Mineral nutrient demands of the water hyacinth (*Eichhornia crassipes* (Mart.) Solms) in the White Nile

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Abstract

The possibility that the stunted growth of the water hyacinth in Bahr el Ghazal river in Sudan is influenced by nutrient elements is considered. Greenhouse experiments were carried out to determine the effects of deficiency and mineral nutrient additions on the growth of this plant. The water hyacinth was found to grow at a wide range of nutrient levels. Maximum growth was recorded at 21 mg l^{-1} N, 62 mg l^{-1} P, and 0.60 mg l^{-1} Fe.

Introduction

Almost all the world's tropical and subtropical waters are infested with water hyacinth (Little, 1965; Holm *et al.*, 1977). The plant has a very high reproductive potential, which resulted in its enormous abundance in the waters which it has invaded (Penfound & Earle, 1948; Obeid, 1975). In the Sudan, the water hyacinth was first recorded in 1958. In a few months time, it had spread along the stretch Juba–Jebel Aulia Dam near Khartoum, i.e. a distance of 1 126 km along the White Nile (Heinen & Ahmed, 1964). A control campaign was initiated in 1960 to make the White Nile navigable for steamers and to stop a further spread of the plant in the River Nile north of Khartoum and in the gigantic Gezira agriculture canalization system. Twenty years have now passed without invasion of the plants into this canalization system, although the canals lie not far from the White Nile. This raised the suggestion that the Blue Nile water and hence the canal water may not be suitable for the growth of the water hyacinth.

It was also observed that in the Bahr El Ghazal – a tributary of the White Nile – the growth of the water hyacinth is stunted, while plants growing on Lake No (the Ghazal flowing through it) or on other White Nile tributaries are flourishing.

These two sets of observations – absence of the plants from Gezira canals and stunted growth on Ghazal – led us to undertake a series of experiments in order to study the relationship between chemical water characteristics and the growth of the water hyacinth.

The culture medium chosen was Hoaglands nutrient solution (1952). The plants were subjected to grow at different concentrations of Hoagland, or grown in solutions lacking one of the macro elements, or at different concentrations of P, N and Fe.

Material and methods

The plants used in the first experiment were collected from different areas of the world, namely Sudan (Kosti), Egypt (Cairo), U.S.A. (Gainesville, Florida), South America (Guyana) and the Philippines (Los Banos). In later experiments only plants originated in the Sudan were used.

All plants were propagated in the greenhouse of the Institute for Phytomedicine, University of Ho-

Hydrobiologia 110, 99–108 (1984).

Table 1. Composition of Hoagland solution.

Salt compound	Molecular weight	Concentration of stock solution		Amount (ml) of stock solution added per l of final solution	Final concentration of elements in mg l^{-1}	
		M	g l^{-1}			
KH_2PO_4	136.091	1	136.091	1	K	234.60
KNO_3	101.100	1	101.100	5	Mg	48.64
$Ca(NO_3)_2$	164.096	1	164.096	5	S	64.13
$MgSO_4$	246.480	1	264.480	2	P	30.98
Fe-EDTA	367.050		5.000	1	N	210.12
H_3BO_3	61.840		2.860		Ca	200.40
$MnCl_2 \cdot 4\ H_2O$	197.910		1.810		Fe	0.60
$ZnSO_4 \cdot 7\ H_2O$	287.550		0.220	1	B	0.50
$CuSO_4 \cdot 5\ H_2O$	249.710		0.080		Mn	0.50
$H_2MoO_4 \cdot H_2O$	161.840		0.020		Zn	0.05
					Cu	0.02
					Mo	0.01

henheim, F.R.G. They were kept in a solution consisting of tap water and humus extract (2:1), iron chelate (Fetrilon - 0.016 g l^{-1}) and NPK fertilizer (12-12-17).

In all experiments - except otherwise mentioned - metal containers (25 × 20 cm and 25 cm deep) lined with plastic bags on the inside were used. They contain up to 10 litres of solution. In each container, one plant was grown. Four replicates per treatment were made. Hoagland solution (Hoagland, 1952) was used as a basic culture medium, according to the aim of each experiment, modifications were made.

Molar stock solutions (except when otherwise indicated) were prepared for each salt as given in Table 1. Aliquots from this stock solution then were used to produce the different experimental treatments.

The culture solution was changed weekly. One or more of the following were taken as measures of growth: the number of mother plant leaves, the number of daughter plants, their leaves and the total leaves produced by mother and daughter plants, fresh and dry weight of the plants.

Influence of nutrient level, time, and origin of plant on reproduction rate of waterhyacinth

In this experiment the response of plants of five different origins to different nutrient levels in relation to the time was studied.

