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9. ABSTRACT

It has been postulated that nutrient absorption by controlled populations of Eichhornia crassipes (water hyacinth) or other species of aquatic plants might reduce concentrations of nitrogen and phosphorus in eutrophic lakes or in effluents prior to their release into natural waters. In this study, water hyacinths were cultivated in nutrient-enriched water of earthen ponds to determine rates of growth and absorption of nitrogen and phosphorus under conditions similar to those in eutrophic lakes or effluent holding ponds. Five hundred water hyacinths were placed in each of three enclosures in the ponds. The average dry weight of individual plants was 1.79 g and initial standing crop was 43.8 g/m^2 in enclosures. Triple superphosphate and ammonium nitrate were broadcast over pond surfaces at 2-week intervals. Plants grew rapidly and the lush green foliage exhibited no signs of nutrient deficiencies, although only nitrogen and phosphorus were added to the water. Data on growth rates and nitrogen and phosphrus absorption were expanded to a kg/ha base. Magnitudes of growth and nutrient absorption by plants in the three ponds were generally similar during a given period of measurement, but rates of dry matter, nitrogen and phosphorus accumulation increased as the study progressed. Plants increased in size during the study, so at the beginning of each period of growth and nutrient uptake measurement, plants were larger than at the beginning of any previous period. Average rates of nitrogen and phosphorus removal over the entire period of growth were 3.4 and 0.43 kg/ha/day, respectively. Research methods and findings are reported in detail. Findings verify previous suggestions that water hyacinth can remove large amounts of nigrogen and phosphorus from water.

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Accumulation of Dry Matter, Nitrogen and Phosphorus by Cultivated Water Hyacinths

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INTRODUCTION

Nutrient absorption by controlled populations of *Eichhornia crassipes* (Mart) Solms (water hyacinth), or other species of aquatic plants, might reduce concentrations of nitrogen and phosphorus in eutrophic lakes or in effluents prior to their release into natural waters (5, 14, 15, 18). Steward (15), assuming dried water hyacinths contained 4% nitrogen and 0.4% phosphorus, suggested that 1 ha of plants in subtropical regions might remove up to 6,000 kg nitrogen and 600 kg phosphorus per year. Boyd (5), using more conservative values for growth and nutrient content, estimated potential annual uptake of nitrogen and phosphorus by water hyacinths in warm climates as 1,980 and 322 kg/ha, respectively. Rogers and Davis (14), after measuring nutrient uptake by *E. crassipes* in growth chamber experiments, concluded that absorption by 1 ha of water hyacinths would exceed 2,500 kg of nitrogen and 700 kg of phosphorus per year if maximum growth could be sustained. Many aquatic plants, including water hyacinth, have a high protein content (3, 4) and plants removed to reduce nutrient enrichment of natural waters could probably be used as animal feed.

In this study, water hyacinths were cultivated in nutrient-enriched water of earthen ponds to determine rates of growth and absorption of nitrogen and phosphorus under conditions similar to those in eutrophic lakes or effluent holding ponds. The effects of water hyacinths on nutrient concentrations in waters and on phytoplankton growth will be considered in another report.

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MATERIALS AND METHODS

Single enclosures measuring 3.2 x 6.4 m and constructed of 5.08-cm diameter polyvinylchloride pipe were attached to metal posts in the center of each of three 0.04-ha ponds on the Fisheries Research Unit, Auburn University, Auburn, Alabama. Five hundred water hyacinths obtained from Jim Woodruff Reservoir (Lake Seminole) near Chattahoochee, Florida, were placed in each enclosure on May 1, 1973. The average dry weight of individual plants was 1.79 g and initial standing crop was 43.8 g/m^2 in enclosures. Between February 5 and September 9, 1973, 1.07 kg of triple superphosphate (46% P_2O_5) and 0.79 kg of ammonium nitrate (34%N) were broadcast over pond surfaces at 2-week intervals. Plants were removed from a 0.25 m^2-quadrat at the center of each enclosure on June 20, July 6, September 5, and September 28, 1973. Plants were drained and weighed and dry matter determinations made on each subsample. Space for continual growth was provided by removing 1/2 of the plants from each enclosure on June 20 and 1/4 on August 6 and September 5. At each date, remaining plants were separated so that they were equally distributed in enclosures.

