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Economic Botany, 33(1), 1979, pp. 1-10
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WATER HYACINTH (EICHHORNIA CRASSIPES) PRODUCTIVITY AND HARVESTING STUDIES

B. C. WOLVERTON AND REBECCA C. McDONALD[1]

Water hyacinth growth rates were monitored from May through October in two sewage lagoons with different nutrient loading rates. The lagoon receiving the heaviest load sustained the highest average growth rates throughout the summer. The lightly loaded lagoon averaged a 29% increase in weight per week over the six month period with the highest growth rate occuring during June with an average weekly weight gain of 71%. The heavily loaded lagoon sustained an average growth rate of 46% per week for the same six month period with the highest measured growth rate of 73% increase in weight per week also occuring in June. In addition, the performance of three harvesters was evaluated. One harvester, consisting of a chopper and conveyor, was capable of picking up and chopping approximately 2.3 t of plants per hour and delivering them to a waiting truck. The second harvester was a single 1.52 m (5 ft) wide conveyor, and the third one was a modified clamshell bucket attached to a dragline. The average harvesting rate of each of these harvesters was approximately 9.3 t of water hyacinths per hour.

Using vascular aquatic plants to treat waste waters has proven to be a very promising method to treat domestic sewage, particularly for small communities of 10,000 people or less that already use lagoons. The aquatic plants studied to date involving waste treatment include the water hyacinth (Wolverton et al., 1976; Wolverton & McDonald, 1976; Dinges, 1978; Cornwell et al., 1977; Schulze, 1966), duckweed (Culley & Epps, 1973; Sutton & Ornes, 1977), bulrush (Seidel, 1976), and submersed plants (McNabb, 1976). Most researchers recognize the water hyacinth as the most prolific of these aquatic plants.

Future waste water treatment facilities using aquatic plants to upgrade their discharge may be designed in two manners. One design, where nutrient removal is not important, may minimize biomass production in order to reduce harvesting and plant disposal costs. The other alternative design, where nutrient removal is desired, should maximize biomass production, and therefore make the conversion of plant material into methane, fertilizer, or feeds a practical and profitable by-product of waste treatment. Two areas of study necessary to design a plant for maximum biomass production include plant growth rates and harvesting techniques.

The National Aeronautics and Space Administration at the National Space Technology Laboratories has been evaluating the effectiveness of water hyacinths to upgrade existing domestic sewage lagoons. Water hyacinth growth rate measurements and evaluation of harvesting techniques with a variety of harvesting equipment were a part of this effort. The results of these productivity and harvesting studies are presented in this paper in two parts.

Previous growth rate studies by Dymond (1949) and Penfound and Earle (1948) were used by Westlake (1963) in estimating the annual productivity of the water hyacinth to be 11–33 t/ha, dry weight. A later study by Wooten and Dodd (1976) found a production of 30 t of organic matter/ha in only 105 days. Westlake (1963) projected that possible maximum annual production rates of 110 to 150 t of organic matter/ha/yr could be obtained if the plants were regularly thinned out to reduce self-shading and grown in tropical or sub-tropical climates.

[1] National Aeronautics and Space Administration, National Space Technology Laboratories, NSTL Station, Mississippi 39529.

Submitted for publication February 6, 1978; accepted for publication March 2, 1978.

TABLE I

A. INFLUENT NUTRIENT CONCENTRATIONS, ESTIMATED FLOW RATES AND SURFACE AREAS OF THE TWO LAGOONS

Parameter	NSTL	Lucedale
5-day biochemical oxygen demand, mg/l	108 ± 41	127 ± 39
Total Kjeldahl nitrogen, mg/l	12.2 ± 2.4	29.3 ± 4.3
Total phosphorus, mg/l	3.6 ± 0.73	8.6 ± 1.4
Flow rate, m^3/day	475	1,140
Surface area, ha	2.08	3.75

B. NORMAL RANGE OF NUTRIENT LOADING RATES

Parameter, kg/ha/day	NSTL	Lucedale
5-day biochemical oxygen demand	16–34	26–50
Total Kjeldahl nitrogen	2.2–3.4	8.6–11.6
Total phosphorus	0.65–1.09	2.2–3.0

The first part of our investigation represents our water hyacinth productivity studies in two, one-cell oxidation ponds with different loading rates located in a sub-tropical climate. The second part is an evaluation of three harvesting systems which can aid in removing the plants from oxidation ponds as necessary in order to encourage maximum biomass production.

