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PILOT-SCALE EXPERIMENTS IN WATER HYACINTH LAGOONS FOR WASTEWATER TREATMENT

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ABSTRACT

Based on some information collected in foreign bibliography which classifies water hyacinth as one of the possible interesting alternatives for the treatment of some types of domestic sewage, CETESB has since 1980 been developing, in participation with other institutions, a series of pilot-scale experiments in order to evaluate the real applicability of this system of wastewater treatment in Brazil.

The conclusions that can be drawn from the experiments that have been carried out up to the present have indicated that the water hyacinth lagoon presents a better performance when it is integrated with other treatment systems, mainly at tertiary level, instead of its direct application to raw sewage treatment.

One of the operational problems of this system, which has been observed during the experiments, refers to the intense proliferation of mosquitos, the control levels of which were not satisfactory even with the periodical application of larvicide. The problem of water hyacinth removal and its use as biomass has not been solved at industrial level yet. In pilot-scale experiments carried out by CETESB, the use of water hyacinth as an organic compost has proved to be economically unfeasible, on an industrial scale, considering that there are many other residues which offer better alternatives both from the economical point of view and the available amounts.

KEYWORDS

Water hyacinth, stabilization pond, biomass, wastewater treatment.

1. INTRODUCTION

The utilization of aquatic plants, especially water hyacinth (Eichhornia crassipes), for wastewater treatment, has recently received especial attention, due to its capacity to assimilate some types of polluting substances.

Water hyacinth is an aquatic plant native to the tropical region of Central America, presently distributed over more than 50 countries around the world.

Considerable operational problems have been found in the water systems where this plant has been introduced, having been considered as a water plague due to its high proliferation capacity. This negative aspect, however, has been partially altered by several research studies undertaken in recent years, mainly in the United States (Wolverton, 1979; O'Brien, 1980; Middlebrook, 1980 and Wolverton, 1979), which showed that water hyacinth is a good pollution removing agent when used in a stabilization pond, to remove some types of polluting substances.

Constant increase in environment quality degradation and the difficulty in obtaining financial support to solve the problem have led to the search for a cheap and appropriate solution suitable to Brazilian conditions, to minimize the deterioration of the quality of the water courses in Brazil.

Experimental results of tests developed in a pilot-scale basis from 1981-1986 are presented in this report. Two experiments were carried out at CETESB's (CETESB - São Paulo State Environmental Protection Agency) Experimental Plant, and joint studies done with municipalities (SANASA - Sociedade de Abastecimento e Saneamento S/A, Campinas and SAAE - Serviço Autônomo de Água e Esgoto de Jacareí, Jacareí, São Paulo) to evaluate the feasibility of using water hyacinth to treat domestic sewage.

2. PILOT-SCALE INVESTIGATION AT CETESB'S EXPERIMENTAL PLANT

Experimental Procedure

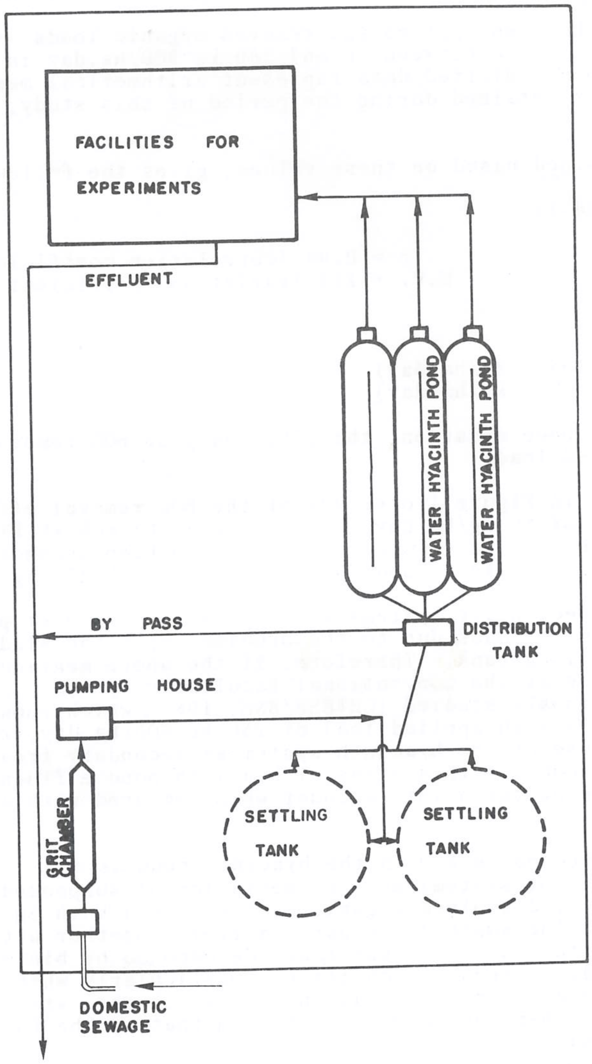
All the operation parameters were obtained at CETESB's Experimental Plant, located at Caxingui, São Paulo, from 1981-1982.

The raw sewage, coming from the strictly residential suburb of Caxingui, passed firstly through a grit chamber and was pumped to the primary settler (see Flowsheet 1). Problems with the sludge discharge system caused an efficiency loss in the solids removal percentage during 70% of the operation time, mainly after application of higher loads. The settler's effluent was discharged into two experimental hyacinth lagoons. These pilot-scale ponds, concrete built, with 72 m^2 of surface area each, were operated with 0.6 m (lagoon 1) and 1.0 m depth (lagoon 2). Lagoon 1 was tested at five different detention times (i.e. different pollution loads) during a 14 month period (October 1981-December 1982). Lagoon 2 was operated with three different detention times for a 6 month period. Lagoon 2 was used to investigate hyacinth growth and crop production, and latterly to obtain operational parameters of the investigation (July-December 1982).

There was usually a lapse of 20 to 30 days after each change in operational conditions for biological stabilization. Samples were then taken for a one month period. Hyacinth population density was usually controlled to about 50% of the pond surface area at the beginning of every experimental detention time. Upon conclusion of every detention time run, the sludge was removed to avoid interference with the lagoon operation. Samples were taken during one month for every experimental detention time, being collected for 24 h with intervals of two to three days.

All chemical and biochemical parameters (BOD, COD, N, P in its various chemical forms) were analyzed at CETESB's laboratories, according to the methodology established by the "Standard Methods", 13th edition. Water and air temperature were measured four times a day (7:00 a.m., 9:00 a.m., 3:00 p.m. and 9:00 p.m.). Solar radiation intensity was measured and recorded with a Fuess actinograph equipment.

Measurement of the hyacinth growth rate started in May 1981 and was repeated several times with every operational load. For this purpose, a box (2.0 m long; 0.8 m wide; 0.5 m deep) with a 1.6 m^2 surface area was mounted in each experimental pond. A small amount of water hyacinth (2 to 3 kg on a dry basis) was placed in the box, at the beginning of every experimental phase. Box and water hyacinth were periodically weighed (every 2 to 4 days) after removal of water drops attached to the plants and the box, using an industrial scale. Dry weight was obtained utilizing the average moisture percentage, experimentally determined.



FLOW-SHEET 1. EXPERIMENTAL SYSTEM

Results and Discussion

Organic load removal (BOD): Average concentrations of the Biochemical Oxygen Demand (BOD) of the 86 samples taken at the inlet of both lagoons, collected for 24 hours, varied from 65 to 424 mg/l, with a global mean value of 171 mg/l. Mean concentration of the same parameter was 192 mg/l for the raw sewage.

The relationship between applied and removed organic loads is shown in Figure 1, obtained in the range between 70 and 380 kg BOD/ha.day in the two experimental lagoons. Plotted data represent arithmetical mean values of the BOD concentrations obtained during the period of this study, at one week intervals.

A regression obtained based on these values, gives the following expression:

$$\lambda = 19.868 + 0.658\ \lambda s$$

r = 0.94 (correlation coefficient)
C.V. = 21% (variation coefficient)

where

λ_g = BOD removed load (kg/ha.day)
λ_s = BOD applied load (kg/ha.day)

According to the above equation, the efficiency of BOD removal decreases with increase in applied load.

As can be seen in Figure 1 over 90% of the BOD removal efficiency obtained with applied load of 80 kg/ha/day, but decreased to 80% at 140 kg/ha.day which corresponds to the minimum efficiency required to keep secondary treatment level, dropping further to around 70% of removal with 350 kg/ha.day.

As already explained, pilot systems were operated at almost primary treatment level, mainly at high loads due to the problems with the sludge discharge system of the settling tank. Therefore, if the above mentioned results are compared with those of the conventional facultative primary pond in the State of São Paulo previously studied (CETESB/BNH, 1981), which showed an efficiency over 80% with applied load of 250 kg BOD/ha.day, there is no advantage in the use of the hyacinth system as secondary treatment. Also the septic condition found in this stage of hyacinth pond effluent is another aspect that should be taken into account when compared with any other treatment system.

The main process to reduce BOD in the hyacinth pond is the retention (by its root system) and sedimentation of suspended organic matter. Direct absorption of dissolved organic matter by hyacinth is very restricted (Wolverton, 1979). The suspended organic matter, together with dissolved organic matter contained in the water, are decomposed by biological action of microorganisms under anaerobic conditions, particularly when this system is used for primary and secondary treatment, in which the stabilization process rate is much lower than the aerobic condition that can be found predominantly in facultative ponds.

There is much information available in the literature on BOD removal capacity of the hyacinth ponds. Middlebrooks (1980) based on investigation in the bibliography, concluded that the organic load assimilation capacity of a water hyacinth lagoon is similar to that of a low-load conventional lagoon and established 50 kg of BOD/ha.day as design criteria for this treatment system for tropical and warm temperature climate regions.

Water hyacinth growth rate: The representative water hyacinth growth rate obtained during the period of the experiment is shown in Figure 2. It is expressed in grams of dry material by unit of surface area.

The data used in this Figure were taken during September and October 1981, and the average air temperature was 22°C. In both boxes used for the experiment,

FIG. 1. RELATIONSHIP BETWEEN APPLIED AND REMOVED BOD LOAD OBTAINED AN EXPERIMENTAL WATER HYACINTH POND.

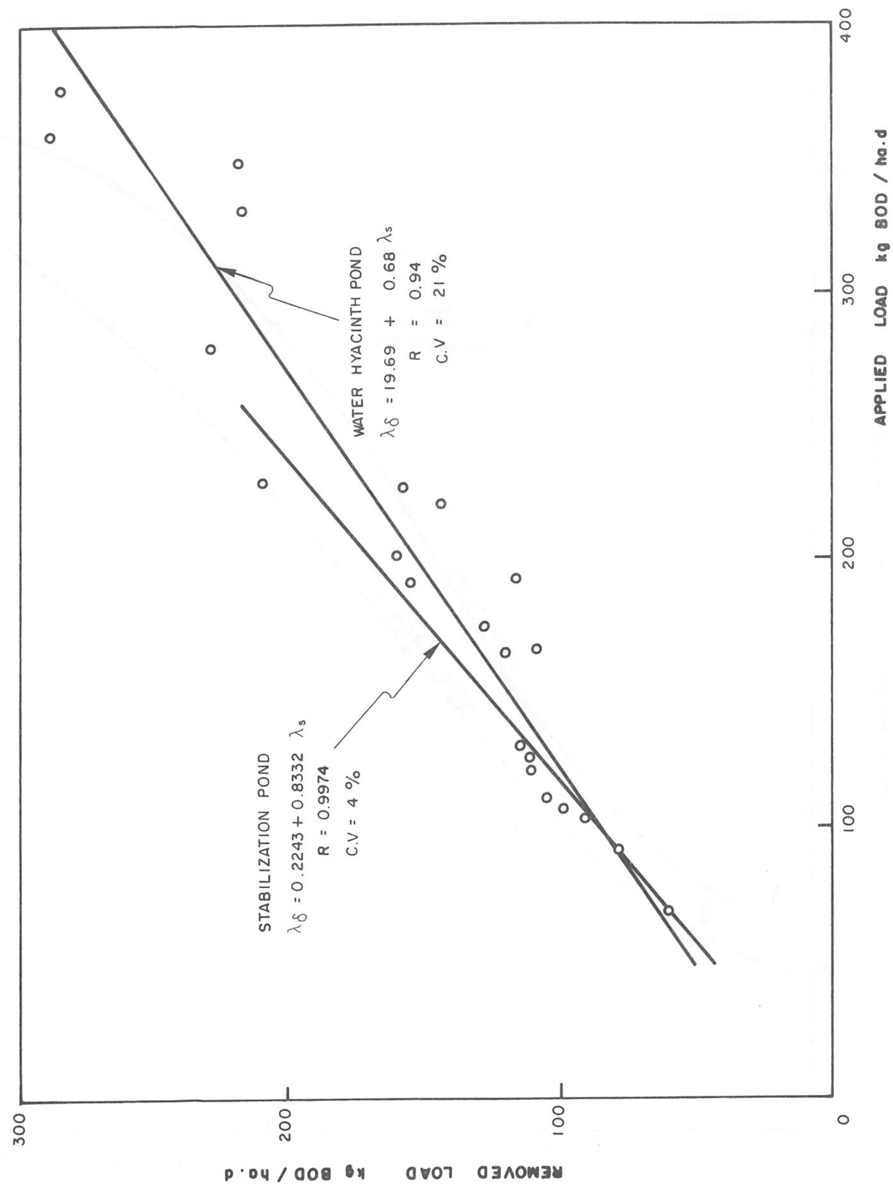
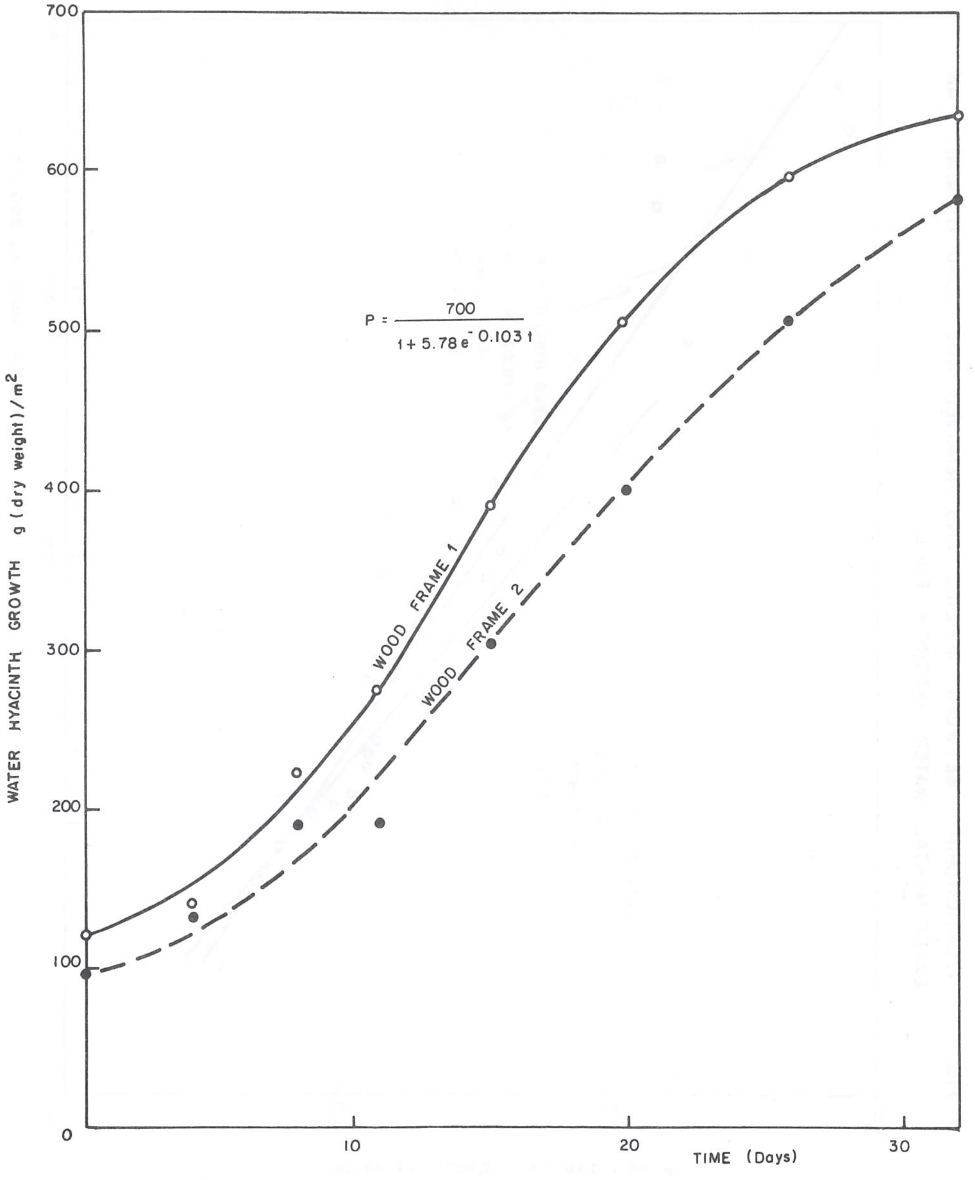


