# Growth of Water Hyacinths in Treated Sewage Effluent[1]

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*Two thousand plants of the water hyacinth,* Eichornia crassipes *Solms., were introduced on April 11, 1971, into a series of five ponds, each 5000 sq. ft. in area and 2.6 ft. deep. Treated waste water effluent from the Ames sewage treatment plant filled the ponds and was added to pond 1 at 127 gallons per minute. By growth and vegetative reproduction, these plants increased to more than 500,000, and all five ponds were covered completely by July 26. On that date, the extrapolated estimate of total wet weight was 287 U.S. tons/acre (645 metric tons/hectare; 64500g/m²). The estimate of oven dry weight was 13.2 U.S. tons/acre (29.7 metric tons/hectare; 2970g/m²). Ammonia and nitrate disappeared rapidly from the pond water, and phosphate concentrations were lowered appreciably. Evapotranspiration and seepage accounted for water losses of more than 0.5 inches per day. The potential economic values of this plant and its possible use in tertiary treatment to reduce N and P components in waste waters are discussed briefly.*

Our interest in the potential use of *Eichornia crassipes* in a waste water recycling system began with the observation that Florida scrub cattle feed eagerly on these plants when they can get at them. Vaas (1951) evidently made similar observations, for he stated that "in the southern states of North America *Eichornia* is eaten by cows, horses and pigs...." In Malaya, a regular cycle of pig and fish production is maintained by growing water hyacinths for use as pig fodder and collecting washings from pig confinement areas in ponds, thus fertilizing the water for continued plant growth and increasing the food chain base for fish as well (Vaas, 1951). Preliminary feeding tests at Iowa State University, reported by Vetter (1972), indicate that cattle find water hyacinths palatable under certain conditions.

Yount and Crossman (1970) recorded productivity values of *E. crassipes* growing in Florida in Milorganite fertilized ponds. In one series, they recorded daily net productivities of more than 54 $g/m^2$ on a dry weight basis, but daily measures of 40 $g/m^2$ (356 lb/acre) were more commonly recorded. Westlake (1963) calculated, from data of Penfound and Earle (1948) on *E. crassipes* growing in Louisiana, a seasonal maximum biomass of 29 $kg/m^2$ fresh and 1.5 $kg/m^2$ dry, a growing season mean daily productivity of 7.4–22 $g/m^2$ dry, with an average biomass of 13,136 lb/acre (1473 $g/m^2$) dry weight. Dymond (1948) found as assumed yield of 34.6–54.4 $g/m^2$/da dry matter (4.3–6.7 tons/month dry matter), based on average weight of the plants/$ft^2$. Westlake (1963) calculated Dymond's data to represent a biomass of 1.4 $kg/m^2$ dry weight. Penfound (1956) reported daily productivity of *E. crassipes* in Louisiana to be 12.7–14.6 $g/m^2$ dry weight. In turn, Boyd (1970) listed theoretical maximum rates of annual production, based on Penfound's data, as standing crop of 12.8 metric tons/hectare (1280 $g/m^2$) dry weight, maxi-

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mum daily productivity of 14.6 g/m$^2$ dry weight, and maximum annual yield, based on daily productivity rates, of 54.7 MT/ha (5470 g/m$^2$).

Nutrients in municipal effluents and drainage from animal feed lots are accelerating the rate of eutrophication of natural waters, and several authors have suggested the use of aquatic vascular plants to reduce nutrient levels in such waters (Boyd, 1968, 1970; Yount and Crossman, 1970; Pirie, 1964; Little, 1968). Boyd (1970) discussed the possible use of water hyacinths and issued a plea for research on the use of higher plants for nutrient removal. The productivity values determined by Yount and Crossman (1970) for *E. crassipes* resulted from a study of eutrophication control in artificial ponds fertilized with Milorganite and hydrated lime. The periodic discard of harvested plants from one set of ponds resulted in a lower total productivity than in control ponds, where all sample plants were returned to the ponds after weighing. The design of these experiments provided for small additions of nutrients to the first set and it is difficult to accurately assess nutrient level reductions in the two series. Dymond (1948) probably provided the first insight into "pioneer work in South Africa in the disposal of town wastes." These limited experiments indicated that "water hyacinth provides a means of purification and of trapping vast amounts of fertile elements which are normally lost."

