaur et at., 1992; Singhal et al., 1992; Singhal et al., 1993; Gupta et al. 1996). Findings from this study are in conformity with previous studies that indicated significantly higher phosphorus release rates during the first 4 to 6 days (Ogwada et al., 1984; Sharma and Goel, 1986).

Under field conditions, dilution effects from the large volume of lake water may mask the amount of phosphorus released into the water from decomposing macrophytes. Thus, highest phosphorus release rate recorded during this study (662.8 ± 91.9 mg m^{-2} day^{1}) may not be representative of the natural situation since the volume of water in the incubation tubes was limited (1.6 L) compared to the lake, where free exchange of water ultimately leads to dilution through various transport mechanisms (e.g., bioturbation, water currents, and diffusion). For example, Reddy and DeBusk (1991) measured decomposition rates of water hyacinth under field conditions in Lake Apopka, Florida, and found phosphorus release rates of 4.4 to 5.2 mg m^{2} day^{-1}.

Other factors may influence the amount of phosphorus released from decomposing water hyacinth under natural conditions. Many plants translocate nutrients from dying plant parts to actively growing shoots (Larcher, 1980). During the growing season, which is on throughout the year in the tropics, plants accumulate major nutrients (N, P, K, etc.) for later use. With increasing age of the plant, the more labile elements (N, P and K) become concentrated in young leaves, their concentrations declining as the leaves mature and age (Larcher, 1980). Thus, by the time senescing and dead plant parts start decomposing and releasing nutrients, most of the essential elements will have been translocated to other parts, thereby lowering the amounts released into the water. In addition, senescing and dead leaves of water hyacinth may remain on the parent plant until an advanced stage of decomposition before they are shed. In this way, the plant has ample time to translocate most nutrients to active growing parts (Center and Van, 1989). During the current study, whole plants were harvested, moribund parts detached and the rest chopped to small pieces for use in the experiments. It was inferred, therefore, that most nutrients in the dying parts had already been translocated to growing parts. It was assumed also that nutrients lost through the detached parts formed an insignificant nutrient pool in the plant tissues.

The profound decline in soluble phosphorus concentration and phosphorus release rate after the high release rates during the initial 4 to 6 days, may be due to phosphorus assimilation by microbes, that may have lead to formation of particulate organic phosphorus (POP). Increase in soluble phosphorus towards the end of the experiment was likely a result of death, decomposition and subsequent release of phosphorus from dying and dead microbes. For example, Reddy and DeBusk (1991) noted an acute reduction in the Carbon to Phosphorus ratio as a result of microbial retention of phosphorus from decomposing macrophytes.

Conclusions

Decomposition of water hyacinth releases nutrients, notably phosphorus, into the aquatic environment. Release was highest during the first 4 to 6 days but later declined to minimal levels. Phosphorus release was enhanced under hypoxic conditions. Under natural conditions, the concentration of nutrients released from decomposition of plant organic matter may be modified by dilution, especially

in large water bodies. In small water bodies or sheltered shallow bays such as Thruston and Waiya of Lake Victoria, the problem may build to levels of concern for deterioration in water quality (e.g., decreased dissolved oxygen, lowered pH and elevated electrical conductance). Particular fishes like *Lates niloticus*, and aquatic fish foods such as the Ephemeroptera larvae (*Povilla adusta*) that survive in waters with high dissolved oxygen content and circumneutral pH are likely to be negatively affected if water hyacinth decomposed in their immediate environment. This is likely to have direct implications on the incomes of fishers through reduction in fish catches hence incomes. The Kagera River continuously transports huge chunks of water hyacinth mats to Lake Victoria where they are destroyed by strong waves, sink to the lake bottom, decompose and release nutrients and organic constituents into the water. Effects of these on water quality and on fish in the lake need to be addressed. It is herewith recommended that water hyacinth and other aquatic weeds be harvested out of the aquatic systems before effects of their decomposition are realised on the water environment.

Acknowledgement

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