FIG. 2 : WATER HYACINTH GROWTH AS DETERMINED IN EXPERIMENTAL PONDS
Period 24/09 to 26/10/81



a sigmoid water hyacinth growth was observed. After 8 to 10 days adaptation, an exponential growth was observed for approximately 10 days, followed by a stationary growth phase.

The mathematical expression that represents the data taken in box 1 (lagoon 1) is:

$$P = \frac{700}{1 + 5.78\ e^{-0.103t}}$$

where

P = water hyacinth production (g/m^2 x day)
t = time (days)

The growth rates evaluated in the exponential and stationary phases were 5% and 1.3%/day, respectively.

Biomass mean productivity, estimated during the period of exponential growth in both boxes varied from 210-250 kg/ha.day dry weight and the time to duplicate the mass of water hyacinth was about 14 days.

Water hyacinth is a plant rather sensitive to temperature variations. The best temperature for hyacinth growth is from 21-30°C (Middlebrooks, 1980). Temperatures under 10°C cause plant growth stagnation and the vegetative part suffers badly at temperatures around 0°C (Penfoud, 1948).

Due to these physiological characteristics, the utilization of water hyacinth for pollutant removal is limited to tropical and subtropical regions. Wolverton and McDonald (1976) presented exponential water hyacinth growth data, related to temperature variation, taken from experiments carried out from May to July in the State of Mississipi, United States, when the monthly mean temperature oscillated between 16.3 and 26.3°C. Temperature coefficients estimated from these data, varied from 1.041 to 1.050 in the mentioned temperature range.

In experiments done by Bock (1966), in a constant temperature chamber, the maximum water hyacinth growth rate (about 5%/day) was obtained at 26.7°C, while at 4.4°C practically no plant growth was observed. However, Yount and Crossman (1970) obtained under natural conditions, in the experimental treatment system, growth rates of 1.78 to 4.08% a day during the winter months, with temperatures higher than those normally registered in the region (15°C).

A high growth rate (7%/day) was recorded by Conwell (1977) in 3 experimental lagoons in the period April-May in the State of Florida. The duplication time of the occupied area was 6.2 days, calculated from the experimental data.

Water hyacinth growth rate is also very dependent on the free space available in the pond. According to Bock (1966) it was possible to keep the growth rate over 5%/day at the beginning of the experiments, while a big free surface was available in the lagoon. As the experiment progressed with the lack in space, the rate fell to 1.8%/day. Investigations by this author in a 1000 m^2 experimental pond showed that the increase of the area occupied by the water hyacinth is sigmoidal, suggesting a considerable interference of the free space in the growth rate. In fact, all the pond surface was covered by the water hyacinth after 55 days.

The same growth behaviour was noted in the present study. Water hyacinth growth rates in the experimental boxes began to decline considerably after approximately 20 days when a significant reduction of the space among the aquatic plants was observed.

With regard to the biological mass production, several investigators express it in terms of weight unit (lagoon area x time). According to Orms and Sutton (1975) studies in Fort Lauderdale, Florida, in the experimental batch system, fed by the effluent coming from the secondary treatment in the warm period (May to July), the maximum water hyacinth production observed was 137 kg/ha.day on a dry basis. As it usually occurs, the water hyacinth production gradually decreased with time in the pilot-scale plant in the discontinued system with the decrease in nutrient concentration in the culture medium.

In investigations carried out by NASA, United States (Wolverton, 1979), in a 0.22 ha area pond, the maximum production was estimated at 154 t/ha.year on a wet basis, adopting the practice of water hyacinth removal to keep the maximum growth rate. This value corresponds to 210 kg/ha.day on a dry weight basis, if a 95% moisture is considered.

Yount and Crossman (1970) carried out studies to check the relationship between water hyacinth production and nutrient removal in the pond. The results showed that the net biomass production represents the most appropriate parameter to evaluate the nutrient removal efficiency. The maximum production obtained during the warm period was 299 kg/ha.day, but in the cold season this parameter remained at a low value (50 kg/ha.day). During the investigations, 50% of the pond area was kept free by periodic removal of the water hyacinth.

To facilitate comparison several biomass production values obtained by different authors are shown in Table 1.

In accordance with all the available data, it is reasonable to adopt 5%/day and 200 kg/ha.day as growth rates in the region of the State of São Paulo for the water hyacinth pond system, if the plants are kept in the exponential growth phase.

Water hyacinth chemical composition: The chemical composition and the growth rate of the water hyacinth are fundamental factors when considering the use of the water hyacinth system for nutrient removal (Dymond, 1948).

TABLE 1 - Water Hyacinth Production Values Recorded in the Bibliography

Author	Production (kg/ha/day)	Period
Yount and Crossman (1970)	50 290	Cold season Warm season
Orms and Sutton (1975)	140	Spring
Penfoud and Earle (1948)	40 280	Cold season Warm season
Boyd (1970)	177-276	August - September
NASA	210	Annual average
CETESB	200-250	September - October/81

N, P and C average concentration results are shown in Table 2. They were analyzed in hyacinth plants, including vegetative parts and roots, obtained in the two experimental ponds during one year, where different organic load values were tested.

The quantitative proportions of C, N and P in water hyacinths, according to the data presented in Table 2, are 68.5:5.7:1.0.

Based on the data available in the bibliography, O'Brien (1980) summed up C, N and P concentrations in water hyacinths grown in several sewage treatment systems, as can be seen in Table 3. Quantitative proportions of C, N and P are 77.1:4.6:1.0, considering the average concentrations.

TABLE 2 - Chemical Composition of Water Hyacinth Grown in the Caxingui Experimental Ponds

Parameter	Percentage (%)
N	3.1
P	0.54
C	37.0
Protein	17.5
Fiber	29.0
Cellulose	29.0
Lignin	15.0

TABLE 3 - Water Hyacinth Chemical Composition (%) Presented by O'Brien

	Average	Variation Range
Carbon	44.80	36.90 - 51.60
Nitrogen	2.90	1.56 - 3.94
Phosphorus	0.63	0.31 - 0.89

As it happens with terrestrial plants, the chemical composition of aquatic plants varies according to the environmental characteristics. Usually, higher percentages of mineral components are found in polluted waters than in an environment preserved from human activities. A study made in 16 natural lagoons unaffected by pollutant loads, in the State of Florida, USA, found much lower levels of nitrogen and phosphorus in the hyacinth (1.6% and 0.3% respectively) if compared with the results from a polluted aquatic environment. With regard to metallic ions, the concentrations found in the hyacinths in the study as shown in Table 4, although much lower than the amount that could result in acute toxic effects to hens, for instance, might cause some concern.

TABLE 4 - Concentrations of Metallic Ions in the Water Hyacinths Cultivated in the Lagoons and the Toxic Levels for Hens

Metallic Ions (mg/kg)	Concentration in the Plant	Toxic Level	Toxicological Effect	Reference
Total Chromium	4.7	120	-	-
Copper	10.4	130	Growth	-
Lead	20.0	778	Decrease	8
Zinc	182.0	606	Decrease	-
Cadmium	0.48	22	-	-
Mercury	0.13	1.3	-	-

Nutrient removal: The applied and removed organic loads and the nitrogen and total phosphorus average removal efficiency obtained with different detention time in the experimental ponds are presented in Tables 5a and 5b.

In general, N and P removal efficiency values show a tendency to increase with the increase in detention time. The maximum efficiency values obtained in pond 1 for N and P were 52% and 58% respectively, with 10 days detention time, during December and January and the minimum values were 12% and 14% with a detention time of 2.5 days in April and May.

TABLE 5a - Total Nitrogen Load and Removal Efficiency, Determined in the Experimental Lagoons

Period	Detention Time (Days)	Average Concentration (mg/1)			Load Kg/ha.day				Efficiency (%)		T (^oC)
					Pond 1		Pond 2				
		Influent Sewage	Effluent Pond 1	Effluent Pond 2	Applied Load	Removed Load	Applied Load	Removed Load	Pond 1	Pond 2	
Oct - Nov/81	10	38.8	18.5		23.3	12.2			52		22.6
Feb - Mar/82	5	25.9	16.1		31.1	11.8			38		25.5
Abr - Mai/82	2.5	33.0	29.1		79.2	9.4			12		19.7
Jul - Aug/82	5	41.0	28.0	33.5	49.2	15.6	98.4	18.0	32	18	19.0
Sept - Oct/82	7	68.4	59.1	59.1	57.5	7.8	114.7	13.9	14	12	20.0
Nov - Dec/82	7	56.8	38.9	43.4	47.7	15.0	95.4	22.5	32	24	22.6

T = Average temperature

TABLE 5b - Total Phosphorus Load and Removal Efficiency, Determined in the Experimental Lagoons

Period	Detention Time (Days)	Average Concentration mg/1			Load Kg/ha.day				Efficiency (%)		T (^oC)
					Pond 1		Pond 2				
		Influent Sewage	Effluent Pond 1	Effluent Pond 2	Average Load	Removed Load	Average Load	Removed Load	Pond 1	Pond 2	
Oct - Nov/81	10	6.6	2.8		4.0	2.3			58		22.6
Fev - Mar/82	5	6.5	4.5		7.8	2.4			31		25.5
Abr - May/82	2.5	7.8	6.7		18.7	2.6			14		19.7
Jul - Aug/82	5	8.5	5.0	6.3	10.2	4.2	20.4	5.3	41	26	19.0
Sept - Oct/82	7	10.8	6.0	7.7	9.1	5.0	18.1	5.2	44	29	20.0
Nov - Dec/82	7	11.1	8.6	9.6	9.3	2.1	18.7	2.5	23	14	22.6

T = Average temperature

In pond 2, (1.0 m depth), N and P removal efficiency is smaller than in the less deep (0.6 m) pond 1. In terms of nutrient loads per unit area, there was no significant correlation between the applied and the removed nutrient mass. The total nitrogen removed loads during the experimental period in pond 1 oscillated between 7.8 kg/ha.day and 15.6 kg/ha.day and 2.1 and 5.0 kg/ha.day for total phosphorus.

The removed organic load values obtained in pond 2 were greater when compared with pond 1, both for N and P, in spite of the fact that the removal efficiency in terms of percentage was always smaller in the second pond.

Nutrient removal results obtained in several experimental lagoons and taken from bibliographical references are compared (Table 6) with the average nutrient removal results obtained by CETESB.