Rogers and Davis (1972) designed laboratory experiments to determine absorption of nitrogen and phosphorus by water hyacinths. In one experiment, five plants were placed in 9.0 liters of sewage effluent and evapotranspiration and nutrient content of the water assayed for four days. These studies showed changes in Kjeldahl nitrogen concentrations from 22.0 to 12.0 mg/L while in control beakers (sewage effluent without plants) nitrogen values were 20.5 on day 1 to 17.5 mg/L at day 4. Phosphorus concentrations were 3.7 to 0.1 mg/L while control solutions were 4.5 to 3.0 mg/L. Rogers and Davis (1972) further determined water losses to be 5.3 times greater from containers with plants than from those without. These laboratory experiments indicate that "1 hectare of water hyacinth could absorb the nitrogen and phosphorus wastes of over 800 persons".

It is a logical premise that various methods for growing and harvesting aquatic plants might be used to reduce the levels of inorganic nutrients in waste waters before release to streams or lakes. *Eichornia crassipes* seems to offer great potential value in this connection, because (1) it is a floating aquatic, easily harvested: (2) it reproduces vegetatively at a very rapid rate (Penfound and Earle, 1948) and (3) chemical evaluations indicate a relatively high rate of utilization of essential elements (Boyd, 1969; Boyd and Vickers, 1971).

The first of the described ponds used in this study was used by Raschke (1968, 1970) in an investigation of the role of algae in tertiary treatment ponds. The other four were used first by Huggins (1969) in a study of the growth of channel catfish in tertiary treatment ponds. In both studies, evaluations of algal growth were made but the possible roles of aquatic vascular plants were not considered. Both studies are interesting and significant but comparisons between them and the present investigation have not been made for the following reasons:

1. The basic intent of the present investigation was to provide a demonstration of the potential usefulness of growing water hyacinths in treated sewage effluent.

2. The productivity of the hyacinths is measurable directly by dry weight increments, while algal productivity is usually measured indirectly by measurements of chlorophyll, plankton counts, $C^{14}$ uptake etc.

3. Oxygen production and carbon dioxide utilization during algal photosynthesis introduce factors of diurnal change in pond waters and the magnitude of such changes is increased by the respirational needs of the entire submerged biomass. Hyacinths do not induce large diurnal changes of this nature.

4. Oxygenation of water by algae greatly increases the potential rate of nitrification of ammonia to nitrate by bacteria and, also, these bacteria add a significant amount to the entire bulk of the biomass. Since the photosynthetic organs (leaves) of the hyacinths are above water, these plants do not add oxygen to water in the same manner as algae. Furthermore, the respiration of hyacinth roots is a constant drain on dissolved oxygen. Thus, the hyacinths probably do not

stimulate increased rates of nitrification.

5. Algal productivity and the expansion of bacterial, protozoan, microcrustacean, aquatic insect, and fish populations have rather obvious causal relationships. But, in order for hyacinths to contribute significantly to food webs, they must die in the water and be decomposed. In the present experiments, they were not allowed to die in the ponds but were removed by a more or less continuous harvest. No evaluation of possible food web relationships was included in the research plan.

6. When algae are relied upon to modify nutrient conditions in non-laboratory environments, there appears to be no economically feasible mechanism for harvesting them, thereby effecting a decrease in nutrient levels. Rather, the harvesting of organisms at higher levels in the food web, i.e., fish, must be depended on to achieve this objective. If a harvest at some level is not achieved, the nutrients are simply recycled.

The harvesting of hyacinths by simple, mechanical means accomplishes a direct removal from the habitat of those nutrient elements incorporated in the plants.

A preliminary report on the potential use of *E. crassipes* to remove nutrients in an anaerobic lagoon effluent system was made by Miner, Wooten, and Dodd (1971). The purposes of the present research were: (1) to determine productivity of *E. crassipes* growing in municipal sewage effluent and (2) to relate productivity values to rates of nutrient removal in such waters.

