J. Aquat. Plant Manage. 19: 40-43

Nitrogen Source, Biomass Production, and Phosphorus Uptake in Waterhyacinth[1]

AZIZ SHIRALIPOUR, L. A. GARRARD
AND W. T. HALLER

Visiting Professor and Associate Professors
Department of Agronomy
University of Florida
Gainesville, Florida 32611

ABSTRACT

Effects of source and concentration of nitrogen (N) on productivity and phosphorus (P) uptake of waterhyacinths [*Eichhornia crassipes* (Mart.) Solms] were investigated. Potassium nitrate (KNO_3), urea [$CO(NH_2)_2$], and ammonium carbonate [$(NH_4)_2CO_3$] were added to three different series of containers containing 10% Hoagland's solution providing 0, 1, 2.5, 5, and 10 mg l^{-1} N in each series. Plants were grown for 2 weeks (first harvest), 3 weeks (second harvest), and 4 weeks (third harvest). The greatest productivity during initial growth (first harvest) was obtained when the concentration of N was 10 mg l^{-1} as NO_3^-; however, at subsequent harvests, optimum growth was obtained when the concentrations of N from $CO(NH_2)_2$ were 10 mg l^{-1} at second harvest and 5 mg l^{-1} at the third harvest. Nitrogen derived from $CO(NH_2)_2$ produced greater biomass than other sources. Plants achieved a 14% daily dry weight increase between the second and third harvest dates, and a productivity of 30 g m^{-2} day^{-1} when grown in 5 mg l^{-1} $CO(NH_2)_2$. Maximum P uptake from the culture solutions at the first, second, and third harvests was obtained when the N concentrations in growth media were 10, 5, and 2.5 mg l^{-1} respectively. During early stages of growth of the waterhyacinth plants, when the concentration of P was high in the growth medium, P uptake was enhanced by increasing the N concentration. When the concentrations of P in the growth medium decreased as a result of plant uptake, increasing the N concentration depressed P uptake.

INTRODUCTION

Aquatic plants have received increasing attention in recent years as collectors of solar energy, energy which may be made available to man. They also have the potential of being used advantageously for water pollution control (10, 14, 15, 17), as food supplies for wildlife, domestic animals, and humans (3, 4, 9, 16), and as material for soil amendment and mulches (1, 8, 11).The reduction in supply of comparatively inexpensive fossil fuels makes imperative the development of new energy technologies based on renewable resources. The fixation of carbon into usable biomass by photosynthesis appears to be one of the most promising sources of readily renewable fixed energy from which new fuels may be derived.

The waterhyacinth is being extensively studied for biomass production and fuel conversion because of its high productivity. Much research has already been conducted with regard to a possible role of waterhyacinths in restoring polluted water, in providing a soil ammendment, and as a source of cellulose for paper production (2, 11). The production of waterhyacinth and other aquatic plants for conversion to fuel is particularly attractive since high quantities of plant material can be grown in areas which may not be utilized for other purposes.

The productivity of waterhyacinth has been studied by several investigators. Penfound and Earle (12) reported a biomass value of 630 to 1472 g m^{-2} on a dry weight basis with an estimated productivity of 15 to 44 mt ha^{-1} yr^{-1}, while Yount and Crossman (18) and Ryther, et al. (13) reported mean annual biomass production of 45 and 88 mt dry wt ha^{-1} $year^{-1}$, respectively.

An important aspect of utilizing any plant in the production of fuel would be the ability to produce a large and constant supply of biomass. This would involve an understanding of the plant's growth requirements, particularly the nutrient requirement for consistently high productivity. The objectives of this study were to determine the most suitable source and the most effective concentration of nitrogen (N) for biomass production and maximum phosphorus (P) uptake by waterhyacinth.

MATERIALS AND METHODS

Seventy liters of 10% Hoagland's solution minus N (7) were prepared in containers with a surface area of 0.12 m^2 and a depth of 60 cm. Potassium nitrate (KNO_3), urea [$CO(NH_2)_2$], and ammonium carbonate [$(NH_4)_2CO_3$] were added to three different series of containers to provide 0, 1, 2.5, 5, and 10 mg l^{-1} N in each series. Three replicates for each treatment were prepared. Five uniform plants (approximately 10 cm long) were transferred to each container on 20 April, 1979. The containers were located in an open field to allow maximum exposure to sunlight. Tap water was added as necessary to compensate for evapotranspiration. Plants were harvested at 2 weeks, 3 weeks, and 4 weeks after they were established in the containers. At each harvest, three plants from each treatment (one from each replicate) were dried at 70 C for 48 h to achieve a constant dry weight. P contents of roots and shoots of all treatments were determined using the Technicon Auto Analyzer II.[2] P uptake was calculated from the differences

---

[1] Contribution of the University of Florida, Agricultural Experiment Station as Journal Series Number 2700. Supported by the Aquatic Plant Research Center and the Center for Environmental and Natural Resources.