It can be observed that it is possible to obtain nitrogen removal efficiency values ranging from 64-96%, with the organic load varying between 11 and 19 kg/ha.day and detention time from 4-6 days. Even utilizing a long detention time (54 days) and consequently low organic loads, 72% and 57% nitrogen and phosphorus removal, respectively, were hardly obtained at the experimental system of the National Space Technology Laboratories (NSTL) of NASA. These results showed that a long detention time does not always mean a higher treatment efficiency.

Nutrient removal in a water hyacinth pond could be done through plant absorption, retention by plant root system and sedimentation and/or open air elimination via nitrification and denitrification, in the specific case for nitrogen compounds.

It is not likely that significant gaseous nitrogen elimination could have occurred during the period of the study, because of the anaerobic predominant conditions and the low pH ($\simeq$ 7).

Assuming that nutrient removal is only done by hyacinth absorption in proportion to its chemical composition and based on the production value of 200 kg/ha.day obtained N and P removal may be estimated as 6.0 and 1.1 kg/ha.day, respectively. These values correspond, approximately, to 50% and 35% respectively, of the mean values for total removal obtained in pond 1 (12.0 kg N/ha.day and 3.1 kg P/ha.day).

The difference between total and hyacinth removal can be explained as the elimination by all physical and chemical processes already mentioned, including suspended nutrients retained by plants root system.

There are many studies available in the literature concerning nutrient removal in stabilization ponds and in eutrophicated lakes, indicating that nutrient removal sometimes exceeds 70% efficiency for total nitrogen and 50% for total phosphorus, depending on the detention time and other environmental factors (Middlebrooks, 1980 and Oswald _et al._, 1973).

The experimental data obtained in a photosynthesis pond are presented in Table 7, which gives a comparative idea of nutrient removal efficiency. This experiment was developed from 1978-1980 in the same pond utilized with hyacinths, being operated with 0.5 m depth and different detention time values (Kawai _et al._, 1982). Although detention time values in the two experimental systems were not the same, the nutrient removed mass in the photosynthesis pond was smaller than in the water hyacinth pond, mainly with regard to total phosphorus removal.

A similar result was obtained in a pilot-scale experiment carried out in Brasilia in maturation ponds with and without hyacinth (Mossé _et al._, 1980). As shown in Table 8 phosphorus and nitrogen removal efficiency in the hyacinth pond is approximately 20-25% greater than that obtained in the pond without hyacinths.

These results suggest the advantage of utilizing the water hyacinth lagoon

TABLE 6 - Nutrient Removal in Sewage Treatment With Water Hyacinth

Site	Pond Area (ha)	Depth (m)	Detention Time (days)	Organic Load Kg. BOD/ ha.day	Nutrient Load (kg/ha.day)				Removal Efficiency (%)		Ref.
					Nitrogen		Phosphorus				
					Applied	Removed	Applied	Removed	N	P	
Williamson Creek Texas											
First step	0.059	1.0	5.3	43	15.3	10.7			70		5
	0.059	0.85	4.5	89	18.5	11.8			64		
Coral Spring, Florida	0.50	0.4	6.0	31	19.5	18.7	4.8	3.2	96	67	17
National Space Technology Lab. NASA	2.0	1.22	54.0	26	2.9	2.1	0.9	0.5	72	57	19
CETESB	0.008	0.6	2.5-10	-	48.0	12.5	9.9	3.1	34	35	-
		1.1	2.5-10	-	102.8	18.1	19.1	4.3	18	23	-

TABLE 7 - Comparison of Average N and P Removal Efficiency in Photosynthesis and Water Hyacinth Ponds (%)

Parameter	Photosynthesis Pond			
	Detention Time (Days)			
	10	6	4	2.8
Total N	32	40	17	14
Total P	35	18	18	8
Parameter	Water Hyacinth Pond			
	Detention Time (Days)			
	10	7	5	2.5
Total N	52	23	35	12
Total P	58	39	36	14

TABLE 8 - Treatment Efficiency Comparative Data Obtained in the Maturation Ponds with and without Water Hyacinth

Pond	Parameter					
	Total P	Total N	Algae	Fecal	D.O.	Transparency
Maturation without water hyacinth	54%	51%	increase	96%	9.0 mg/l	26 cm
Maturation with water hyacinth	70%	63%	91%	97%	2.9 mg/l	56 cm

Source Mossé, R.A. (1980)

instead of the conventional stabilization pond, with regard to nutrient removal. It is important to mention that besides the nutrient assimilation capacity, water hyacinths efficiently remove suspended matter (e.g. algae), through physical action of roots (Table 8).

For this reason, the water hyacinth pond is an attractive system for advanced treatment, when used in combination with the conventional stabilization pond, especially in warm climate regions.

The data presented above suggest the adoption of 18 kg N/ha.day and 4 kg P/ha.day for the design of water hyacinth lagoons to obtain 80% of removal efficiency, for the average climatic conditions in the State of São Paulo. In 7 stabilization ponds located in cities of the interior of São Paulo (CETESB/BNH, 1981), the daily contributions per capita were estimated as 7 g N and 1.4 g P.

Comparing these values with design load ones it can be concluded that a one hectare hyacinth pond may treat, daily, a sewage mass equivalent to a 2,500 population burden, with approximately 80% nutrient removal efficiency.

Water hyacinth density and treatment efficiency: As mentioned above when the hyacinth density in the lagoon exceeds a certain amount, its growth rate tends to decrease with the consequent decrease of biological activities related with the assimilation of pollutant substances. Therefore, from a practical operation view, it is necessary to keep a permanent control of the hyacinth density to obtain a better performance in terms of treatment efficiency of the system.

Two curves were established to help in the determination of the water hyacinth density necessary for the efficient operation of the lagoon; one of them, named treatability potential, represents the product of the production rate times the hyacinth quantity at every moment during growth, the other shows the evolution of the percentage of the total area covered by water hyacinth in the lagoon, as a function of the treatability potential variation.

The treatability potential (T) was evaluated by the following expression:

$$T = \alpha P \quad \ldots\ldots \quad 3$$

where

α = hyacinth production rate at any moment during growth (%/day)
P = hyacinth mass produced until a determined moment (g/m^2).

Production rate was calculated by the following equation:

$$\frac{dP}{dt} = \frac{Wa\ E\ e^{-ET}}{(1 + A\ e^{-Et})^2} \quad \ldots\ldots \quad 4$$

where

W = maximum hyacinth mass produced (g/m^2); 700 g/m^2 dry weight was adopted.

$$A = \frac{W - Po}{Po}$$

where

Po = initial hyacinth mass (g/m^2)
E = coefficient
t = growth time (days)

The hyacinth mass (P) in equation (3) was obtained from the experimental data taken at the box 1 in the present study.

The pond area percentage occupied by hyacinth as a function of time was evaluated from the value of (P), by assuming that 700 g hyacinth/m^2 (considered as maximum mass produced, in this study) corresponds to 100% of the pond area covered by the water hyacinth. As can be shown in Figure 3, the point that presents the highest potential treatability (556 g/m^2.day), coincides with the area that corresponds to around 70% of the total area covered by aquatic plants.

This means that a higher treatment yield of the system may be obtained by keeping 70% of the lagoon area covered with hyacinths and 30% free surface, adopting the practice of periodical removal of the aquatic plants. It must be pointed out that it is convenient to keep a uniform hyacinth density distribution all over the pond surface, in order to permit some free space among the plants.

Hyacinth mass to be harvested daily under this operational condition is estimated as 20 g/m^2 or 200 kg/ha, for the average climatic conditions in the State of São Paulo.

Operational Problems

Water hyacinth removal is one of the critical operational problems of the system.

As mentioned above, water hyacinth excess in the lagoon decreases the operational efficiency of the system, not only due to reduction in assimilation capacity of the aquatic plants, but also due to the increase of

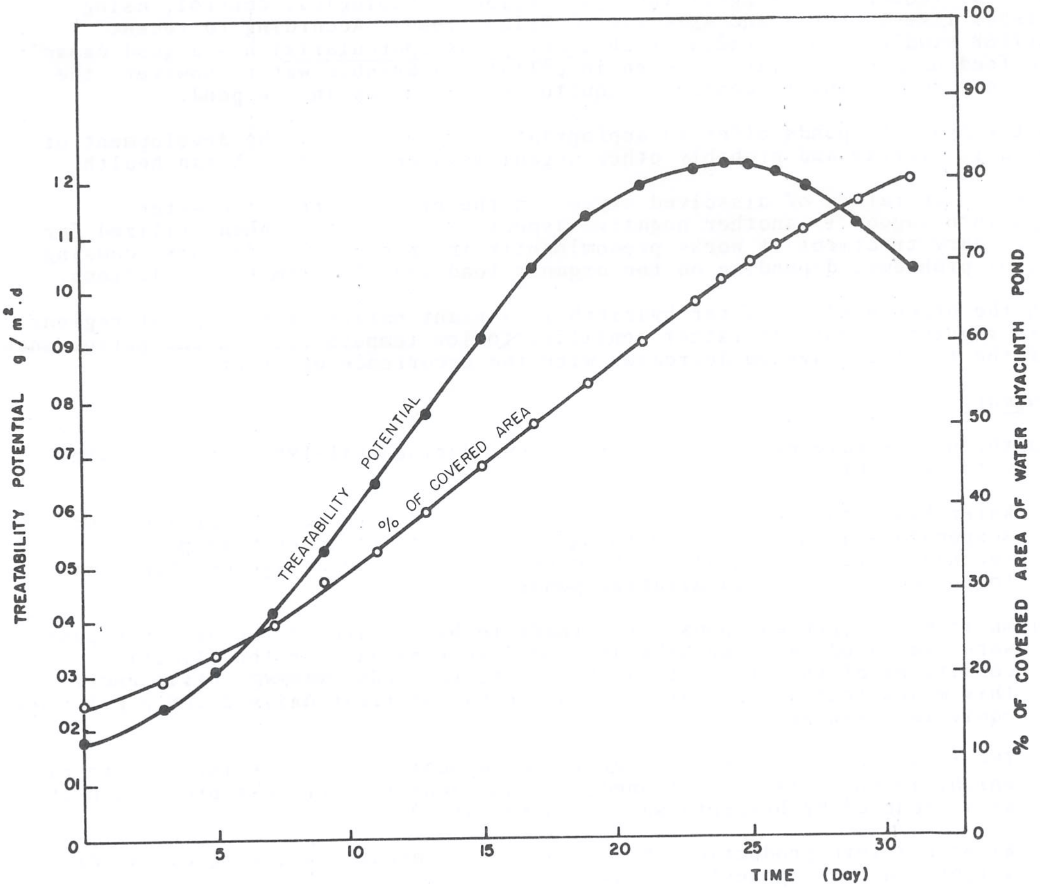


FIG- 3 : TREATABILITY POTENTIAL AND PERCENTAGE OF COVERED AREA OF THE WATER HYACINTH POND.

pollutants in the system coming from decomposition of dead biomass.

Mosquito proliferation must be enhanced as another important factor to be considered in the utilization of this system. Although some investigators did not find problems caused by mosquitoes, the majority of them recommend the adoption of some control scheme (Middlebrooks, 1980). Besides being troublesome to adjacent populations, the proliferation of mosquitoes may become hazardous when species hosting parasites appear.

Several researchers suggest the utilization of biological control, using fishes like Gambusia and Axtyarax (O'Brien, 1980). According to recent CETESB studies, the paradise fish (Macropodus opercularis) has a good capacity to feed on mosquito larvae, even in polluted anaerobic water, however, they are not sufficient to control mosquito proliferation in the pond.

Water hyacinth ponds offer an appropriate environment to the development of mosquito larvae and probably other organisms undesirable to human health.

Low concentration of dissolved oxygen in the effluent from the water hyacinth lagoon is another negative aspect of the system. When utilized for secondary treatment it works predominantly in anaerobic conditions, causing odour problems, depending on the organic load and the climatic conditions.

On the other hand, as water hyacinth is a plant native from tropical regions, its vegetative part is rather sensitive to low temperature and the performance of the treatment system decreases with the occurrence of frost.

Summary

In the pilot-scale experiments carried out during 1981-1982, the following results were obtained:

a) Water hyacinth lagoons showed an efficient performance in nutrient and suspended solids removal, although BOD removal efficiency to produce secondary treatment quality effluent was not so advantageous when compared to the conventional facultative ponds.

b) Maximum nitrogen and phosphorus loads to be applied in the hyacinth pond were evaluated as 18 kg N/ha.day and 4 kg P/ha.day for the climatic conditions of the State of São Paulo, to keep 80% treatment efficiency. This means that one hectare hyacinth pond can treat daily 2,500 population equivalent sewage.

c) The treatment efficiency of the lagoon depends on the hyacinth growth rate which, in turn, is conditioned to plant density. The best proportion of area occupied by hyacinth was estimated at 70%.

d) Water hyacinth production in the lagoon was about 210-250 kg/ha.day dry weight, in the exponential growth phase.

e) One of the most critical problems in the practical implementation of this system is the proliferation of disease vectors, mosquitoes, etc., the control of which must be carefully considered before the adoption of the water hyacinth system.

3. PILOT-SCALE EXPERIMENT IN WATER HYACINTH POND CARRIED OUT AT CAMBUI'S WASTE TREATMENT PLANT, SANASA, CAMPINAS, SÃO PAULO

Out of the several alternatives for Campinas waste disposal scheme under study, SANASA considered the hyacinth pond as one possible solution from an economical and operational view. However, it was necessary to carry out further studies as regards its practical applicability, particularly for raw wastes direct treatment. For this reason, CETESB-SANASA joint pilot-scale studies have been conducted. SANASA was responsible for building and operating the system, and for field follow-up. The system was built according to design suggested by CENA (Centro de Energia Nuclear na Agricultura). CETESB was responsible for carrying out the analysis of the main operational parameters, as well as for technical guidance.