## MATERIALS AND METHODS

Plants used in this study were collected from a roadside ditch alongside U. S. 90, LaFourche Parrish, four miles west of Allemands, Louisiana, and transported to Ames, Iowa, in sealed plastic bags. Effluent from secondary treatment at the Ames Water Pollution Control Plant was discharged into the first of a series of five ponds, each 100 ft x 50 ft and 2.6 ft deep at a rate of 127 gal/min. Pond 1 flowed into pond 2 through an 8-inch conduit situated at the surface level. Similar conduits connected the ponds in series so that water flowed from 1 to 2 to 3 to 4 to 5 and from 5 into a ditch that led to the plant outfall to the receiving stream. Capacity of each pond was 98,000 gal. (370,000 l). Surface area of each pond was approximately 1/8 acre or 465 $m^2$. The final discharge rate was usually much less than half the entrance rate, and the water losses are attributed mainly to evaporation, transpiration, and seepage.

Approximately 2,000 plants were introduced into pond 1 April 11, 1971. At this time they were barely noticeable, covering perhaps 5% of the pond surface. By vegetative reproduction, the surface of this pond was covered with plants by June 7, at which time 25% of the plants were transferred into pond 2, 25% into pond 3, and 25% into pond 4. The plants in all of these ponds increased rapidly thereafter, and, on June 29, 25% of the plants in pond 1 were transferred to pond 5. By the end of July, all ponds were fully covered, and the estimated total exceeded 500,000 plants.

Water samples were taken weekly from the inflow and outflow of all ponds. A Leeds and Northrup Meter (Model 7417) was used to determine pH. Analyses were made for ammonium nitrogen (Nesslerization), nitrate nitrogen (cadmium reduction with 1-napthylamine-sulfanilic acid), orthophosphate (Stannaver), and chloride (Mohr) according to Hach (1969) methods. To estimate maximum nutrient uptake efficiency of the system, inflow water was turned off for a two-week period in August. During this time, dissolved oxygen also was determined by the PAO method (Hach, 1969).

Total standing crop was estimated on July 26 by removing all plants from $m^2$ quadrats and determining wet and oven-dry weights.

## RESULTS AND DISCUSSION

Starting with the 2,000 plants used as inoculum in pond 1, full coverage of the five ponds (2325 $m^2$) was attained in approximately 100 days. The estimated total production values on July 26 are shown in Table 1 and are expressed in several ways to permit comparisons of the growth of hyacinths in treated sewage effluent with growth in other habitats as variously reported in the literature.

These data for *E. crassipes* growing in water enriched with effluent from a secondary

Table 1. Various expressions of wet and oven-dry weights of water hyacinths grown in treated sewage effluent from April 11 - July 26, 1971.

| | Fresh | Oven-dry |
|---|---|---|
| Estimated plant weights for all 5 ponds on July 26 (total area 2325 $m^2$) | 334,800 lb | 15,400 lbs |
| | 167 tons | 7.7 tons |
| | 150 metric tons | 6.9 metric tons |
| Seasonal maximum biomass (as of July 26) | 287 tons/acre | 13.2 tons/acre |
| | 645 MT/ha | 29.7 MT/ha |
| | 64.5 $kg/m^2$ | 2.9 $kg/m^2$ |
| | 64516 $g/m^2$ | 2970 $g/m^2$ |
| Growing season productivity (105 days) | 614 $g/m^2$/day | 29 $g/m^2$/day |