[2] Technicon Industrial Systems. 1976. Total inorganic phosphate in water and wastewater. Ind. Method No. 93-70 w/B. Tarrytown, N.Y.

between P content of plant tissues at each harvest and the content at the beginning of the experiment.

RESULTS AND DISCUSSIONS

Waterhyacinth plants which did not receive N (control plants) gained little dry weight (Table 1). Most of the increase in biomass in this case was attributable to root growth, hence the shoot/root ratio was the smallest in comparison to those of other treatments (Table 2). The roots of these plants grew long and had an iridescent purple hue. Haller, et al. (6) observed the same phenomenon when waterhyacinths were grown in P-deficient media. This increase in root absorbing surface is likely an adaptive feature which allows the floating plant to compensate for the nutrient deficits of naturally occurring waters.

TABLE 1. EFFECT OF NITROGEN SOURCE AND CONCENTRATION ON DRY WEIGHT (G) OF WATERHYACINTH.

Nitrogen source	Nitrogen concentration (mg l^{-1})	Growth period (wks)[a]		
		2	3	4
None	0	3.9a	4.4a	5.1a
Urea $CO(NH_2)_2$	1.0	4.4ab	5.0ab	6.9a
	2.5	6.2cde	6.3bc	12.9bc
	5.0	7.3efg	8.7de	17.2e
	10.0	7.9fg	10.1e	15.4cde
Potassium Nitrate KNO_3	1.0	4.8abc	5.2ab	6.6a
	2.5	6.7def	6.4bc	11.0b
	5.0	7.9fg	8.8de	16.2de
	10.0	8.9g	9.1de	14.5cd
Ammonium Carbonate $(NH_4)_2CO_3$	1.0	4.2ab	5.3ab	6.0a
	2.5	5.3abcd	5.8ab	6.3a
	5.0	5.6bcd	9.4de	13.9cd
	10.0	6.9def	8.0cd	13.6cd

[a] Values in a column followed by the same letter are not significantly different at 5% level as determined by Duncan's Multiple Range Test. Each value is the mean of three replicates. Harvesting periods were 2, 3, and 4 weeks after establishment of the experiments.

TABLE 2. EFFECT OF NITROGEN SOURCE AND CONCENTRATION ON SHOOT/ROOT DRY WEIGHT RATIO OF WATERHYACINTH.

Nitrogen source	Nitrogen concentration (mg l^{-1})	Growth period (wks)[a]		
		2	3	4
None	0	1.1 ± 0.1	1.0 ± 0.1	0.8 ± 0.0
Urea $CO(NH_2)_2$	1.0	1.2 ± 0.2	1.1 ± 0.2	0.9 ± 0.0
	2.5	1.3 ± 0.3	1.3 ± 0.1	1.0 ± 0.0
	5.0	2.0 ± 0.2	1.4 ± 0.2	1.3 ± 0.1
	10.0	2.7 ± 0.3	1.9 ± 0.1	1.3 ± 0.1
Potassium Nitrate KNO_3	1.0	1.3 ± 0.3	1.3 ± 0.2	1.0 ± 0.0
	2.5	1.4 ± 0.2	1.6 ± 0.1	1.2 ± 0.2
	5.0	2.0 ± 0.3	1.4 ± 0.4	1.3 ± 0.1
	10.0	2.2 ± 0.4	1.8 ± 0.3	1.2 ± 0.1
Ammonium Carbonate $(NH_4)_2CO_3$	1.0	1.1 ± 0.2	1.3 ± 0.3	0.9 ± 0.1
	2.5	1.5 ± 0.1	1.1 ± 0.1	0.9 ± 0.2
	5.0	1.6 ± 0.3	1.5 ± 0.1	1.3 ± 0.2
	10.0	2.4 ± 0.3	1.6 ± 0.2	1.2 ± 0.1

[a] Each value is the mean of three replicates. Harvesting periods were 2, 3, and 4 weeks after establishment of the experiments.