PRODUCTIVITY STUDIES

Procedure

Both lagoons used in these productivity studies are single-cell, facultative ponds, commonly referred to as oxidation ponds, which receive only domestic sewage. These lagoons are located at the National Space Technology Laboratories in Hancock County, MS and at Lucedale, MS. Both of these locations are in the Gulf Coast Region. The normal range of influent nutrient concentrations and loading rates, based on 5-day biochemical oxygen demand (BOD_5), total Kjeldahl nitrogen (TKN), and total phosphorus (TP), for these lagoons are presented in Table I, A and B. These values were obtained from estimated flow rates and the analysis of two influent grab samples per week for a period of one year, including the growth rate study months.

Two galvanized wire mesh baskets, 2 m W × 2 m L × 0.5 m D, supported by

TABLE II

AVERAGE GROWTH RATES OF THE WATER HYACINTH AT NSTL AND LUCEDALE

Month, 1977	Average percent increase by weight			
	NSTL		Lucedale	
	Daily	Weekly	Daily	Weekly
May	6	52	7	61
June	8	71	8	73
July	3	27	5	42
August	2	15	5	39
September	1	8	4	35
October	0	0	3	24

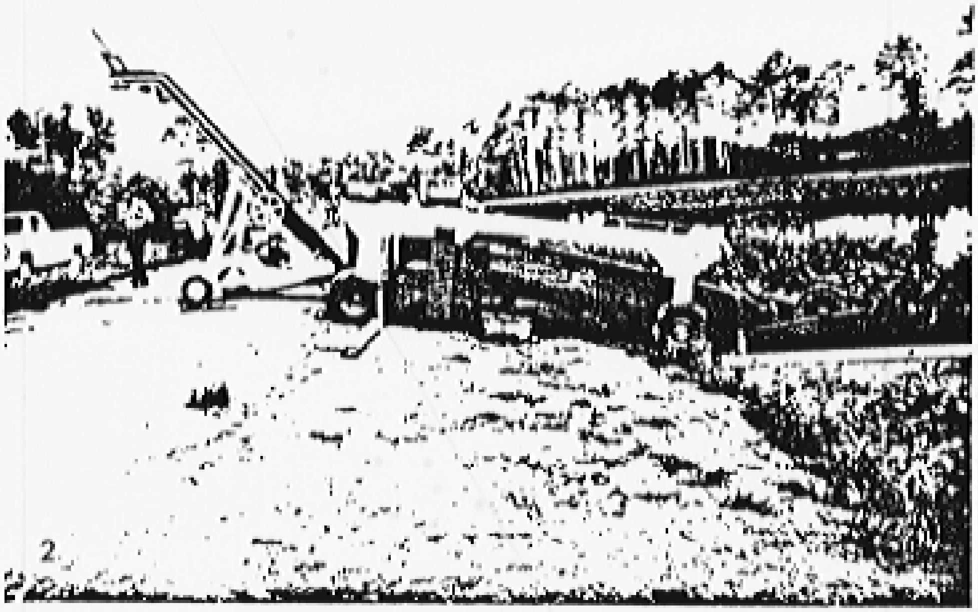

FIG. 2. Chopper-conveyor harvester.

This difference in nutrient loading is directly reflected in the measured growth rates shown in Table II.

Water hyacinths grew the fastest in the early summer months of May and June in both systems. This observation correlates with that of Scarsbrook and Davis (1971). The highest growth rates averaged 71% and 73% per week for NSTL and Lucedale, respectively. At this rate the plants doubled their mass every nine to ten days.

In order to use the growth rates more effectively, one must also use the data graphically as represented in Figure 1. This data was collected from the basket at the NSTL lagoon which was maintained at 100% coverage. The average root and stalk heights were measured, and the plants were weighed. The straight line of best fit was obtained by least squares analysis for the plot of total plant length (stalk height plus root length) versus wet weight (t) per hectare. We found that the total weight was more linearly related to the total plant length than just the stalk height alone. This relationship also held true with the plants from the Lucedale lagoon, although these plants had a much higher ratio of stalk height to root length as compared to those grown in the less fertile environment at NSTL.