sewage treatment plant indicate that much higher growth rates are attained than when plants are grown in natural habitats. Westlake's (1963) recalculation of Penfound and Earle's (1948) data indicated an average biomass of 13,136 lb/acre (1473 $g/m^2$) dry weight, whereas plants grown in the Ames treated sewage effluent produced a calculated average biomass of 26,409 1b/acre (2962 g/m) dry weight. At the time of maximum production, sewage ponds had a total calculated plant mass of 150 metric tons wet and 6.9 metric tons dry weight. This is equal to a production of approximately 30 metric tons of organic matter per hectare in approximately 105 days. Growth rates seem to reach optimum levels when nutrients are constantly maintained at high levels and plants are periodically harvested to alleviate overcrowding. In a climate permitting continuous growth throughout the year, more than 100 metric tons per hectare (44 U. S. tons/acre; 10000 $g/m^2$) could be produced annually starting with a small inoculum every hundred days and, with continuous harvesting under ideal conditions, Westlake's (1963) estimate of a possible annual yield for *E. crassipes* of about 150 metric tons/hectare (66 U. S. tons/acre; 1500 $g/m^2$) organic matter could easily be achieved. As pointed out by Boyd (1970), "if even 50 percent of the maximum value was actually obtained, it would represent a yield much higher than obtained with crop plants."

One of our primary concerns in this research was an evaluation of the removal of those inorganic nutrients from waste water that contribute most significantly to the eutrophication of natural waters. Previously (Miner et al., 1971), effluent from an anaerobic lagoon supporting rapid growth of *E. crassipes* was shown to contain only 7% as much nitrogen at the end of four months as was introduced into the system, amounting to a calculated withdrawal of 500 1b N/acre. The nitrogen data in Table 2 may be interpreted very broadly as showing a rapid disappearance of both ammonium and nitrate in the series of ponds. This is shown even more strikingly by the data in Table 3 for the two-week period when the inflow was turned off. Although much of this nitrogen was absorbed by the hyacinths, many other factors must be considered, among them: composition of the treated effluent shows marked variations throughout any given day, re-

Table 2. Results of pH determinations and analyses of nutrient levels (ppm) in tertiary sewage ponds in 2-week period after full coverage with water hyacinths.

| July 19 | pH | Ammonium Nitrogen | Nitrate Nitrogen | Ortho-phosphate | Chloride |
|---|---|---|---|---|---|
| Main inflow | 7.5 | 2.4 | 2.9 | 18.8 | 45.5 |
| Pond 1 outflow | 7.2 | 2.7 | 4.1 | 17.5 | 45.5 |
| Pond 2 outflow | 7.1 | 1.5 | 2.0 | 16.2 | 46.5 |
| Pond 3 outflow | 7.0 | 1.1 | .9 | 15.6 | 46.0 |
| Pond 4 outflow | 6.9 | 0.7 | 0 | 19.3 | 47.5 |
| Pond 5 outflow | 7.0 | 0.5 | 0 | 16.8 | 48.5 |
| August 2 | | | | | |
| Main inflow | 7.2 | 13.1 | 1.0 | 23.1 | 50.0 |
| Pond 1 outflow | 7.1 | 9.7 | 2.6 | 28.1 | 49.0 |
| Pond 2 outflow | 7.0 | 5.5 | 1.5 | 26.2 | 49.5 |
| Pond 3 outflow | 6.9 | 4.2 | .8 | 23.7 | 49.0 |
| Pond 4 outflow | 6.8 | 3.5 | 2.5 | 19.3 | 51.0 |
| Pond 5 outflow | 6.9 | 0.6 | 0.0 | 21.0 | 53.0 |

flecting habits of the local citizenry. In periods of rainy weather, the unauthorized diversion of runoff water into the sanitary sewer system is reflected by a dilution of the effluent; the major nitrogen component in fresh effluent is ammonia, and this is mostly converted to nitrate in time by bacterial action. Some ammonium ions, however, are absorbed directly by plants, and some ammonia is lost directly to the air in gaseous form; a series of vertical samples taken on July 23 from Pond 5 suggests a possible stratification of ammonia. This is a matter of some concern, because the flow from one pond to the next was at the surface, and no mechanism for mixing the water in each pond was installed; the anaerobic conditions frequently existing under dense stands of *E. crassipes* may result in extensive nitrogen losses due to denitrification; water losses due to evapotranspiration constantly tend to increase the relative concentration of solutes in the remaining solution; the design of these demonstration experiments was not sophisticated enough to permit evaluation of precipitates that accumulate in the sediments of the ponds.