The leaves of control plants were light green in color at the beginning of the experiment and became progressively chlorotic, apparently as a result of N deficiency. Plants grown in the medium containing 1 mg l^{-1} N, regardless of the source, and 2.5 mg l^{-1} N in NH_4^+ form showed no significant increases in their yields at any harvest (Table 1). Higher concentrations of N resulted in significant increases in biomass production. At first harvest, the greatest productivity was obtained when the concentration of N was greater than 5 mg l^{-1} as $CO(NH_2)_2$ or KNO_3, but at the second and third harvests, the greatest dry weights were obtained when the concentrations of N from $CO(NH_2)_2$ were 10 and 5 mg l^{-1}, respectively. It was concluded that waterhyacinths respond initially to higher concentrations of N (10 mg l^{-1} in these experiments), while after 3 and 4 weeks of growth 5 mg l^{-1} is preferred. Increasing the concentrations of N from 5 mg l^{-1} between the second and third harvests actually caused a slight decrease in biomass production. At the end of the 3-week period, 5 mg l^{-1} N from $CO(NH_2)_2$ produced the greatest biomass, with comparable amounts of N from KNO_3 giving somewhat smaller values. It is interesting to note that at 5 mg l^{-1} N, NH_3-N from $CO(NH_2)_2$ was significantly better for biomass production than NH_3-N from $(NH_4)_2 CO_3$. In experiments with 5 mg l^{-1} N from $CO(NH_2)_2$, plants achieved a 14% daily weight increase between the second and third harvests, corresponding to a doubling time of 7.1 days. The calculated productivity of approximately 30 g m^{-2} day^{-1} compares favorably to other photosynthetic crops (5). The lower productivity values reported by Penfound and Earle (12) may have resulted from their plants being grown in a natural, unharvested environment. Waterhyacinths have a much higher potential for production of biomass when frequent harvesting is practiced. Harvesting frequently, Yount and Crossman (18) obtained productivity ranges of 5 to 8 g dry wt m^{-2} day^{-1} during the winter and 20 to 29 g dry wt m^{-2} day^{-1} during the summer months. Ryther et al. (13) reported an even higher productivity for waterhyacinths with harvesting intervals of 1 to several weeks depending on seasons of the year. Net productivity of waterhyacinths ranged from 5 to 10 g dry wt m^{-2} day^{-1} during the winter and 28 to 35 g dry wt m^{-2} day^{-1} during the summer months. It is possible to assume that the maximum productivity obtained with 5 mg l^{-1} N from $CO(NH_2)_2$ could be increased by harvesting one-half of the plants each 7 days, the doubling time under these conditions.

Increases in N concentration invariably increased shoot/root ratios at the first and second harvest (Table 2). At the third harvest, however, this was true only for concentrations of N up to 5 mg l^{-1}. The shoot/root ratios were highest at first harvest and decreased gradually in the second and third harvests for all treatments. This phenomenon is likely due to the fact that the roots had more vigorous growth than the shoots between the second and the third harvest periods because of the reduction in nutrients in the growth media.

Increases in N concentrations in the growth medium resulted in increases in P uptake by the plants. After 2 weeks in the nutrient medium (first harvest), the plants contained considerably more P at 1, 2.5, 5 and 10 mg l^{-1} N than control plants which received no N (Figure 1). The rate of P uptake was markedly influenced by N concentration up to about 5 mg l^{-1}; however, increasing the N concentration to 10 mg l^{-1} produced limited additional response. All N sources appeared to be effective in stimulating P uptake, although $CO(NH_2)_2$ appeared to be somewhat more effective than others tested. Maximum P uptake for these conditions was 5 mg P g^{-1} dry wt when the medium contained 10 mg l^{-1} N from $CO(NH_2)_2$.

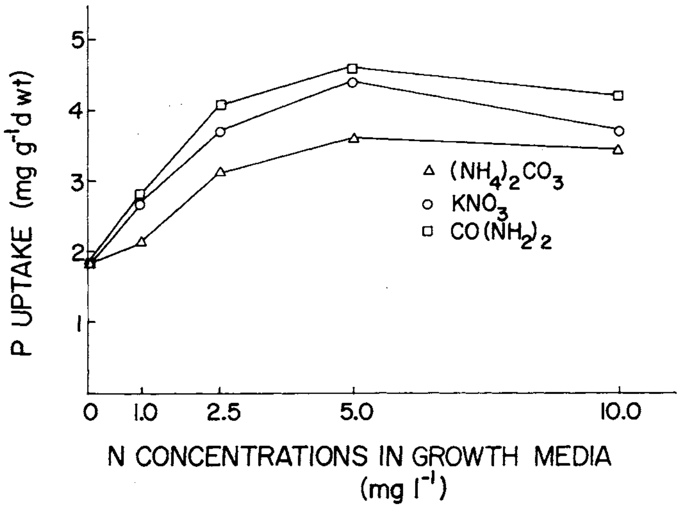

Figure 1. Effect of N source and concentration on P uptake from growth media after 2 weeks.