Experimental Procedure

Two 200 m^2 ponds (56 m wide/35.5 m long and 0.60 m deep) were dug at Cambuí Treatment Plant which belongs to SANASA.

Some of the wastewater from a predominantly residential area reaching the plant was diverted, after being screened and decanted to the two ponds through linking channels.

A 37 m^3 masonry tank which already existed in the plant was adapted to be used as an anaerobic primary treatment system which worked in series with one of the hyacinth ponds.

The effluent flow of each experimental system was controlled through a weir-installed on each linking channel.

Up to the present, two operational parameter surveys have been carried out: the objective of the first was to make a comparison of treatability between the unicellular hyacinth pond which directly receives raw wastes and a compound system (anaerobic pond/hyacinth pond); the aim of the second survey was to compare the treatability between ponds with and without water hyacinth. Figure 4 shows the flow-sheets of both experimental processes.

The first survey was developed October-November 1984 and the second December 1984-August 1985.

The detention times applied to the first survey were 10 and 33 hours, respectively, for the anaerobic tank and two hyacinth ponds; in the second survey in both ponds the flow rate was controlled in order to keep a 33 hour detention time.

The experimental pond system was built up in March 1984. From that date onwards, the two experimental ponds received wastes for 6 months uninterruptedly to prepare proper aquatic conditions.

Before starting sampling for each survey, it took around a month for each experimental period to reach a sufficiently stable biological phase.

All sample collections were made on a 24 hour basis. As regards raw waste, 12 compound samples were collected every two hours and four compound samples of the effluents were collected every six hours.

A larger number of raw waste samples was taken because of the marked quality variation according to the time of the day, whereas with regard to the quality of the effluent, a higher stability was expected as a consequence of the biological stabilization and mixture processes which occur in the experimental ponds. These samplings were repeated five times in the first survey and ten times in the second.

In the hyacinth ponds, periodic (weekly) removal of the vegetation was made to keep the covered area around 70% of the total pond.

The analysis included the following parameters: pH, BOD, COD, total phosphorus, orthophosphate, Kjeldahl nitrogen, ammonia nitrogen, total solids, volatile solids, suspended solids. In the without-hyacinth pond effluents, nitrite, nitrate and Dissolved Oxygen analyses were made in addition to the above mentioned parameters.

Results

Tables 9, 10 and 11 summarize the results of several experimental parameters that have been obtained in the first survey (October-November 1984).

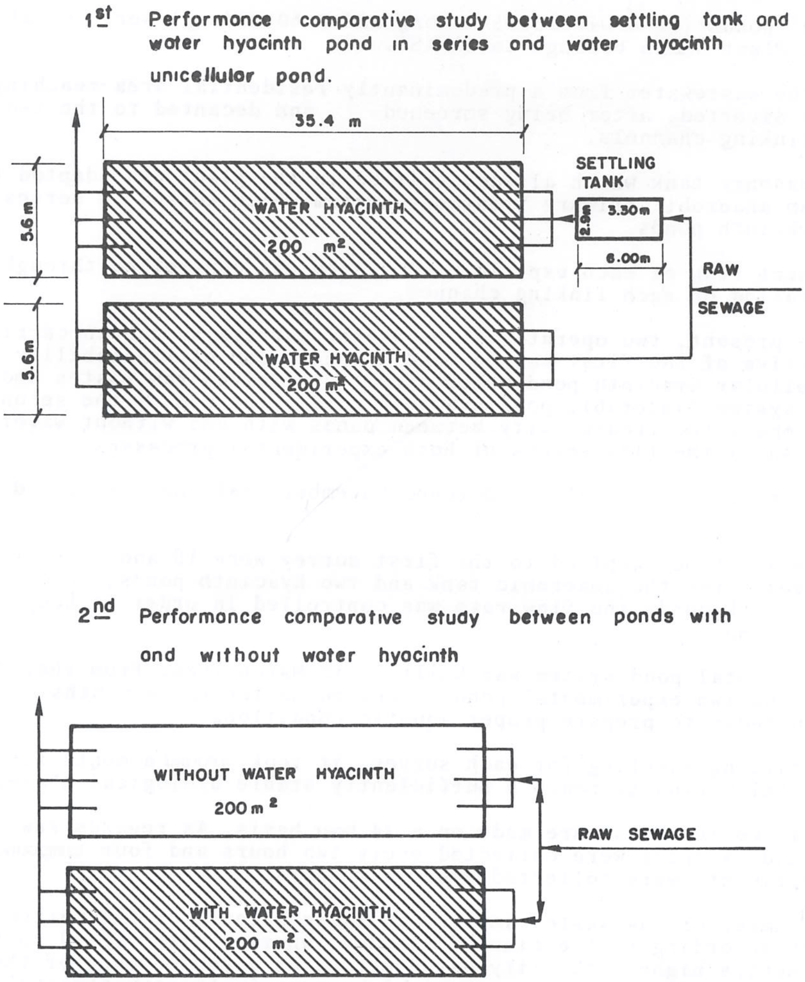


FIG. 4 : FLOW SHEET OF EXPERIMENTAL PROCESSES

Table 9 shows average BOD values determined in the five samplings made on a 24 hours basis. As regards the other parameters, Tables 10 and 11 show the total mean values of the five samplings and the corresponding treatment efficiencies.

Tables 12, 13 and 14 show the analytical data obtained in the second survey (December 1984-April 1985) and Tables 15, 16 and 17 show the results obtained in the period corresponding to July-August 1985.

As shown in Table 9, the BOD removal efficiency was only 17%, whereas in the hyacinth pond in series with the anaerobic pond, the efficiency reached 51%, amounting to a total of 68% as regards treatability in the joint system.

TABLE 9 - BOD Average Values Obtained in the First Survey Carried Out in the Period Oct-Nov 1984 (mg/l)

Station / Date	Influent Waste	Anaerobic Pond Effluent	Effluent Hyacinth Pond Anaerobic Pond Series	Effluent Unicellular Hyacinth Pond
08.10.84	169	125	39	67
18.10.84	191	174	66	59
24.10.84	159	121	69	65
31.10.84	108	112	28	44
12.11.84	108	80	32	38
Average	147	122	47	54
Efficiency %		17	68	63

Mean temp. of the period under survey 22.4°C.

TABLE 10 -Average Values of Several Operational Parameters Obtained in the First Survey Carried Out in the Period Oct-Nov 1984 (mg/l).

Station / Parameter	Influent Waste	Anaerobic Pond Effluent	Effluent Hyacinth Pond Anaerobic Pond Series	Effluent Unicellular Hyacinth Pond
COD	427	375	163	182
Total Phosphate	3.99	4.26	3.81	4.19
Total Nitrate	48.0	46.4	56.0	51.0
Ammonia Nitrogen	25.6	29.1	35.9	34.0
Total Solids	2.024	1.416	1.490	1.521
Volat. Solids	1.371	1.164	1.249	1.330
Susp. Solids	146	115	37	48

TABLE 11 - Removal Efficiency of Several Parameters Obtained in the First Survey Carried Out in the Period Oct-Nov 1984 (Percentage %).

Parameter \ Station	Anaerobic Pond	Hyacinth Pond in Series	Unicellular Hyacinth Pond
COD	12	62	58
Total Phosphate	Neg.	5	Neg.
Total N	4	9	1
Ammonia Nitrogen	Neg.	Neg.	Neg.
Total Solids	30	32	25
Volat. Solids	15	9	3
Susp. Solids	21	75	67

The efficiency of the unicellular pond was a little lower than that of the joint system (63%). However, if we compare the two hyacinth ponds, the unicellular pond was more efficient than the joint system.

The parameter COD kept up with BOD variation. Nevertheless, as regards phosphorus and nitrogen, treatability was highly limited particularly in the unicellular hyacinth pond, in which practically no or negative efficiency has been detected for these parameters.

Although the volatile and total solids removal rates have been low, the suspended solids parameter have shown efficiencies of 75% and 67% for the hyacinth pond in series and the unicellular pond, respectively.

The results of the second survey, which was carried out both in the first period (December/84 - April/85) and in the second period (July - August/86) in the hyacinth and without-hyacinth ponds, indicated a higher BOD removal efficiency in the first pond as compared to the second.

BOD removal efficiencies obtained in the first and second periods were 74% and 60% in the hyacinth pond and 62% and 40% in the without-hyacinth pond, respectively.

COD and suspended solids parameters followed the tendency of BOD efficiency variation and for this last parameter, differences of 47% and 21% have been registered between the two experimental ponds, respectively, in the two periods under study.

In the without-hyacinth pond, a continuous generation of gas in the sludge was detected which caused suspended solids flotation. In the second period of collection there was a scum on the water surface which was partly eliminated with the effluent.

In the hyacinth pond, except for some days of collection, no significant presence of suspended solids in the effluent was noticed, although there was sludge accumulation in the without-hyacinth pond.

Although nutrients (N and P) treatability level was a little higher in the hyacinth pond as compared to the without-hyacinth pond, removal efficiency of these nutrients was very low.

In the first period of collection removal efficiencies of 15% and 1% for total phosphorus and 21% and 15% for total nitrogen were recorded in the hyacinth and without-hyacinth ponds, respectively. In the second period the efficiency decreased to only 3% and 2% for total phosphorus in the hyacinth and the without-hyacinth ponds, respectively. In both experimental ponds, total nitrogen was either zero or negative.

TABLE 12 - BOD Average Values Obtained in the Second Survey Carried Out in the Period Dec/84-April/85 (mg/l)

Station / Date	Influent Waste	Hyacinth Pond Effluent	Without-Hyacinth Pond Effluent
13.12.84	93	29	27
03.01.85	99	30	46
10.01.85	108	29	52
17.01.85	132	31	63
30.01.85	206	44	57
11.04.85	204	64	99
24.04.85	222	48	63
Average	152	39	58
Efficiency %		74	62

TABLE 13 - Average Values for Several Operational Parameters Obtained in the Second Survey Carried Out in the Period Dec/84-April/85 (mg/l)

Station / Parameter	Influent Waste	Hyacinth Pond Effluent	Without-Hyacinth Pond Effluent
COD	412	151	247
Total Phosphate	3.39	2.88	3.35
Total Nitrogen	64.4	51.2	55.0
Ammonia Nitrogen	34.8	43.5	42.8
Total Solids	1.153	865	836
Volat. Solids	944	658	766
Susp. Solids	157	48	75

Mean Temperature: 22.6°C

TABLE 14 - Removal Efficiency for Several Parameters Obtained in the Second Survey Carried Out in the Period Dec/85-April/85 (Percentage %).

Parameter \ Station	Hyacinth Pond	Without-Hyacinth Pond
COD	63	40
Total Phosphate	15.1	1.0
Total Nitrogen	21	15
Ammonia Nitrogen	Neg.	Neg.
Total Solids	25	18
Volat. Solids	30	18
Susp. Solids	69	52

TABLE 15 - BOD Average Values (mg/1) and Efficiency Obtained in the Period July-August 1985

Date \ Station	Raw Waste	Hyacinth Pond Effluent	Without-Hyacinth Pond Effluent
09.07.85	232	87	157
24.07.85	210	112	99
07.08.85	165	38	106
Average	202	79	121
Efficiency %		61	40

Mean temperature: 19^{o}C

TABLE 16 - Average Values for Several Operational Parameters Obtained in the Period July-August 1985 (mg/1)

Parameter \ Station	Raw Waste	Hyacinth Pond Effluent	Without Hyacinth Pond Effluent
COD	393	201	258
Total Phosphate	4.53	4.48	4.54
Total Nitrogen	37.5	35.3	36.2

TABLE 17 - Removal Efficiency for Several Parameters Obtained in the Period July-August 1985 (%).

Station / Parameter	Hyacinth Pond	Without-Hyacinth Pond
COD	49	34
Total Phosphate	3	-
Total Nitrogen	6.0	3.5

Interpretation and Discussion

In a conventional 2 to 3 m deep anaerobic pond and 2-5 day detention time, a significant part of the organic material derived from the waste is removed by sedimentation, the balance being degraded in the liquid medium. Some of the sediment in the bottom of the pond ferments and generates gases (CH_4, N_2, etc.) which go into the atmosphere, some goes back into the water as soluble organic matter, the remaining sediment stays in the bottom. In the liquid medium both anaerobic and facultative degradation occur, especially in the higher layers. Although organic-matter treatability in the anaerobic pond is variable, in view of hydraulic and environmental factors, efficiencies around 60% - 70% are normally accepted for the climatic conditions in the São Paulo State, 40% of which are due to sedimentation and the balance is due to degradation in the liquid medium (Marais and Shaw, 1964).

Aquatic plants in an anaerobic pond may reduce the air oxygen introduction rate, therefore reducing the stabilization rate of the organic matter in the higher layer of water in a facultative condition, while the hyacinth would contribute to BOD removal by biological activity around the roots and suspended solids retention by the root system. However, it should be pointed out that the size of the roots is considerably reduced in a higly polluted aquatic environment as in the case of domestic wastewater.

In the first survey the removal of organic matter by aquatic plants was one of the main objectives. For this reason two pond systems were tested, i.e. one joint system: anaerobic pond plus hyacinth pond in sequence and the other was just a hyacinth pond.

In the first system, removal by sedimentation of a large part of the suspended organic matter in the anaerobic tank was expected to occur; this would enable us to compare the efficiency of the two hyacinth ponds which contained organic matter of different characteristics, i.e. the hyacinth pond in sequence receiving almost exclusively soluble organic matter and the unicellular pond receiving all the raw waste organic matter.

In the conventional stabilization pond system with a short detention time, the pond that receives primary treated effluents presents a lower BOD removal rate than the unicellular pond. This happens because the sedimentation process is more efficient than soluble organic matter stabilization by microbial activity in BOD treatability under short detention time conditions.