In culture experiments, increase in nitrogen levels has been shown to increase both plant numbers and total yield but did not, by itself, seem to cause any change in mean weight per plant (Chadwick and Obeid, 1966). These authors further showed that the maximum yield of *E. crassipes* was attained at the highest nitrogen level used in the experiments, 25 ppm. We have noted vigorous growth of plants in animal waste waters with 100 ppm N (Wooten, Dodd, and Miner, unpublished), and it appears that the usual nitrogen levels in sewage-enriched waters will not be high enough to inhibit vigorous growth.

This growth in animal waste waters is in agreement with data on sewage effluent given by Rogers and Davis (1972) but does not confirm their conclusion, based on poor plant

Table 3. Measurements (ppm) of ammonia, nitrate, and orthophosphate at outflow areas of hyacinth ponds with no treated sewage effluent added during a 2-week period, Aug. 3 - Aug. 17.

| | Ammonium Nitrogen | | | Nitrate Nitrogen | | | Orthophosphate | | |
|---|---|---|---|---|---|---|---|---|---|
| | Aug 3 | Aug 9 | Aug 17 | Aug 3 | Aug 9 | Aug 17 | Aug 3 | Aug 9 | Aug 17 |
| Pond 1 | 9.7 | 1.2 | 0.6 | 2.6 | 0.0 | 0.29 | 28.1 | 21.2 | 18.7 |
| Pond 2 | 5.5 | 0.8 | 0.7 | 1.5 | 0.8 | 0.07 | 26.2 | 12.5 | 5.0 |
| Pond 3 | 4.2 | 0.8 | 0.6 | 0.8 | 2.5 | 0.13 | 23.7 | 13.5 | 15.0 |
| Pond 4 | 3.5 | 0.05 | 0.1 | 2.5 | 0 | 0.05 | 19.3 | 15.0 | 15.0 |
| Pond 5 | 0.6 | 0.0 | 0.2 | 0.0 | 1.5 | 0.03 | 21.0 | 15.7 | 17.5 |

absorption (96 to 97 mg/l), in 50% Hoagland's solution, that "water hyacinths would be expected to effectively decrease nitrogen concentration for the lower concentrations but not the higher concentrations".

Results of analyses for orthophosphate (Table 2) seem less striking than for nitrogen. However, they should be viewed in light of the following factors, which influence interpretations of data on phosphate removal in open ponds such as these, particularly when the measurements taken are of amounts remaining in solution.

1. Continued evaporation and transpiration water losses have the effect of concentrating phosphate in the remaining solution, even though water levels are maintained by a constant inflow. If, for instance, the measured concentration of phosphate remained the same after half the water had evaporated, an amount equal to the measured value must have gone out of solution (by absorption, adsorption, or precipitation).

2. Complex precipitates involving phosphate form at undetermined rates and take significant amounts of phosphate out of solution.

3. Phosphorus use by plants is generally less than the nitrogen use.

4. If nitrogen should be depleted to near zero levels, the absorption of phosphorus would be slowed significantly.

During the period, August 3 - August 17, when the inflow was turned off (Table 3), the average drop in dissolved orthophosphate levels in the five ponds was 9.4 ppm (approximately 40%). In terms of pounds per acre of a pond 2.5 feet deep, this represents a removal from solution of approximately 63 lb phosphate in two weeks. This figure is conservatively low, because the observed water losses could not be distributed between leakage and evapotranspiration on any reasonable basis, and, thus, the concentrating effect of evapotranspiration could not be estimated.

Contrary to the data of Rogers and Davis (1972), indicating that water hyacinths were increasingly less effective in removing phosphorus from 7.5 mg/l concentrations in Hoagland's solution and were not effective when the initial concentration was 15.6 mg/l phosphorus, Table 2 and 3 show values up to 28.1 ppm and apparent subsequent decrease in phosphorus content of the sewage effluent.

The determinations of pH made at weekly intervals from the first week in May to the first week in September showed that pH differences among ponds were seldom more than 0.2 or 0.3 units. The pH of the effluent from the treatment plant ranged from 7.6 to 7.2, and the water in each pond fluctuated within this general range until it was completely covered, when a slight depression to a range of 7.2 to 6.7 was noted. The observed pH ranges are in accordance with those established as optimum for growth of *E. crass-*

*ipes* by Chadwick and Obeid (1966) and Parija (1934).