HARVESTING

Harvesting Equipment

A. The first harvester designed under contract for NASA is shown in Figure 2. This harvester received plants pushed by a boat. The plants were picked up by a 1.83 m (6 ft) wide rotary head, coarse chopped and loaded into a dump

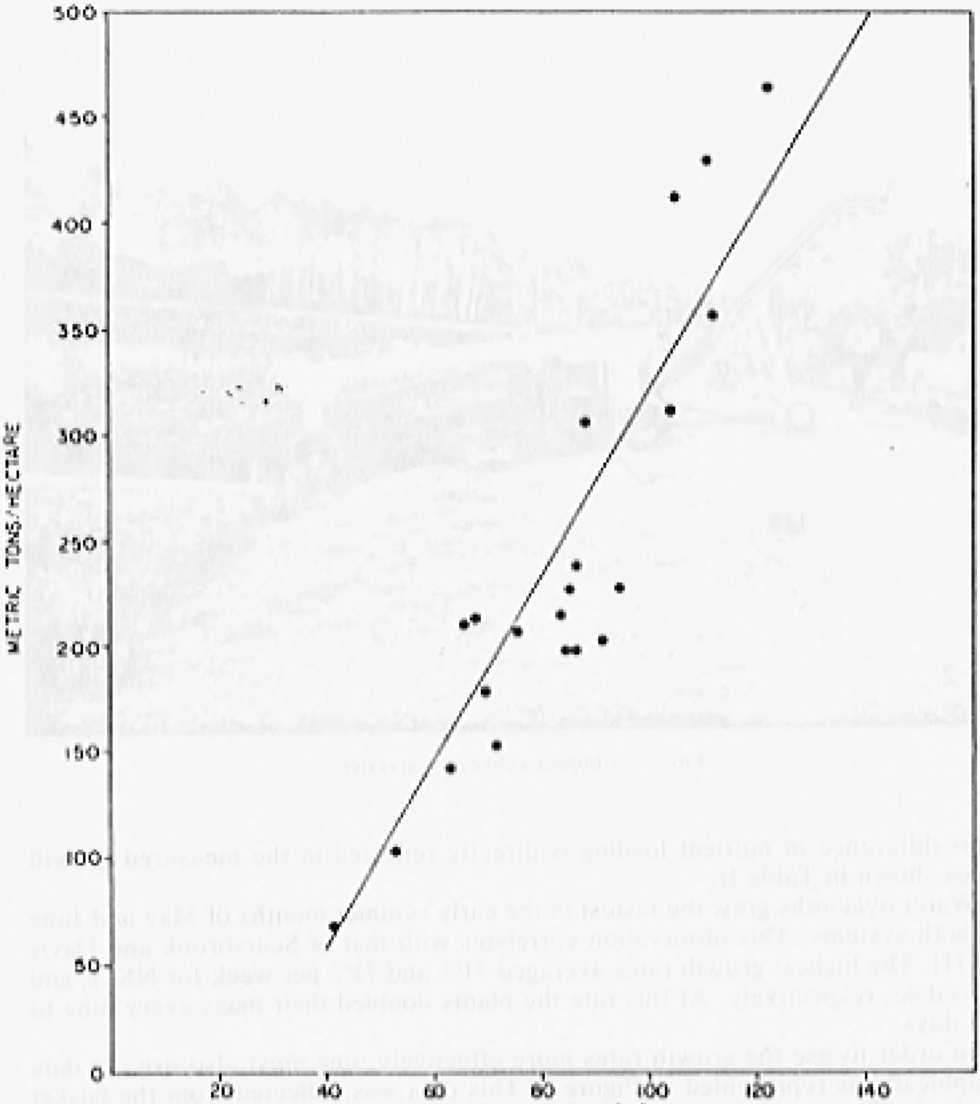

FIG. 1. Chart for estimating water hyacinth wet weight/hectare based on total plant length. The straight line of best fit was obtained by least-squares analysis.

pontoons were placed in the NSTL lagoon. One basket was partially harvested at one to three week intervals to encourage maximum growth rates. The other basket was partially harvested every eight to ten weeks in order to collect data on plant length versus mass/surface area. An identical basket was placed in the Lucedale lagoon and partially harvested every three to six weeks.

Results

The NSTL sewage lagoon, loaded at a rate of 16–34 kg BOD_5/ha/day (15–31 lb BOD_5/ac/day), receives a relatively light nutrient and organic load. The Lucedale lagoon receives almost two times the BOD_5 load and four times the nutrient load.