In the present study, the same tendency has been found. Although the performance expected in the anaerobic tank was not achieved due to hydraulic problems, there was a reduction around 20% of suspended materials in the tank, obtaining a lower BOD removal efficiency in the hyacinth pond in sequence as compared to the unicellular pond. Thus, it may be assumed that the soluble organic matter removal due to its absorption by the aquatic plants and bacterial activity is lower than the suspended organic matter removal. Otherwise, BOD treatability efficiency in the hyacinth ponds should be the same or higher than found in the unicellular pond.

Then, how would the hyacinth have participated in the organic matter stabilization process in the experimental ponds? This question could be answered to a certain extent by data obtained in a survey carried out in hyacinth and without-hyacinth ponds.

As shown in Tables 12 and 14 BOD removal efficiency in the hyacinth pond is higher than in without-hyacinth pond. Considering also the superiority of the suspended solids removal rate in the first pond to that in the second pond and taking into account that this parameter is significant to wastewater BOD, it seems that BOD removal by hyacinth is achieved through suspended solids retention by the root system.

It should be pointed out that in the without-hyacinth pond a continuous flotation of suspended solid particles has been noticed, deriving from sludge fermentation, which passes out with the pond effluent, increasing the BOD and suspended solids. The lower removal efficiency of these parameters in the without-hyacinth pond as compared to that in the hyacinth pond, is therefore due not only to the low removal rate of the pollutants from the influent waste, but mainly to the addition of materials from the sludge. The return of the pollutants to the water body is of importance in a rather shallow pond, such as the experimental one. In the hyacinth pond the majority of such materials is retained by the roots of the plants covering the pond surface, helping to improve treatability efficiency.

In deeper conventional anaerobic ponds, the sludge solid flotation phenomenon does not occur as frequently as found in the experimental pond. The explanation is that stirring of the water caused by the accumulation of sludge gas is not enough to raise the material from the bottom to the surface.

As regards BOD assimilation capacity by direct absorption by the aquatic plants, experiments by Wolverton (1979) showed that this capacity is very limited, and it cannot be responsible for BOD removal in the hyacinth pond.

An important aspect that should be discussed is the relationship between detention time, depth and applied load. As mentioned before, the water depth in the experimental ponds was 0.8 m and detention time was 33 hours. Under these conditions, BOD removal efficiency in the range of 60% - 75% may be taken as highly satisfactory. Yet, in terms of applied load, the values that have been used ranged from 600 to 800 kg/ha/day which correspond on average to only 1/3 of the loads applied to conventional anaerobic ponds.

According to the project criteria based on the data obtained from several anaerobic ponds in the State of São Paulo (Kawai et al., 1981), on average an efficiency a little lower than 70% with an applied load of 2,000 kg/ha/day has been obtained (see Figure 5).

In accordance with these criteria, there is practically no advantage in treating BOD in a hyacinth pond, as compared to the conventional ones, at least under these hydraulic conditions. On the contrary, from an economical view, the conventional pond is more advantageous because its treatment capacity per area unit is three times higher than the hyacinth pond.

As regards nutrients (nitrogen and phosphorus) removal, none of the experimental processes was feasible. The highest removal efficiency was 21% for total nitrogen in the hyacinth pond according to the second survey data. Negative efficiencies for some nutrient parameters, such as ammonia nutrients, and total phosphate were recorded.

Like the BOD, such nutrients' behaviour can be explained by the influence of the sludge. Some of the nutrients from the waste are kept in the liquid medium and the remaining part settles down in the sludge. While the sludge ferments, the mineralized nutrients are released into the water body. The nutrient release rate, particularly phosphorus, under the anaerobic conditions observed in the experimental ponds, is considerably higher than under aerobic conditions. Besides, the factor depth must have had an important role in the reduction of nutrients treatability in the hyacinth ponds.

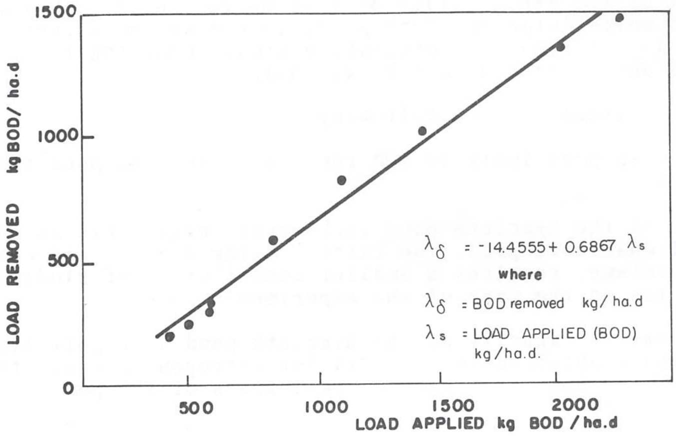


FIG. 5 : CORRELATION BETWEEN APPLIED AND REMOVED BOD LOAD ESTABLISHED FOR ANAEROBIC POND.

- SAO PAULO STATE -

One of the operational problems faced during the experiment was the intense proliferation of mosquitoes.

Sometimes larvae generation was so intense that it formed a black layer on the water surface. To minimize the nuisance caused by the mosquitoes to the neighbourhood a larvicide called "Abate" was periodically applied.

Hyacinth removal is another serious problem for practical implementation of the system. First of all, the pond to be built must be long-shaped to make hyacinth removal easier, which might increase building costs, depending on topographic characteristics of the site. At the same time, technical and economical feasibility of removed hyacinth disposal has not yet been defined.

Sludge accumulation in the system is another aspect that must be taken into account. According to a survey carried out in January 1985 by using a "Newman" sampler, a 10-15 cm sludge layer was formed; the thickness depended on the survey point in the hyacinth experimental pond. This means that there was a 10-15 cm sludge accumulation during only ten months of operation. This can naturally decrease the hydraulic capacity; consequently it will decrease the stabilization capacity of the hyacinth pond.

In addition to these items, the hyacinth ponds may become a favourable environment for the development of snail of schistosomiasis and other types of disease vectors.

SUMMARY

In order to investigate the feasibility of using hyacinth ponds for (raw wastes) primary treatment, some pilot experiments have been carried out at Cambuí's Waste Treatment Plant in Campinas.

Two 0.6 m deep and 200 m^2 area ponds were dug into the ground. An existing

masonry tank which was adapted to be used as an anaerobic pond was also used.

The first survey carried out in October and November 1984 was a comparative study of the treatability of systems made up by anaerobic pond - hyacinth pond and unicellular hyacinth pond; in the second survey, (December 1984 - August 1985), a comparative study involving two ponds, one with hyacinth and one without hyacinth, was made.

The main results obtained are the following:

a) The hyacinth works positively in BOD removal in shallow pond tanks due to the root system.

b) This advantage of the hyacinth pond is, however, negligible as compared to a conventional anaerobic pond. The latter, being deeper, and consequently holding a larger volume, receives a smaller contribution of sludge than shallow ponds (as in the case of the experimental ones).

c) The nutrient removal capacity of the hyacinth pond is highly limited; the highest efficiency obtained reached 21% for nitrogen removal; this low efficiency has also been ascribed to shallowness of the pond associated to sludge contribution.

d) During the experiment period (10 months) a 10-15 cm sludge layer accumulated. This can decrease the hydraulic and stabilization capacity of the pond.

e) In addition to the above-mentioned operational parameters, solution of some problems such as mosquito proliferation, hyacinth removal and disposal, possible infestation by disease transmitting agents, is important before practical implementation of the system.

4. PILOT-SCALE EXPERIMENT, WATER HYACINTH POND IN JACAREÍ

In 1984, Water and Sewage Works (SAAE) in Jacareí, São Paulo State, built an experimental wastewater treatment plant consisting of a water hyacinth pond and a filtering soil area to treat the effluents from septic tanks into which the sewage from a residential area (1300 inhabitants) was discharged.

The design, construction and operational aspects of the plant were guided by CEPAM (Studies and Research Center for Municipal Administration) and CENA (Center for Nuclear Energy in Agriculture).

CETESB - Environmental Protection Agency in São Paulo State - was responsible for monitoring the water hyacinth pond.

Experimental Procedure

Until September 1984, the sub-basin wastewater was treated by four parallel septic tanks. Their effluents flowed to a water hyacinth pond built in the soil in an extended geometric form, with a surface area of 1007.5 m^2 (155 m long and 6.5 m wide) and 0.7 m deep. From this pond the sewage flowed down to three filtering soil areas, with 500 m^2 (10 x 50) each. The plant lay-out made it possible to dilute the effluents from the septic tank with water from a near-by stream up to 1:4 ratio (See Figure 6).

The phytopedological system was started in September 1984, with 100% of the pond surface area covered by plants and dilution with fresh water at the ratio 1:4. The water hyacinth pond effluent passed through half the filtering soil area. The right kind of soil was not used because the builder (SAEE) had not followed the design. Rice was not planted as well.

In December of the same year a predator (a species of butterfly) proliferated intensively causing the death of almost every water hyacinth and the filtering soil clogged.

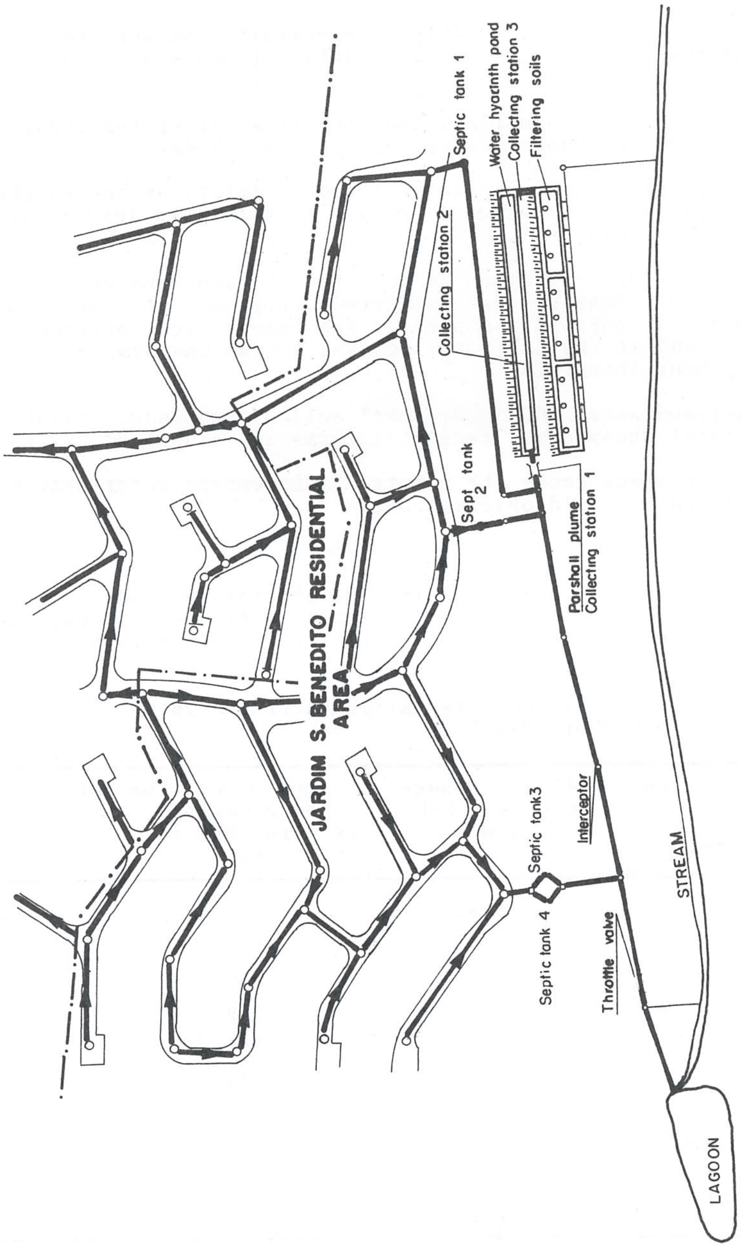


FIG. 6. SEWAGE TREATMENT SYSTEM FOR JARDIM S. BENEDITO RESIDENTIAL AREA - JACAREI CITY

In January 1985, SAEE put new plants in the pond which were taken from the Paraiba River. The SAEE staff noted that the plants located near the inlet did not develop well, and decided to keep the first third of the pond without plants.

In February 1985, CEPAM suggested to CETESB to evaluate the performance of the water hyacinth pond treating the septic tanks effluents with no dilution.

In March 1985, CETESB started sampling. The mean flow during the study period was 0.8 l/s and the theoretical detention time 10 days.

Three sampling points were distributed in the pond inlet, at the Parshall flume (point pl); upstream of the reach covered by water hyacinth (point P2) and at the outlet pipe (point P3).

From March to December 1985, fourteen 24 hour period campaigns were conducted for each sampling point. Samples were collected every hour at every sampling point and made up as 12 compound samples at the inlet, each corresponding to 2 hour intervals and at the other two points, 4 compound samples, corresponding to 6 hour intervals.

The parameters analysed were: BOD, COD, total solids, suspended solids, nitrogen series, total phosphorus, fecal coliforms and dissolved oxygen.

In order to keep some space among the plants, SAAE removed water hyacinths at time intervals defined by field observations.

Results

The main analytical results achieved during the monitoring study are summarized in Table 18. Table 19 shows the removal efficiency of each studied parameter. Based on these data, Figure 7 shows the water hyacinth pond performance.

TABLE 18 - Mean Operational Characteristics Water Hyacinth Pond - Jacareí - March-December 1985.