Local water sources usually are somewhat alkaline, and the depression of the pH range to neutrality and slightly below probably is due to respiration of the entire submerged biomass, of which hyacinth roots are a part. The variation in total respiration would be minor in any 24-hr period, and large fluctuations in pH due to respiration were not expected.

Because the leaves of this plant are emergent, they cannot effect pH changes through photosynthetic utilization of carbon sources in solution as is the case with algal blooms and dense growths of submerged aquatic vascular plants. Furthermore, light intensities underneath dense hyacinth mats are low enough to inhibit growths of algae and other submerged aquatics.

Measurements on July 26 showed the influent waste water to pond 1 to have an oxygen concentration of 5 ppm while the effluent from this pond had only 1 ppm. The concentration rose slightly in succeeding ponds, however, and was 3 ppm at the outlet from pond 5. Measurements on August 9 showed a similar trend. These measurements were essentially of surface water, but, in the succeeding year (1972), when the ponds were similarly treated, measurements of a series of vertical samples were made on Aug. 12 and Aug. 30. These samples were collected at 5 a.m., 9 a.m., 1:30 p.m., 6 p.m., and 10 p.m. All samples from near the bottom (50 cm depth) had an oxygen concentration of 0 ppm. At the 30-cm depth, the concentration ranged from 0.2 to 1.0 ppm. Surface samples ranged from less than 1 ppm at 9 a.m. on a cloudy day to 14.6 ppm in late afternoon of a bright, sunny day.

The rapid drop in $O_2$ concentration in pond 1 is probably associated with a rapid oxidation of ammonia by bacterial action, while the metabolic requirements of all groups (bacteria, fungi, protozoa, insect larvae, microcrustaceans, hyacinth roots, etc.) account in general for the anaerobic conditions at the bottom.

The observed fluctuations in $O_2$ concentrations at the surface and the volume of oxygen actually utilized in metabolism of the total submerged biomass might well be evaluated more critically. Some or all of the following may be pertinent to such an investigation.

(a) Oxygen increases due to photosynthesis by algae and submerged aquatics are not likely since they are essentially eliminated by shading.

(b) Heavy rains usually add oxygen-rich water to the ponds.

(c) When air turbulence is slight, an oxygen-rich layer of air may exist around the hyacinths as a result of rapid photosynthesis, and, since the shaded waters remain relatively cool, a higher rate of oxygen absorption may occur than in open-pond surfaces free of plants.

(d) Strong winds may induce vertical mixing.

(e) Hyacinths contain aerenchyma tissue, which allows for internal ventilation, and oxygen seemingly reaches root tissues in this way. It is conceivable that oxygen may diffuse from roots into the water under some circumstances.

A rough estimate of the water budget in this system was obtained when the inflowing waste water was turned off for 14 days (August 3-17). During this period, the average drop in water level in four of the ponds was 1.3 inches per day. One of the ponds lost water much more rapidly than this, evidently through an undetected drainage opening. Miner et al. (1971), reported evapotranspiration losses from hyacinths to be slightly more than double pan-evaporation losses alone during a 120-day period. This would be comparable to a rate of approximately 0.6 inches per day lowering of water levels. Even if greater-than-average evapotranspiration rates are assumed for the 14-day period, it is evident that no more than half the observed water losses can be accounted for by evapotranspiration. The balance is assumed to have been lost by groundwater seepage.

In a different approach to the same problem, the rate of inflow to ponds and the rate of outflow from pond 5 were measured and compared on August 2, 1971. The difference, approximately 60 gallons per minute, is the amount to be accounted for by various losses from the ponds. In terms of volume per day, this amount is approximately 86,400 gallons, which is equivalent to slightly more than 5 inches per day. This value is directly influenced by the large unmeasured leakage loss from pond 4.