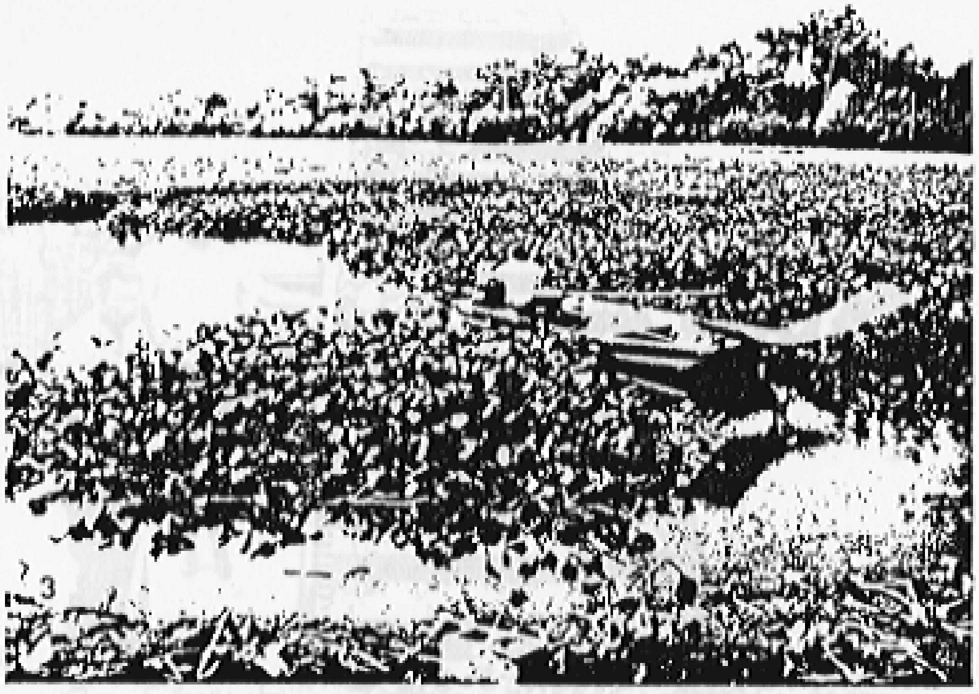

FIG. 3. Pusher boat.

truck via a 46 cm (18 in) conveyor belt. The chopper harvester required a four cylinder gasoline engine, and the small conveyor used a five hp gasoline engine.

The pusher boat shown in Figure 3 was a 4.27 m (14 ft) aluminum boat driven by a 20 hp outboard motor. A heavy wire mesh scoop (0.64 m W × 2.84 m L) was mounted on the front of the boat. This scoop was easily lowered or raised by hand by the boat operator.

B. The second harvester designed by NASA and fabricated at NSTL consisted of a single large conveyor belt (Fig. 4). The conveyor belt was 1.52 m W × 8.53 m L and was driven by a four cylinder diesel engine. The plants were pushed to the conveyor by the pusher boat described above.
C. The third harvester evaluated by NASA was a modified clamshell bucket attached to a standard drag line (Fig. 5). The bucket was expanded to 3.05 m long and could pick up a 1.52 m wide area.

Results

Because the mass of water hyacinths per hectare is dependent on the size of plants, the efficiencies of the three harvesters are best compared by estimating surface area harvested per hour and correlating this value with the size of the plants to be harvested using Figure 1. Table III gives the maximum and realistic harvesting capabilities of the three machines.

The limiting factor for both the single conveyor and the conveyor-chopper was the pusher boat. At best a single pusher boat can only keep plants on the con-

FIG. 4. Single conveyor harvester.

veyors 25% of the time. These systems could be further optimized by using two or more pusher boats or by devising another system that could continuously feed the harvesters.

The conveyor-chopper was subject to more mechanical breakdowns than the simple conveyor due to its more complex nature. The rotary pickup head was easily clogged with sticks and other rigid objects. The single large conveyor was far more reliable because its moving parts could not be clogged by floating debris.