Parameter \ Sampling Station	Influent Sewage (P1-Parallel Flume)	Upstream of The Reach Covered by Water Hyacinth (P2)	Effluent Sewage (P3-Pond's Outlet)
Flow (l/s)	0.81	-	0.80
BOD (mg/l)	387	162	70
COD (mg/l)	742	460	255
SS (mg/l)	358	249	86
VSS (mg/l)	271	178	64
Total N (mg/l)	72.4	74.9	60.3
Total P (mg/l)	10.4	9.6	8.5
Fecal Coliforms (MPN/100 ml)	$\geq 2.7\times10^8$	$\geq 2.3\times10^7$	$\geq 2.3\times10^7$
pH	5.0x8.7	5.0-8.7	5.2x8.9
Temperature (^oC)	23.5	22.5	21.6

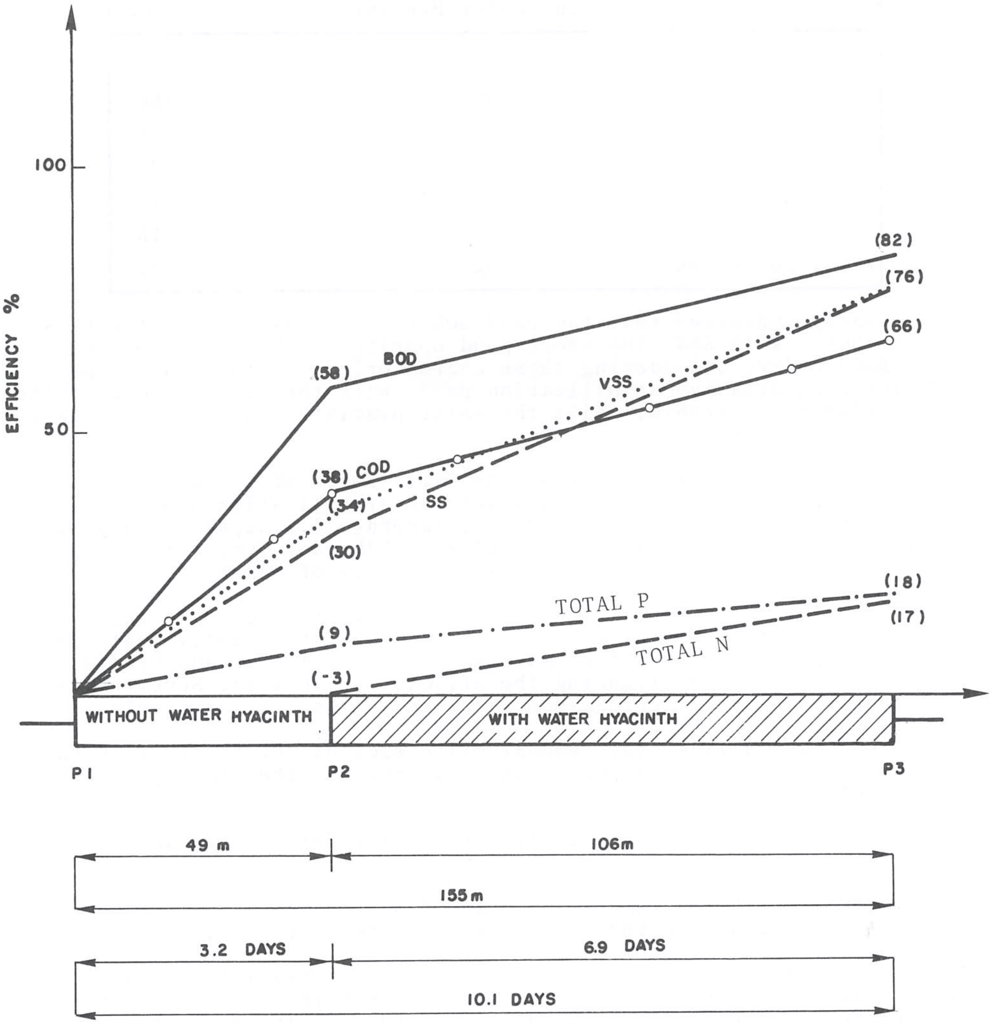


FIG. 7. REMOVAL EFFICIENCY OF SOME PHYSICO CHEMICAL PARAMETERS - WATER HYACINTH LAGOON - JACAREI CITY . MAR./DEC. 1985

TABLE 19 - Mean Removal Efficiencies (%) - Water Hyacinth Pond - Jacareí - March-December 1985.

Parameter	Initial Reach Without Water Hyacinth	Total Pond
BOD	58	82
COD	38	66
SS	30	76
VSS	34	76
Total N	-	17
Total P	-	18
Fecal Coliforms	92	92

The data clearly indicates that the pond BOD removal was 82% and the first reach contributed with 58%. The whole pond operated with surface organic load of 269 kg BOD/ha/day. Considering these characterístics, the studied pond behaved like a facultative stabilization pond, with the difference that the latter's effluent is aerobic, while the water hyacinth pond remained always in anaerobic conditions.

As normally occurs in elongated ponds, the first reach of the monitored pond showed characteristics comparable to anaerobic stabilization ponds. The detention time varied from 1.8 to 4.9 days (average 3.2 days) and organic surface load of 505 kg BOD/ha/day to 1607 kg BOD/ha.day (volumetric load of 72-230 g BOD/m^3.day), with a BOD removal efficiency of nearly 60%.

It is convenient to point out that organic removal efficiency in the reach not covered by water hyacinths was high until June 1985 (nearly 70%). Since then, coinciding with winter time, much more scum formation and sludge solids rise were observed, lowering the efficiency (40-50%). Nevertheless, after September, the pond performance returned to the initial levels.

Regarding suspended solids, the removal efficiency of the first reach varied greatly (from 1 to 70%) and a very high efficiency in the area covered by the plants was noted.

Nutrients (N and P) removal was nearly zero in the first reach and 17% and 18% for N and P, respectively, in the second reach.

Concerning fecal coliforms removal, a mean of 92% in the reach not covered by plants and no efficiency in the last area were recorded in 10 month sampling.

Based on above results, it can be assumed that water hyacinth ponds are not significant as far as organic material removal in terms of BOD is concerned, but a better performance was noted regarding suspended solids removal. On the other hand, there was no improvement in effluent quality from nutrients removal point of view. Such performance was expected based on the explanations already given.

One of the most serious operational problems found during the study was long-legged mosquitoes proliferation.

According to a survey made by CETESB staff, the system treats the sewage from 258 houses, out of which 110 were interviewed. 61% of them complained about the mosquitoes increase, 20% about the bad smells and 11% about small mosquitoes which appeared after implementation of the experiment. The problem was more serious towards the end of 1984 and beginning of 1985, coinciding with summer months, less serious in winter, getting worse again in August 1985.

Up to May 1985, insecticides (Cithion) and larvicides (Abate) were sprayed every fortnight and from June 1985 a simultaneous weekly application was carried out.

The plants removed from the pond were left to dry naturally, but the resulting dry matter was very small for agricultural purposes.

The filtering soil areas were used from August-December 1985 with low efficiency. It must be noted that SAAE had not received the rice seeds and adequate guidance on how to cultivate them until the end of the year. The effluent sampling indicated the following characteristics: 37 mg BOD/1 (43% of removal), $7x10^5$ MPN fecal coliforms/100 ml (80% efficiency), 160 mg COD/1 (27% removal) and 66 mg SS/1 (6% efficiency).

SUMMARY

a) From March to December 1985, the operational condition of the water hyacinth pond built to treat sewage from a residential area in Jacareí was evaluated.

b) The water hyacinth pond operated efficiently and BOD surface load was similar to those observed in conventional facultative stabilization ponds, with the disadvantage of effluent anaerobic conditions.

c) Just as noted in the experiments related to the preceding items, the reach covered with water hyacinth presented a significant suspended solids removal efficiency, but this did not apply to BOD removal.

d) Due to the re-alimentation resulting from both sludge accumulation and the shallow pond, nutrients removal was very limited.

e) One of the most serious operational problems during the study was the proliferation of mosquitoes. Over 60% of inhabitants interviewed complained about the nuisance caused by the water hyacinth pond implementation.

f) The filtering soils performance was poor, showing a reduced pollutants removal efficiency.

5. PILOT-SCALE EXPERIMENT TO PRODUCE ORGANIC COMPOST FROM WATER HYACINTH

This experiment was carried out within the Research Project entitled "Study of the Integrated Systems and Wastes Recycling", developed at the CETESB Biotechnology Experimental Station in Novo Horizonte.

The objective of the study was to verify the feasibility of hyacinth compost production via fermentative process in open air, and to establish the possibility of using it as fertilizer.

Experimental Composting Procedures

To run composting assays, water hyacinth harvested from one of the arms which form the Tiete Reservoir, next to Novo Horizonte, was used.

The water hyacinth, about 8,200 kg, was hand harvested and transported by truck to CETESB Experimental Station. Two loadings of 4,100 kg each were necessary, and 7 operators worked for 2 days on a 8-hour day journey to complete the harvesting and transportation operation. The hyacinth was dried in the open air, spread in 30 cm thick layers. Seven days later, it was chopped in a Penha mod. 5200 U disintegrator.

The chopped hyacinth was spread on the veranda of the Experimental Station for further drying, since it still had a moisture content too high for composting. It was then used to form the piles for composting. 3 different piles were prepared: one with 1,000 kg chopped hyacinth, the second with 1,000 kg chopped hyacinth and 50 kg poultry manure and the third with 665 kg hyacinth, 31.5 kg poultry manure and 3.5 kg special enzymes (see Table 20).

TABLE 20 - Preparation of the Piles for Composting

Compost	Composting
I	Chopped hyacinth (blank)
II	Chopped hyacinth + 5% poultry manure
III	Chopped hyacinth + 5% poultry manure + 0.5% powdered enzyme

Temperature was measured daily (8:00 am, 12:00 am and 4:00 pm) and moisture was periodically measured (3 times a week); eventually water was added to maintain the required moisture.

Flowsheet nº 2 shows the procedure followed for preparing the experimental piles. Follow up was done during the assay period by determining moisture, total Nitrogen, total Phosphorus, Potassium, Carbon, fixed residue and pH, on three samples taken weekly from each pile.

The piles were revolved after 10 and 18 days to introduce oxygen and composting was considered completed on the 32nd day, when the temperature came down to ambient levels, indicating the end of fermentation.

The mentioned enzyme was produced starting from 4 types of vegetables and 2 types of fruit, as presented in Table 21.

TABLE 21 - Materials Used in the Preparation of Enzymes

Material	Weight (kg)	Proportion (%)
Turnip	71	20.3
Carrot	52	14.9
Cucumber	62	17.7
Tomato	63	18.0
Banana	62	17.0
Pineapple	44	12.0
Total	350	100.0

Results and discussion: Analytical results are presented in Tables 22, 23 and 24. Figure 8 shows temperature variation curves in the experimental piles. Curves were built considering the 3 days moving average; this device was used to more clearly show the behavior of the temperature during the assay period.

In the aerobic fermentation process, as in the composting of organic matter, temperature is a fundamental parameter to check the evolution of the fermentation process. In a pile adequately prepared from the nutrients and microorganisms viewpoint, the temperature evolution usually follows a sigmoid curve, with the following steps: mesophilic, thermophilic and maturation. This type of standard curve could be observed in experimental piles 2 and 3 which received respectively manure and manure + enzyme. This could be especially well observed in pile 3.

During the fermentation process, development of several types of microorganisms occurs. At the beginning of the process, the autochthonous flora of bacteria multiplies, leading to an increase in temperature. Once the

FLOWSHEET 2

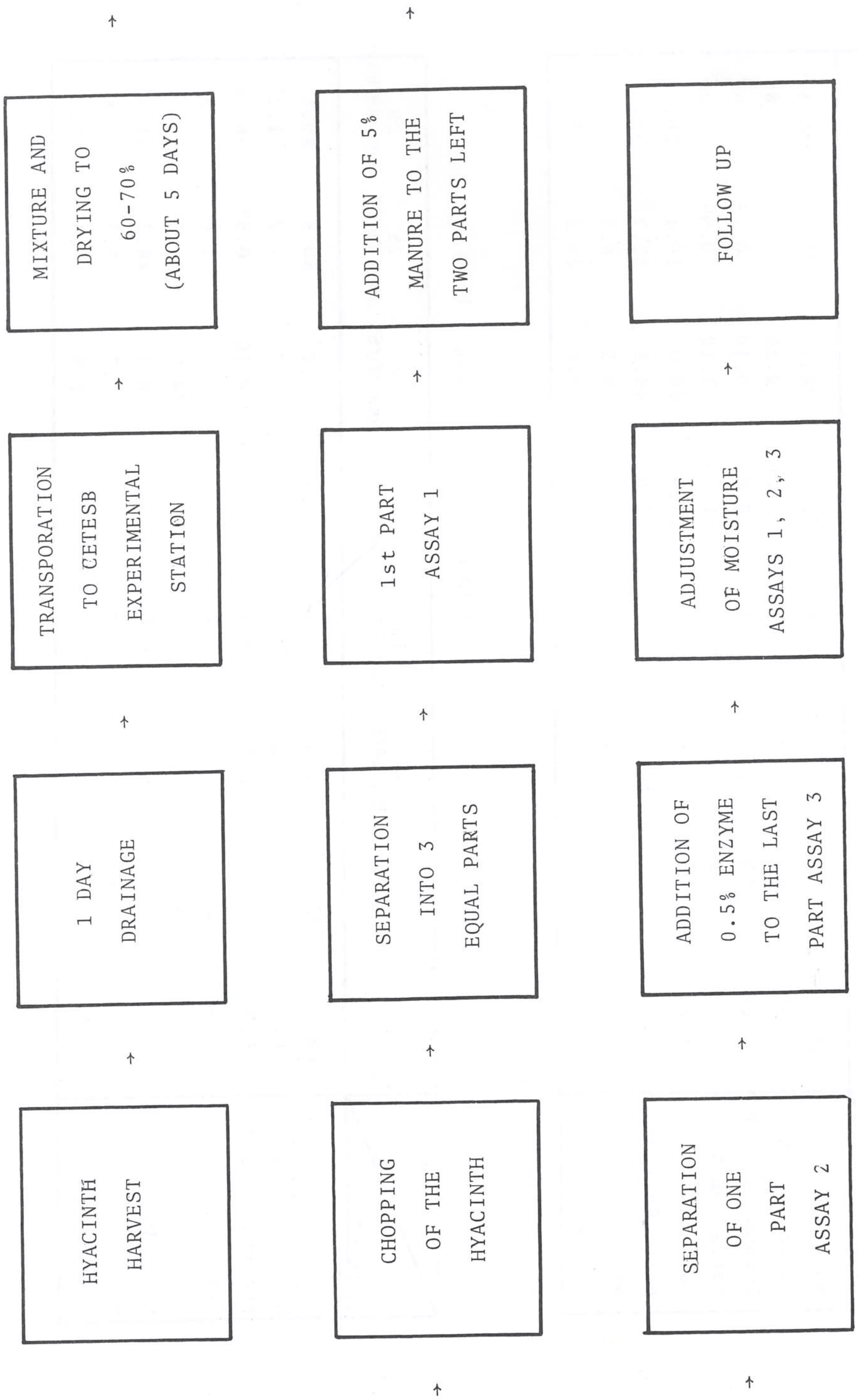

HYACINTH HARVEST
1 DAY DRAINAGE
TRANSPORATION TO CETESB EXPERIMENTAL STATION
MIXTURE AND DRYING TO 60-70% (ABOUT 5 DAYS)
CHOPPING OF THE HYACINTH
SEPARATION INTO 3 EQUAL PARTS
1st PART ASSAY 1
ADDITION OF 5% MANURE TO THE TWO PARTS LEFT
SEPARATION OF ONE PART ASSAY 2
ADDITION OF 0.5% ENZYME TO THE LAST PART ASSAY 3
ADJUSTMENT OF MOISTURE ASSAYS 1, 2, 3
FOLLOW UP