Surface water samples were collected at 2-week intervals and analyzed for nitrate and dissolved inorganic phosphate content (1). Chlorophyll *a* concentrations (16) in the water were measured periodically to provide an index of phytoplankton density. Following analysis of dry matter, water hyacinth plants were ground to pass the 40-mesh

Table I

Average concentrations of chlorophyll a, nitrate, and soluble inorganic phosphorus in waters of ponds used for cultivation of water hyacinths.

Date	Chlorophyll a (µg/l)	Nitrate (mg/l N)	Soluble inorganic phosphorus (mg/l P)
May 17	19	0.18	0.02
May 30	20	0.12	0.06
June 15	21	0.18	0.01
June 30	61	0.16	0.06
July 1	65	0.17	0.08
July 13	32	0.15	0.04
August 1	45	0.12	0.01
August 17	55	0.10	0.03
September 1	62	0.05	0.06
September 14	58	0.05	0.15

screen of a Wiley mill. Nitrogen analyses of plant materials were made by the micro Kjedahl technique (2). The vanadomolybdophosphoric acid yellow color method was used to determine phosphorus in 0.5 N nitric acid extracts of plant ash (8).

RESULTS AND DISCUSSION

Plants grew rapidly and the lush green foliage exhibited no signs of nutrient deficiencies, although only nitrogen and phosphorus were added to the water. Wahlquist (17) demonstrated earlier that nitrogen and phosphorus were the nutrients limiting growth of water hyacinths in ponds at Auburn University. Concentrations of nitrate and soluble inorganic phosphorus (Table I) were as high as concentrations reported for eutrophic lakes (10). As indicated by chlorophyll *a* data (Table I) and observation, ponds contained dense phytoplankton blooms. Therefore, water hyacinth populations covering 5% of the pond surfaces did not reduce nutrient concentrations enough to prevent dense algal growth.

Data on growth rates and nitrogen and phosphorous absorption (Table II) were expanded to a kg/ha base. Magnitudes of growth and nutrient absorption by plants in the three ponds were generally similar during a given period of measurement, but rates of dry matter, nitrogen, and phosphorus accumulation increased as the study progressed and reached maxima in September. Concentrations of phosphorus in the water were no higher in September than at certain other times and nitrate levels were lowest in September (Table I). However, water

Table II

Rates of growth and absorption of nitrogen and phosphorus by water hyacinths cultivated in nutrient-enriched ponds

Pond	Period of measurement: May 1 to June 19	June 20 to August 5	August 6 to September 4	September 5 to September 28	Average
	Dry matter (kg/ha/day)				
1	106	205	159	207	170
2	153	149	205	333	185
3	113	201	207	388	227
Average	125	185	190	276	194
	Nitrogen (kg/ha/day)				
1	2.2	4.7	2.7	3.8	3.4
2	3.0	3.3	3.6	3.4	3.3
3	2.5	3.4	3.5	4.9	3.6
Average	2.6	3.8	3.3	4.0	3.4
	Phosphorus (kg/ha/day)				
1	0.26	0.41	0.25	0.60	0.36
2	0.40	0.37	0.49	0.68	0.48
3	0.32	0.32	0.37	0.74	0.44
Average	0.33	0.37	0.37	0.64	0.43

analyses are only suggestive of nutrient status in an environment. Added nitrogen and phosphorus is absorbed by plants, nitrogen is lost by denitrification in muds (11) and phosphorus is rapidly absorbed by muds (7). Phytoplankton growth also generally increased throughout the study, so lessened competition by phytoplankton for nutrients will not explain the gradual increase in water hyacinth production. Plants increased in size during the study, so at the beginning of each period of growth and nutrient uptake measurement, plants were larger than at the beginning of any previous period. Possibly, larger plants were more capable of rapid growth than smaller ones when space for expansion was created by harvest.