The original design for the single conveyor called for wing conveyors to extend

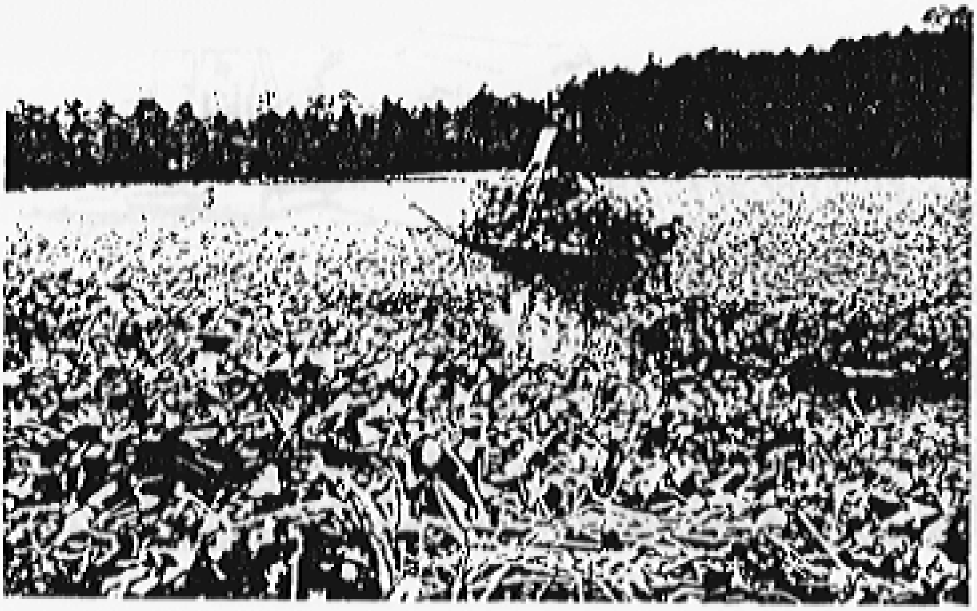

FIG. 5. Modified clamshell bucket.

out into the water at the base of the central conveyor belt. These wing conveyors would form a funnel and greatly aid the pusher boat in channeling plants up to the central harvester. However the size of the lagoon at NSTL was not large enough to warrant the extra expenditure of funds necessary to enlarge the conveyor.

The modified clamshell bucket proved to be the easiest harvester to use continuously. Its overall harvesting capacity of 418 m^2/hr was comparable to that of the single conveyor. This harvester was very efficient in harvesting the plants from the water hyacinth-chemical waste treatment system which was constructed

TABLE III

COMPARATIVE EFFICIENCIES OF THE THREE HARVESTERS USED TO HARVEST WATER HYACINTHS FROM WASTE WATER LAGOONS

Harvester	Av. % time harvesters loaded with plants	Surface area harvested per hour (m^2/hr)		Mass harvested per hour (t/hr)*	
		Max. possible	Average	Max. possible	Average
Conveyor-chopper	25	414	104	9.1	2.3
Single conveyor	25	1,670	418	36.7	9.2
Modified clamshell bucket	75	558	418	12.3	9.2

* Based on an average standing crop of 220 t/ha.

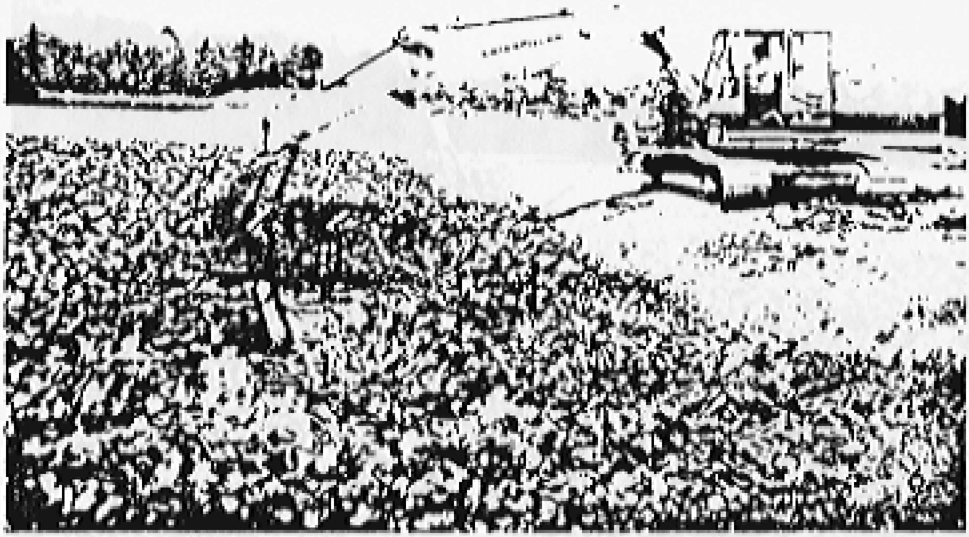

FIG. 6. Modified bucket attached to a back hoe.

in a zig-zag configuration that was 6.4 m wide (Wolverton & McDonald, 1977). It could be easily moved around the lagoon and harvest specific areas of plants. This flexibility was very important in the chemical waste system due to its configuration. Plants at the upper end of the canal required harvesting more frequently than those at the discharge point because they became saturated with heavy metals quicker and had to be replaced periodically.