TABLE 22 - Analytical Results of Hyacinth Composting - Pile 1

Analyses \ Period	* Start May 10/85	7 May 17/85	14 May 24/85	17 May 27/85	20 May 30/85	24 June 03/85	27 June 06/85	31 June 10/85
Moisture %	68.5	69.4	70.1	69.6	72.3	70.1	77.7	86.3
Nitrogen % N	0.99	0.99	0.98	0.99	1.00	0.80	0.82	0.89
Phosphorus % P	0.09	0.09	0.09	0.10	0.09	0.10	0.05	0.09
Potassium % K	0.98	0.98	1.00	1.00	1.00	1.10	0.99	1.00
Carbon % C	28.4	28.6	26.5	23.4	23.6	24.0	19.1	20.6
Fixed Residue %	48.4	48.3	50.4	50.3	52.6	48.3	52.2	51.1
pH	6.0	6.5	6.2	6.3	6.5	6.5	6.3	6.4
C/N Ratio	28.7	28.9	27.0	23.6	23.6	30.0	23.3	23.1

* Hyacinth "in natura".

TABLE 23 - Analytical Results of Hyacinth Composting - Pile 2

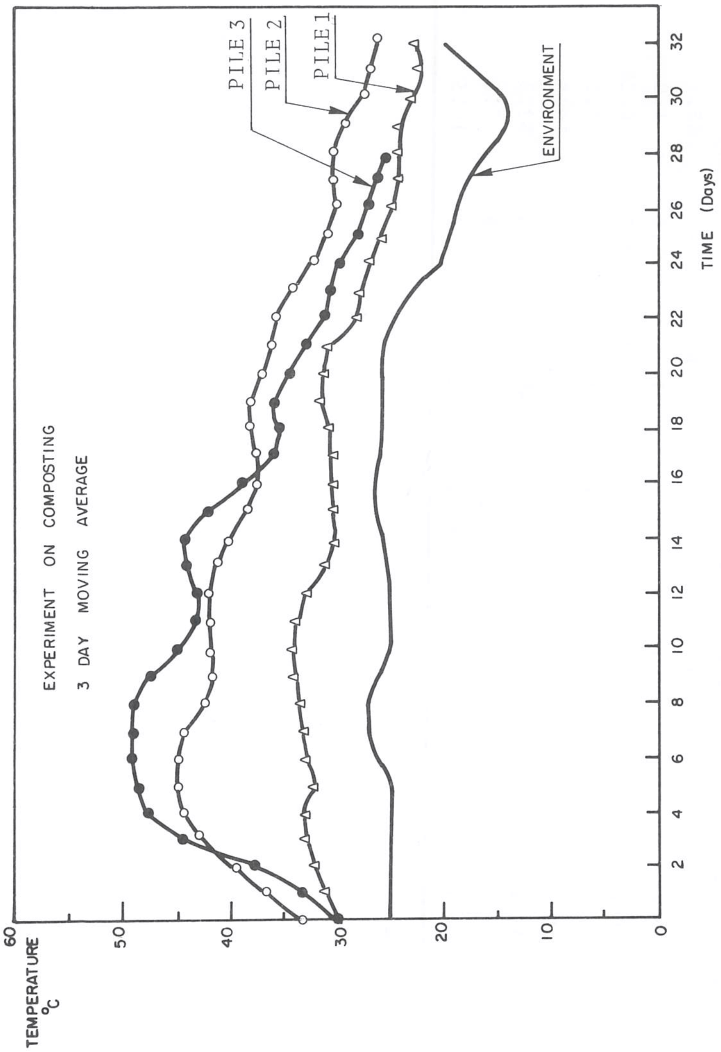
Analyses \ Period	* Start May 10/85	5 May 17/85	12 May 24/85	15 May 27/85	18 May 30/85	22 June 03/85	25 June 06/85	29 June 10/85
Moisture %	68.5	77.9	74.5	75.4	77.5	75.2	80.8	80.5
Nitrogen % N	0.99	1.3	1.0	1.3	1.3	1.2	1.2	1.2
Phosphorus % P	0.09	0.55	0.36	0.45	0.43	0.30	0.35	0.26
Potassium % K	0.98	2.1	1.5	1.7	2.0	1.9	2.0	1.9
Carbon % C	28.4	28.1	28.4	26.3	27.6	24.9	21.0	18.5
Fixed Residue %	48.4	43.1	46.4	50.8	47.6	50.8	48.7	51.4
pH	6.0	7.1	7.7	8.0	7.6	7.7	7.7	7.8
C/N Ratio	28.7	21.6	28.4	20.2	21.2	20.8	17.5	15.4

* Hyacinth "in natura".

TABLE 24 - Analytical Results of Hyacinth Composting - Pile 3

Analyses \ Period	* Start May 10/85	2 May 17/85	9 May 24/85	12 May 27/85	15 May 30/85	19 June/03/85	22 June 06/85	26 June, 10/85
Moisture %	68.5	59.2	67.9	67.2	67.6	-	83.1	74.9
Nitrogen % N	0.99	1.2	1.1	1.1	1.1	1.0	1.0	1.1
Phosphorus % P	0.09	0.32	0.37	0.22	0.24	0.30	0.25	0.23
Potassium % K	0.98	1.5	1.5	1.4	1.6	1.5	1.5	1.5
Carbon % C	28.4	29.5	26.4	26.5	24.0	19.3	19.5	18.3
Fixed Residue %	48.4	47.1	49.6	52.8	51.7	50.3	52.2	52.9
pH	6.0	6.0	7.8	7.8	7.7	7.8	7.5	7.6
C/N Ratio	28.7	24.6	24.0	24.1	21.8	19.3	19.5	16.6

* Hyacinth "in natura".



Δ Pile 1 - 1000 kg CHOPPED WATER HYACINTH

o Pile 2 - 1000 kg CHOPPED WATER HYACINTH
50 kg POULTRY MANURE

● Pile 3 - 665 kg CHOPPED WATER HYACINTH
31,5 kg POULTRY MANURE
3.5 kg POWDERED FRUIT ENZYMES

FIG. 8. TEMPERATURE VARIATION CURVES IN EXPERIMENTAL PILES

temperature exceeds $40^{o}C$, the mesophilic population is the autochthonous thermophilic microbial population. The thermophilic step, which occurs in the range of $55^{o}C$, is the most important of the composting process. Too high temperatures inhibit the microorganism enzymes, reducing the decomposition rate (Finstein, 1980).

The fermentation temperature levels reached in the experimental piles were relatively low when compared to the above-mentioned temperatures. $45^{o}C$ and $50^{o}C$ were reached in piles 2 and 3, respectively.

The main reason for this limited temperature evolution could be the volume of hyacinth piles. When the volume is too small, a significant part of the heat generated inside the pile by microbial activity is lost. The ideal volume for this type of pile for open air fermentation must be greater then 3 m^3 (1.5 m height and 1.5 m width).

Furthermore, the relatively high moisture content (65 to 80%) observed during the experiment, could have hindered the satisfactory development of the microbial flora, which caused low temperatures. The ideal moisture for composting is 50-60% (Finstein, 1980). The curves presented in Figure 8 show that the enzyme used helped the fermentation process.

The chemical composition of the hyacinth used in the experiment showed almost 50% fixed residue, is poor in nutrients (N and P), with a C/N ratio around 29%, and a pH of 6.0. With the development of the fermentation process, the pH rose gradually in piles 2 and 3, reaching a pH of about 8.0, probably due to volatilization and decomposition of organic acids. Following the decomposition of organic matter, the quantitative C/N ratio decreases. After one month fermentation, the C/N ratio dropped to 17% in both piles. This ratio is considered satisfactory concerning the quality of the organic compost (Kiehl, 1985). From the reported results, it can be stated that the hyacinth is a material easily cured and transformed into organic compost using auxiliary fermentation materials (manure, enzymes, etc.) and maintaining satisfactory volume and moisture.

Evaluation of the Hyacinth Compost as Fertilizer

The experiment was carried out using 3 types of hyacinth composts produced according to the above-mentioned procedures. The chemical composition of these composts is presented in Table 25.

The chosen test plant was wheat (*Triticum* sp) IAC-05, due to its short cycle and that it can be grown during this period of the year.

The soil used was the quartz sand taken from the Novo Horizonte area, with its chemical composition presented in Table 26.

For the tests of the compost, clay pots of 5 liters each (60 pots) were used, as they are easily handled and followed up. They were disposed on the veranda of the Experimental Station. To avoid any eventual loss of nutrients each pot was lined with "neutrol".

The following procedure was adopted for the preparation and experimental treatment: 3 types of compost and soil in amounts of composting corresponding to applications of 10, 20 and 40 tons per hectare were distributed, and it was assumed that the effective depth of the soil was 20 cm to correlate the application unit per ha to the pots. 6 replicates were prepared for each treatment and the amounts of hyacinth compost used for each treatment are shown in Table 27.

After wheat seedling (8 seeds per pot), the pots were randomly disposed on the veranda of the Experimental Station.

The 50 cm high plants needed a wire support to grow normally.

73 days after seeding, the plants were harvested and washed. The roots and the

TABLE 25 - Chemical Composition of Composts Obtained from Composting Assays

Composition	Compost		
	I	II	III
Moisture %	78.3	81.7	77.8
N %	0.9	1.1	1.0
P %	0.1	0.3	0.3
K %	1.1	1.9	1.6
C %	22.8	18.5	18.3
Fixed residue %	51.2	46.6	52.8
pH	6.4	7.7	7.5
C/N ratio	25.3	17.0	18.3

TABLE 26 - Chemical Composition of the Soil Used in the Experiment

Parameter	Results	Parameter	Results
N %	0.03	Al meq/100 g	0.32
P ppm	1.00	H+Al meq/100 g	1.65
K ppm	20.00	S e mg/100 g	0.85
C %	0.22	T e mg/100 g	2.50
Ca meq/100 g	0.56	V %	34.00
Mg meq/100 g	0.24	pH	5.60

S = Sum of bases; T = Cation exchange capacity; V Saturation of bases

NOTE: Analysis run at the Chemical Department of the Escola Superior the Agricultura "Luiz de Queiroz"/University of São Paulo.

TABLE 27 - Conditions of Experimental Raising

Type	Amount of Compost Applied to the Pot	Number of Pots
I Compost only	25	6
	50	6
	100	6
II Hyacinth + poultry manure	25	6
	50	6
	100	6
III Hyacinth + poultry manure + enzyme	25	6
	50	6
	100	6
Blank Soil only	0	6

aerial parts from each pot were dried separately in paper bags at 65°C to constant weight.

Results and discussion: Tables 28 and 29 show results obtained for the root system and aerial part respectively for each treatment and for each type of compost, and Tables 30 and 31 the results of statistic handling for each part of the plants. Figure 9 graphically represents results, in weight, for the root system and aerial part.

As it can be seen from the results and from statistical analysis, there is no significant difference in growth of the root system and the aerial part for the different doses applied. Composts II and III, however, which were fermented with manure or with manure + enzyme, presented much better results than compost I. As already pointed out, in view of chemical composition and temperature evolution during fermentation, little microbial activity occurred, and therefore little decomposition of hyacinth in the compost with a small contribution to plant growth.

Concerning the growth differences between compost II and compost III, the pots which received manure + enzyme presented slightly inferior results than the pots which received compost with manure only, in both parts of the plants, which suggests some negative influence of the enzymes in the growth of wheat although they do contribute to the fermentation process.

It is interesting to point out that the application of hyacinth without nutrients does not show any significant difference when compared to the blank, in fact production tends to decrease upon increasing the application, because the hyacinth needs nutrients for its decomposition in the soil. Or else, there is competition between compost and plants for nutrients, particularly for nitrogen, therefore it is not recommended to apply hyacinth alone to the soil without an adequate fermentation.

Economic Aspects

Considering the use of any sewage treatment by-product on an industrial scale, the following fundamental factors should be kept in mind: quality, delivery conditions and cost of the product.