The P contents of plants grown in media containing 1, 2.5 and 5 mg l^{-1} N generally followed the same patterns at the second harvest as were observed at the first harvest. However, small decreases in the P contents of tissues were observed when the concentration of N was increased from 5 to 10 mg l^{-1} (Figure 2).

Maximum P uptake at the third harvest occurred with a N concentration of 2.5 mg l^{-1}, and higher N concentrations caused decreases in P in the tissue (Figure 3). From these data, it appears that at early stages of growth when the concentration of P was high in growth media, P uptake could be enhanced by increasing the N concentration. As the concentration of P in growth media decreased as a result of plant uptake, increasing the N concentration inhibited P uptake (Figure 3). Hence, the optimum N concentration for maximum P uptake by waterhyacinth appears to be dependent on the P concentration of growth media and probably the stage of growth. For example, optimum concentrations of urea-N for maximum P uptake at first, second and third harvests under these experimental conditions were 10, 5, and 2.5 mg l^{-1}, respectively.

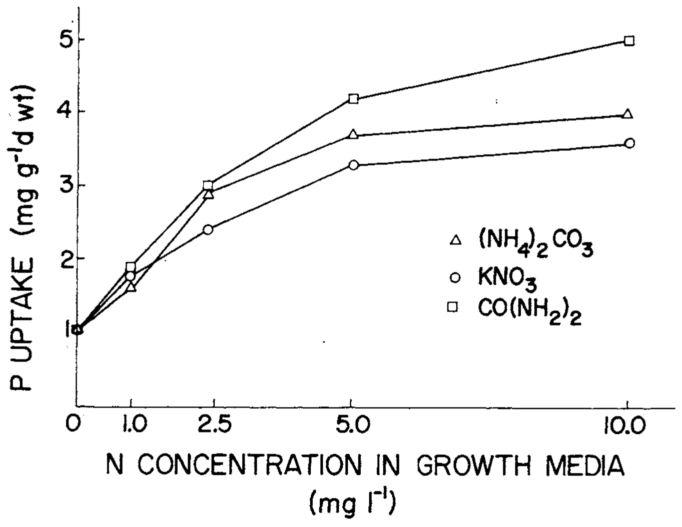

Figure 2. Effect of N source and concentration on P uptake from growth media after 3 weeks.

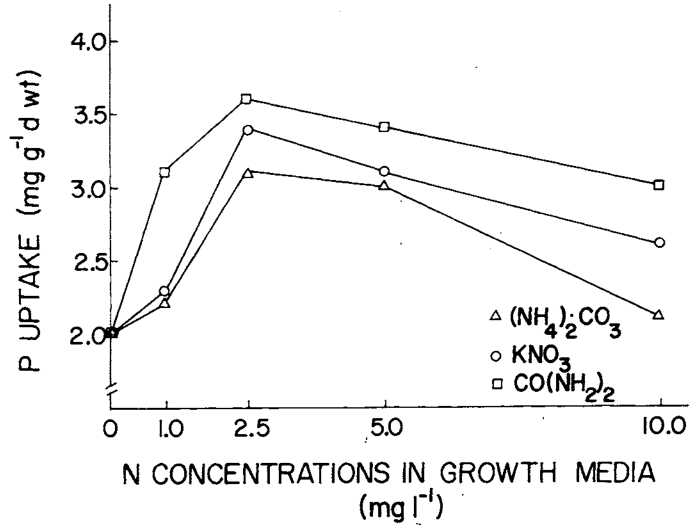

Figure 3. Effect of N source and concentration on P uptake from growth media after 4 weeks.

Most of the P taken up by the waterhyacinths was transferred to the shoots. The distribution of P taken up ranged from 64 to 84% in shoots and 16 to 36% in roots (Table 3). During the 2nd and 3rd weeks of growth, the amount of P in shoots increased and that in roots decreased with increased amounts of N. However, this phenomenon was true only for N concentrations of 0, 1 and 2.5 mg l^{-1} at third harvest, where the maximum P uptake took place. In general, it appears that there is a direct relationship between P uptake and the amount of P transported into the shoots.

ACKNOWLEDGMENTS

The authors wish to express their appreciation to J. L. Carter for her technical assistance.