Growth rates averaged 194 kg/ha/day over the 5-month period (Table II) and an average 27 metric tons of plants were produced (Table III). Assuming a 12-month growing season, this yield increases to 65 metric tons per hectare. Yount and Crossman (18) reported growth rates as high as 540 kg/ha/day for water hyacinths cultivated in a eutrophic lake, but most values were between 150 and 200 kg/ha/day. Penfound (12) reported a maximum growth rate of 146 kg/ha/day for a wild population of water hyacinths. Average standing crops of

Table III

Accumulation of dry matter, nitrogen, and phosphorus in metric tons/ha by water hyacinths cultivated in nutrient-enriched ponds

	May 1 through September 28			Calculated for 12-month growing season		
Pond	Dry matter	Nitrogen	Phosphorus	Dry matter	Nitrogen	Phosphorus
1	24.6	0.50	0.05	50.5	1.20	0.12
2	26.1	0.49	0.07	63.2	1.18	0.16
3	30.2	0.50	0.06	73.0	1.21	0.14
Average	27.0	0.50	0.06	65.2	1.20	0.14

Table IV

Concentrations of nitrogen and phosphorus (% dry weight) in water hyacinths cultivated in nutrient-enriched ponds

Pond	June 20	August 6	September 5	September 28
		Nitrogen		
1	2.00	2.28	1.71	1.92
2	1.95	2.20	1.75	1.44
3	2.19	1.68	1.71	1.25
Average	2.05	2.05	1.72	1.54
		Phosphorus		
1	0.24	0.20	0.16	0.24
2	0.26	0.25	0.24	0.29
3	0.28	0.16	0.18	0.19
Average	0.26	0.20	0.19	0.24

water hyacinths in ponds at Auburn University increased from 6.7 metric tons/ha on June 20 to 16.2 metric tons/ha on September 28. Even at the lowest standing crop, plants were tightly confined within the enclosures and growth consisted primarily of vertical expansion. Rapid growth was only sustained by partial harvest at intervals. Water hyacinths produce new plants vegetatively and expand into vacant areas rapidly. Ten plants, given space and good growing conditions, can potentially produce 655,360 plants (0.4 ha of plants) in an 8-month growing season (13). Standing crop estimates for natural populations of water hyacinths are as great as 25 metric tons/ha (9). However, these values represent accumulation of plant material over several years and growth rates were probably low at the time of standing crop determinations.

Average rates of nitrogen and phosphorus removal over the entire period of growth were 3.4 and 0.43 kg/ha/day, respectively (Table II), or an estimated accrual of 1.20 metric tons of nitrogen and 0.14 metric tons of phosphorus in climates conductive to year around growth. Plants generally absorbed nitrogen 5 to 10 times as rapidly as phosphorus. Average percentages of nitrogen in harvested plants (Table IV) decreased from June to September. Average phosphorus concentrations in plants were similar on June 20 and September 28, but slightly lower on the other two dates (Table IV). Concentrations of nitrogen and phosphorus in dried samples of water hyacinths from 32 natural populations (4,6) ranged from 1.2 to 5.6% for nitrogen (average of 2.5%) and from 0.1 to 0.8% for phosphorus (average 0.47%). Rapidly growing plants in nutrient-enriched earthen ponds had lower concentrations of nitrogen and phosphorus (Table IV).

Highest and lowest rates of growth and absorption of nitrogen and phosphorus (refer to data in Table II for Pond 1, May 1 to June 20, and for Pond 3, September 5 to 28) were used to set upper and lower limits for dry matter production and nutrient uptake over a 12-month growing season. These limits were, 39 to 142 metric tons/ha of dry matter, 0.8 to 1.8 metric tons of nitrogen, and 0.1 to 0.3 metric tons of phosphorus. These values are considerably lower than estimates given by Steward (15) and Rogers and Davis (14), but the upper limits are similar to estimates of potential dry matter, nitrogen and phosphorus accrual given by Boyd (5). Findings from this pilot study verify previous suggestions that water hyacinth can remove large amounts of nitrogen and phosphorus from water.

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