It was stated earlier that compost may be classified as organic fertilizer of satisfactory quality, with a good possibility for marketing. Although the mineral content is low, it is acceptable as organic fertilizer due to its amount of organic matter, C/N ratio, easiness to handle, etc.

Concerning the amounts and continuity in the delivery, which are important factors in assuring industrial-scale production, they may be easily met. According to earlier data (Kawai and Grieco), a 100 to 150 kg/ha.day dry weight hyacinth production, or 2-3 ton/ha.day wet weight, in the treatment system and a 50-100 kg/ha.day dry weight hyacinth production, or 1-2 ton/ha.day wet weight, in the reservoir could be adopted.

A hyacinth lagoon, with a 1 ha area, can treat approximately 150 kg BOD/ha.day with an efficiency of 80%, corresponding to a population of 3000 (Kawai and Grieco). It is important to point out that for every small community the hyacinth productivity is very limited, making the fermentation process difficult and increasing operational costs.

One of the serious problems which have to be faced in the use of hyacinth, is the high moisture content and low density. As with other aquatic plants, hyacinth contains more than 95% moisture, representing an increase in industrialization costs. Another negative aspect is its large volume: 1 ton occupies about 3 m^3, which hinders production, transportation and marketing.

Based on initial considerations, costs of the hyacinth compost production were estimated as follows:

TABLE 28 - Results, in Weight*, for the Root System According to the Type of Compost and Dose (D).

Doses \ Treatment	I						II						III					
D1	1.4	1.9	1.3	3.3	1.5	1.7	3.4	1.8	2.9	2.4	4.2	2.3	3.0	3.0	2.5	2.4	2.5	1.4
D2	1.6	2.1	1.3	1.4	1.7	1.8	3.1	3.3	4.1	5.0	3.9	2.0	2.8	3.1	2.6	3.2	2.8	3.5
D3	2.2	1.4	0.7	1.5	1.9	1.5	2.3	2.3	2.5	3.5	2.5	3.9	3.0	2.1	2.9	4.2	3.9	1.4
Blank	1.1	0.7	0.7	1.5	0.7	1.5												

* Weight in g

TABLE 29 - Results, in Weight*, for the Aerial part, According to the Type of Compost and Dose (D)

Doses \ Treatment	I						II						III					
D1	1.7	2.1	1.0	2.3	1.6	2.4	4.1	3.9	3.9	3.5	4.2	3.4	3.7	4.5	3.5	2.9	3.3	2.9
D2	1.1	2.5	1.2	1.1	2.1	1.9	4.1	4.5	5.5	5.1	3.7	4.2	4.3	4.6	3.2	3.4	3.3	4.4
D3	2.5	1.9	0.3	1.8	2.6	1.7	3.2	4.3	4.7	4.2	4.0	4.4	2.4	3.4	3.8	2.9	4.1	2.6
Blank	1.2	0.9	0.6	0.5	1.2	2.3												

* Weight in g

TABLE 30 - Statistical Treatment of the Aerial Part

CV	GL	SQ	QM	F
Doses	2	1.06	0.530	1.157
Types	2	55.19	27.595	60.251
Interaction	4	1.83	0.458	0.682
Factorial	8	58.08	7.260	10.804
Factorial x Test	1	7.48	7.48	11.131
Treatment	9	65.56	7.284	10.839
Residue	50	33.61	0.672	
Total	59	99.167		

$$\text{Variation Coefficient} = \frac{0.82}{2.943} \times 100 = 27.85\%$$

TABLE 31 - Statistical Treatment of the Root System

CV	GL	SQ	QM	F
Doses	2	1.35	0.675	1.286
Types	2	19.72	9.860	18.781
Interaction	4	2.10	0.525	0.879
Factorial	8	23.17	2.896	4.851
Factorial x Test	1	6.410	6.410	10.737
Treatment	9	29.58	3.287	5.506
Residue	50	29.85	0.597	
Total	59	59.430		

$$\text{Variation Coefficient} = \frac{0.773}{2.368} \times 100 = 32.64\%$$

Legend:
CV = Cause of variation
GL = Freedom degree
SQ = Sum of squares
QM = Average squares
F = F test

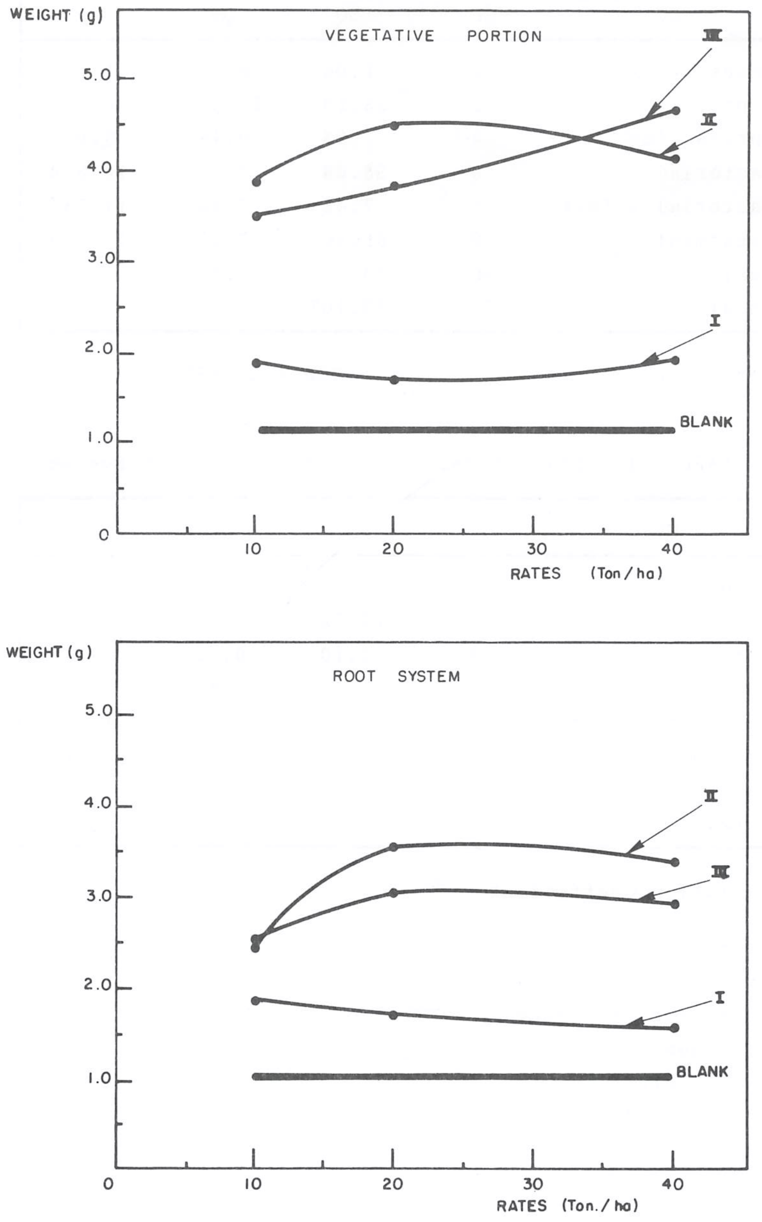


FIG. 9. DATA EXPRESSED IN WEIGHT OF THE ROOT SYSTEM AND THE VEGETATIVE PORTION IN WHEAT CROP EXPERIMENT

Removal of Hyacinth → Preliminary Drying → Chopping → Drying →

→ Preparation of Fermentation → Open Air Fermentation → Revolving → Cured Compost

Costs for hyacinth removal from the reservoir were based on information obtained from SABESP experiment in Mariporã stabilization pond and from the CETESB experiment with the hyacinth reservoir in Jacareí and Promissão. Monthly incomes (including social charges) adopted were Cz$ 2000.00 per worker, for removing hyacinth.

It takes 4-7 days to dry hyacinth to the appropriate fermentation moisture content (50-60%). Construction costs of a covered area for this purpose were estimated. A wooden structure, a plastic cover and a soil and cement coating of the ground were considered. Relying on prior experience, 750 m^2 for daily drying of 3,000 kg of hyacinth, with a 5 days drying period, were adopted. The estimated life of the chopper was 1 year, and 5 years for the cover, except for the plastic cover which has to be annually renewed.

The following calculations were made for a 1 ha pond and for a 3000 kg/day hyacinth production (wet weight).

Cz$/t of hyacinth (95% moisture)

Removal of hyacinth from the pond	100/t
Handling for chopping, drying and preparation of piles	80/t
Cost of manure	20/t
Depreciation	30/t
Energy	20/t
Miscellaneous	20/t
Sub-total	270/t
Cost of fertilizer production with 43% moisture	595/t

For calculation purposes all production processes were considered to occur next to the treatment system of the reservoir.

All expenses related to production were calculated on a 95% moisture basis of the hyacinth. The Ministry of Agriculture establishes the moisture content of organic fertilizer for commercialization at less than 43%. For this reason, the production costs were adjusted according to the moisture content before and after the composting process (95% and 43%).

At present, the domestic organic compost, with 1% N, 0.8% K and 40% organic matter, costs about Cz$ 150/t. The crude manure, though, with higher chemical composition than the hyacinth compost from the mineral and organic fertilizer view, costs about Cz$ 300/t.

These prices show that the production cost of hyacinth compost is too high for general use.

Even deducting removal costs of hyacinth, eventually transferring them to operational costs of the treatment system or of the reservoir, the hyacinth compost would cost as much as Cz$ 400/t, therefore not reaching a wide range of the market.

SUMMARY

The objective of the study was to evaluate the technical and economical feasibility of hyacinth compost production via fermentation process in open air, and to establish its fertilizing value.

The study was developed in the CETESB Biotechnology Experimental Station in Novo Horizonte.

The following main results were obtained:

a) It is possible to obtain organic compost from hyacinth produced in reservoirs or treatment systems by open air fermentation process.

b) The studies about the fertilizing value of the hyacinth compost presented positive aspects concerning its applicability. Production costs on industrial level, though, as estimated based on experimental data, are excessively high. It cannot, therefore, be considered as a fertilizer to reach a wide portion of the market.

c) The most reasonable use of this aquatic plant seems to be the individual use, on a small scale, by those who live next to hyacinth production sites (reservoirs or treatment ponds).

REFERENCES

Bock, J.H. (1966). An Ecological study of Eicchornia crassipes with especial emphasis on its reproductive biology. University of California, Berkeley. CA.

Boyd, C.E. (1970). Vascular aquatic plants for mineral nutrient removal from polluted waters. Economy Botany 24.

CETESB/BNH. (1981). Condições de funcionamento de sete lagoas de estabilização no Estado de São Paulo. Revista DAE nº 124.

Corwell, D.A. et al. (1977). Nutrient removal by water hyacinths, JWPCF.

Dinges, R. (1979). Development of hyacinth wastewater treatment systems in Texas. Aquaculture Systems for Wastewater Treatment. Seminar Proceedings and Engineering Assessment. EPA 130/9-80-006.

Dymond, G.G. (1948). The water hyacinth, cinderella of the plant world. Soil Fertility and Sewage. Doner Publication, New York.

Finstein, M.S. et al. (1980). Microbial ecosystems responsible for anaerobic digestion and composting. Journal of Water Pollution Control Federation, 52(11):

Kawai, H., Grieco, V.M. and Jureidini, P. (1984). A study of the treatability of pollutants in high rate photosynthetic ponds and the utilization of the proteic potential of algae which proliferate in the ponds. Environmental Technology Letters, Vol. 5.

Kawai, H. et al. (1981). Estabelecimento de critérios para dimensionamento de lagoa de estabilização. Revista DAE nº 127.

Kiehl, E.J. (1985). Fertilizantes Orgânicos. Piracicaba. Agronomica "Ceres".

Marais, C.V.R. and Shaw, V.A. (1964). A rational theory for the design of sewage stabilization ponds in Central and South Africa. Trans. S. Afr. Inst. Civ. Engrs., 3.

Middlebrooks, E.J. (1980). Aquatic process assessment. Aquaculture systems for wastewater treatment: An Engineering Assessment. EPA 450/9-80-007.

Mossé, R.A., Chagas, J.M.C and Terra, A.R.S. (1980). Utilização de lagoas de maturação com aguapé (Eicchornia crassipes) na remoção de algas e coliformes em efluentes da lagoa de estabilização. Engenharia Sanitária, v. 19:1.

O'Brien, W.J. (1980). Use of aquatic plant systems for wastewater treatment: An Engineering Assessment. EPA 430/9-90-007.

Ornes, W.H. and Sutton, D.L. (1975). Removal of phosphorus from static sewage effluent by water hyacinth. Hyacinth Control Journal, 13.

Oswald, N.J., M. Aaron, M. and Zabat, M.D. (1973). Designing waste ponds to meet water quality criteria. In: International Symposium for Waste Treatment Lagoons. Missouri basin engineering health.

Penfoud, W.T. and Earle, T.T. (1948). The biology of the water hyacinth. Ecological Monographs. (USA) v. 18 (4).

Swett, Dan. (1979). A water hyacinth advanced wastewater treatment system. Aquaculture Systems and Engineering Assessment. EPA 130/9-80-006.

Wolverton, B.C. and McDonald, R.C. (1975). Water hyacinths for upgrading sewage lagoons to meet advanced wastewater treatment standards. Part II TMX-72730 NASA, NSTL.

Wolverton, B.C. (1979). Engineering design data for small vascular aquatic plant wastewater treatment systems. Aquaculture systems for wastewater treatment. Seminar Proceedings and Engineering Assessment. EPA 130/9-008

Wolverton, B.C. (1979). The water hyacinth: from prolific pest to potential provider. AMBIO vol. VIII.

Yount, J.L. and Crossman, R.A. (1970). Eutrophication control by plant harvesting, JWPCF vol. 42.