LITERATURE CITED

1. Aboul-El-Fadl, M., S. G. Rizk, H. F. Abdel-Ghani, K. Kh. El-Mofty, M. F. A. Khadr, S. M. Shehata, and F. A. Farag. 1968. Utilization of waterhyacinth as an organic manure with special reference to water-born Helminths. J. Microbiol. V.A.R. 3:27.
2. Archana, S. 1971. Eradication and utilization of waterhyacinth, a review. Current Sci. 40:51-55.
3. Boyd, C. E. 1968. Fresh water plants; A potential source of protein. Econ. Bot. 22:359-368.
4. Boyd, C. E. 1969. The nutritive value of three species of water weeds. Economic Botany 23:123-127.
5. Hakk, D. O. 1977. Will photosynthesis solve the energy problems?

Table 3. Effect of nitrogen source and concentration on phosphorus distribution (%) in waterhyacinth.

Nitrogen source	Nitrogen concentration (mg 1^{-1}	Uptake period (wks)[a]					
		2		3		4	
		Root	Shoot	Root	Shoot	Root	Shoot
None	0	36±2	64±2	35±3	65±3	35±2	65±2
	1.0	31±3	69±3	25±3	75±3	30±1	70±1
Urea	2.5	26±4	74±4	19±1	81±1	27±2	73±2
$CO(NH_2)_2$	5.0	20±2	80±2	18±2	82±2	24±2	76±2
	10.0	16±1	84±1	18±1	82±1	26±2	74±2
	1.0	36±4	64±4	24±4	76±4	24±1	76±1
Potassium	2.5	28±3	72±3	21±1	79±1	23±3	77±3
Nitrate	5.0	22±2	78±2	21±4	79±4	27±1	73±1
KNO_3	10.0	17±2	83±2	19±2	81±2	32±1	68±1
	1.0	32±4	68±4	31±5	69±5	26±3	74±3
Ammonium	2.5	24±1	76±1	26±3	74±3	21±3	79±3
Carbonate	5.0	24±4	76±4	23±1	77±1	26±2	74±2
$(NH_4)_2CO_3$	10.0	21±3	79±3	19±2	81±2	27±1	73±1

[a] Each value is the mean of three replicates. Harvesting periods were 2, 3, and 4 weeks after establishment of the experiments.

pp. 27-52. In: Solar power and Fuels, J. R. Bolton, (ed.), Academic Press, New York, N. Y.

6. Haller, W. T., E. B. Knipling, and S. H. West. 1970. Phosphorus absorption by and distribution in waterhyacinths. Proc. Soil and Crop Sci. Soc. of Fla. 30:64-68.
7. Hoagland, D. R. and D. I. Arnon. 1950. The water culture method for growing plants without soil. Calif. Agric. Exp. Sta. Circ. 347 Berkeley, California. pp. 31.
8. Kamal, I. A., and E. C. S. Little. 1970. The potential utilization of waterhyacinth for horticulture in the Sudan. PANS 16:488-496.
9. Knipling, E. B., S. H. West and W. T. Haller. 1970. Growth characteristics, yield potential, and nutritive content of waterhyacinths. Proc. Soil and Crop Sci. Soc. of Fla. 30:51-84.
10. Ornes, W. Harold and D. L. Sutton. 1975. Removal of phosphorus from static sewage effluent by waterhyacinth. Hyacinth Control J. 13:56-58.
11. Parra, J. V., and C. C. Hortenstine. 1974. Plant nutritional content of some Florida waterhyacinths and response by pearl millet to incorporation of waterhyacinths in three soil types. Hyacinth Control J. 12:85-90.
12. Penfound, W. T. and T. T. Earle. 1948. The biology of the waterhyacinth. Ecol. Monogr. 18:477-472.
13. Ryther, J. J., L. D. Williams, M. D. Hanisak, R. W. Stenberg, and T. A. DeBusk. 1979. Biomass production by marine and freshwater plants. Proc. Third Annual Biomass Energy Systems Conference, Golden, Colorado. pp. 13-23.
14. Shieffield, C. W. 1967. Waterhyacinth for nutrient removal. Hyacinth Control J. 6:27-30.
15. Sutton, D. L. and R. D. Blackburn. 1971. Uptake of copper in hydrilla. Weed Res. 11:47.
16. Taylor, K. G. and R. D. Robluns. 1968. The amino acid composition of waterhyacinth (*Eichhornia crassipes*) and its value as a protein supplement. Hyacinth Control J. 8:24.
17. Wolverton, B. C. and Mary M. McKown. 1976. Waterhyacinths for removal of phenols from polluted waters. Aquatic Botany 2:191-201.
18. Yount, J. L. and R. C. Crossman, Jr. 1970. Eutrophication control by plant harvesting. J. Water Pollut. Contr. Fed. 42:174-183.