Plant uptake of chloride from the pond waters during the period when the inflow was turned off occurred at rates of 8-14 ppm/week. Although chloride may be significant to growths of some plants in trace amounts (Levitt, 1969), our interest in measuring this parameter was a hope that it might be used to evaluate concentration effects due to water losses by transpiration and evaporation. The results are inconclusive because of the unmeasured leakage losses from pond 4.

## CONCLUSIONS

The results of this study permit the conclusion that plants of the water hyacinth (*Eichornia crassipes*) will grow vigorously in domestic sewage effluent from a modern secondary treatment plant. They use appreciable amounts of the inorganic forms of nitrogen and phosphorous found in such effluents and, in so doing, effect a significant reduction in the concentrations of materials that are major contributors to the inorganic nutrient enrichment of natural waters.

Claims of efficiency should perhaps be guarded at this time because the experimental procedures followed did not permit an accurate budget accounting for all possible losses of the various nutrients involved. Nitrogen losses as evaporated ammonia, water and dissolved ion losses to groundwater seepage, and the formation of complex precipitates accumulating in the pond sediments were not evaluated. Yet, the enormous growth rate of this plant, which, in terms of dry weight of organic matter, exceeds that of any crop plants, by itself accounts for a large share of those nutrients that "disappeared" from the pond water. The potential value of water hyacinths in effecting a type of tertiary treatment of sewage effluent is clear and, in our opinion, warrants the expense of a larger and more sophisticated experimental program to more accurately define the nutrient budget of this plant.

It is a premise with which we concur that the use of water hyacinths in tertiary treatment may provide a product valuable enough to pay a major part of the expense of operation. The free floating habit of water hyacinths makes them amenable to simple mechanical harvest, which can be further simplified and reduced in cost through engineering studies.

A main objection to the use of water hyacinths in animal nutrition is the high water content (95-96%). Dehydration, with or without pelletting, can be achieved with existing equipment, and the cost could well be reduced by adapting equipment or developing new equipment suited to treating this plant. Also, it has been show (Vetter, R., unpublished data) that mixing water hyacinths with corn-plant residues can lead to a type of ensilage with potential food value for ruminant animals.

Once the economic value of this plant is established, then the use of larger ponds would become feasible. Surface waters could be diverted to such ponds to mix with the effluent and increase the volume. An experimental determination of the total growth needed to reduce phosphates to legally acceptable levels might well determine the final size of such ponds. It is conceivable that nitrogen or other nutrients might become limiting before the desired reduction in phosphates is achieved and that the addition of some type of chemical fertilizer might be required to maintain a balanced growth.

As a cautionary note, the abundant presence of calcium oxalate crystals in *Eichornia* tissues has been reported by Arnott (1966) and should be considered as a potential hazard in nutritional use.

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**Book Reviews** (*continued from page 28*)

**Hallucinations: Behavior, Experience, and Theory.** Edited by R. K. Siegel and L. J. West. 322 pp. illus. John Wiley and Sons, New York, 1975. $25.00

Although most of this absorbing book lies far afield from botany, it is appropriate to take note of it in *Economic Botany.* Many of the best-known hallucinogens are of plant origin, and many hallucinogens are still used in our society and in aboriginal cultures as natural products.

Most contributions in this volume are concerned with social or psychological aspects of hallucinations, but references to plants employed to induce hallucinatory states are found on many pages. Two chapters, however, deserve special mention for their concern with plants.

Siegel and Jarvik's chapters, "Drug-induced Hallucination in Animals and Man," is a fascinating field and laboratory study of evidence that many animals feeding upon hallucinogenic plants (examples: *Amanita muscaria, Trichocereus, Cannabis, Anadenanthera peregrina,* etc.) may experience hallucinatory or other psychoactive effects that attract them to the plants.

The chapter most pertinent to ethnobotany is La Barre's "Anthropological Perspectives on Hallucination and Hallucinogens." La Barre discusses in detail many intricate aspects of the use and significance, especially in primitive societies, of plants that induce hallucinations or "dissociated states." He mentions many hallucinogens, both Old World and New, with deep authority born of a professional lifetime of studies in the use of such psychoactive plants. This chapter is well worth the attention of every ethnobotanist. Of particular interest is the bibliography of some 300 items.

R.E.S.

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