Many people have built their own aquatic plant harvesters from equipment that they already owned in order to economize. One example is shown in Figure 6. This harvester consists of a modified bucket attached to a suitable piece of heavy equipment. The cost of modifying the bucket was nominal. For small water hyacinth treatment systems where harvesting requirements are minimal, devising harvesters out of existing back hoes and related equipment can be very practical. Other water hyacinth harvesters are compared in a comprehensive survey prepared by the U.S. Army Corps of Engineers (Bureau of Aquatic Plant Research and Control, 1972).

DISCUSSION

Overall, the water hyacinth in the enriched environment at Lucedale, MS averaged a 46% increase in weight per week during the months of May to October. The growing season also includes April for the Gulf Coast region, although the growth rate studies were not begun in time to include this month.

The number of metric tons per week will fluctuate due to monthly growth rate differences. More biomass can be harvested during May, June, and early July than during the other months. However, on an average, 101 wet metric tons of biomass can be harvested per hectare per week from April through October based on maintaining an average standing crop of 220 t/ha. Over the seven months, 3,080 wet metric tons or 154 dry metric tons (based on an approximate solids content of 5% of wet weight) per hectare can be obtained. This value is amazingly close to Westlake's prediction of an annual productivity of 150 t organic matter/ha/yr under ideal conditions (1963).

This potential yield of 154 t/ha/yr far exceeds the dry biomass yields of any terrestrial, saltwater, or freshwater plant, except algae, yet recorded. For example, sugar cane and sweet sorghum, which are considered potential candidates for bioconversion due to high growth rates, can yield 44.8 t/ha/yr (Alich & Inman, 1976). In California average yields of *Eucalptus* sp., a woody plant, have been as high as 53 t/ha/yr (Greeley, 1976).

Macroscopic red algae (Rhodophyceae) can produce 41.8 to 55.0 t/ha/yr when grown in enriched seawater (Ryther, 1976). The giant algae or kelp (*Macrocystis*) that has been considered a prime candidate for bioconversion produces an average yield of 14.5 t organic matter/ha/yr or approximately 26.1 total t of mass per ha/yr (North, 1971). These yields have been reported as high as 30.6 and 55.1, respectively.

Algae are considered among the most prolific of the freshwater plants. Maximum obtainable growth rates for these plants vary greatly. Oswald (1976) reports yields of 35.2 to 70.4 t/ha/yr for algae harvested from enriched sewage lagoons. However McGarry and Tongkasome (1971) report that yields of 157 t/ha/yr are obtainable when algae are grown year-round.

This potential crop of 154 t/ha produced during seven months of the year has shown promise for feeds and fertilizers. On a dry weight basis, the crude protein averaged 22.3% (32% in the leaves) (Wolverton & McDonald, 1979). The phosphorus and ash content averaged 0.89% and 15.1% of dry weight, respectively. The plants are also rich in potassium, calcium, iron, manganese, magnesium, etc., along with many vitamins such as thiamine, riboflavin, niacin, and B_{12} (Wolverton & McDonald, 1979).

Water hyacinths are also a major candidate for bioconversion to produce methane for energy. In batch studies of anaerobically digesting water hyacinths, NASA has found that 350 to 411 liters bio-gas per kg dry weight (5.7 to 6.6 scf per dry lb) can be obtained (Wolverton et al., 1975, and unpublished data). This bio-gas contains approximately 60% methane. Therefore, one hectare of water hyacinths grown in an enriched environment in a warm climate for seven months of the year can be used to produce approximately 58,400 m³ (2,290,000 scf) of bio-gas containing 35,100 m³ (1,370,000 scf) methane.

These potential products are presently being explored by NASA as well as other investigators. This phenomenal annual production of organic matter per hectare that can be obtained as a by-product of domestic waste treatment contributes to the economic attractiveness of using the water hyacinth as a new source of feed, fertilizer, and energy.

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