The test plants used were 20–25 cm high each, having four leaves and a well-developed root system. Four different treatments were established, corresponding to 10%, 50%, 100% and 200% strength of Hoagland's solution. The concentrations, in mg l^{-1}, of the constituent elements of the nutrient solutions are given in Table 2.

The experiment continued for 10 weeks. At the end of each week the daughter plants produced were cut off and their fresh and dry weights were determined, resulting in a total of 800 readings - (4 treatments × 4 replicates × 5 countries × 10 weeks). From these, the reproductive rate for each of the

Table 2. Final concentrations of elements in mg l^{-1} in different Hoaglands nutrient solution levels.

Element	Element concentration (mg l^{-1}) (Hoagland nutrient level)			
	10%	50%	100%	200%
K	23.16	117.30	234.60	469.20
Mg	4.86	24.30	48.64	97.20
S	6.41	32.07	64.13	128.26
P	3.00	15.04	30.98	60.14
N	21.01	105.06	210.12	420.24
Ca	20.04	100.20	200.40	400.80
Fe	0.060	0.300	0.60	1.20
B	0.050	0.250	0.50	1.00
Mn	0.050	0.250	0.50	1.00
Zn	0.005	0.025	0.05	0.10
Cu	0.002	0.010	0.02	0.04
Mo	0.001	0.005	0.01	0.02

three factors studied – nutrient level, country, and time – were determined. The reproduction rate per country is a mean of 160 readings (4 nutrient levels × 4 replicates × 10 weeks). The reproduction rate for each nutrient level is a mean of 200 readings (5 countries × 4 replicates × 10 weeks), and the reproduction rate for each week is a mean of 80 readings (4 nutrient levels × 5 countries × 4 replicates).

Effect of elemental deficiencies on growth of water hyacinth

Solutions were prepared lacking one of the essential elements, N, K, P, Ca, and Mg. Their mineral compositions is given in Table 3. Complete Hoagland solution was used as a control to show normal growth. Distilled water was used as a second control to demonstrate the effect of all mineral elements combined. The test plants used had a length of 20–25 cm. The experiment continued for 3 weeks.

Table 3. Composition of the modified Hoagland solutions used to study the deficiency effect of mineral elements on growth of water hyacinth.

Compounds stock solutions in M	Volume of stock solution added to final solution ml l^{-1}					
	Complete Hoagland solution	N	K	P	Ca	Mg
0.5 M K_2SO_4	–	5	–	–	–	3
M $MgSO_4$	2	2	2	2	2	–
0.05 M $Ca(H_2PO_4)_2$	–	10	10	–	–	–
0.01 M $CaSO_4$	–	200	–	–	–	–
M $Ca(NO_3)_2$	5	–	5	4	–	4
M KNO_3	5	–	–	6	5	6
M KH_2PO_4	1	–	–	–	1	1

Element	Final concentration of elements in mg l^{-1}					
	Complete Hoagland solution	N	K	P	Ca	Mg
K	234.60	97.75	0.00	234.60	234.60	351.90
Mg	48.64	48.64	48.64	48.64	48.64	0.00
S	64.13	208.43	64.13	64.13	64.13	48.10
P	30.98	30.98	30.98	0.00	30.98	30.98
N	210.12	0.00	40.08	196.11	70.04	210.12
Ca	200.40	100.20	220.44	160.32	0.00	160.32
Fe	0.60	0.60	0.60	0.60	0.60	0.60
B	0.50	0.50	0.50	0.50	0.50	0.50
Mn	0.50	0.50	0.50	0.50	0.50	0.50
Zn	0.05	0.05	0.05	0.05	0.05	0.05
Cu	0.02	0.02	0.02	0.02	0.02	0.02
Mo	0.01	0.01	0.01	0.01	0.01	0.01

Table 4. Composition of culture solution used to study the effect of different nitrogen levels on the growth of water hyacinth.

Source stock solution	Volume of stock solution added to final solution ml l^{-1}	Final concentration of elements	
		Element	mg l^{-1}
1 M $NH_4 \cdot NO_3$	0.00	N-Treatment I	0.00
	0.75	N-Treatment II	21.00
	7.50	N-Treatment III	210.00
	15.00	N-Treatment IV	420.00
1 M KH_2PO_4	1.00	K	351.90
0.5 M K_2SO_4	8.00	P	30.98
1 M $MgSO_4$	2.00	Mg	48.64
0.01 M $CaSO_4$	400.00	Ca	160.32
5.00 g l^{-1} Fe-EDTA	1.00	S	322.26
2.86 g l^{-1} H_3BO_3		Fe	0.60
1.81 g l^{-1} $MnCl \cdot 4\,H_2O$		B	0.50
0.22 g l^{-1} $ZnSO_4 \cdot 7\,H_2O$	1.00	Mn	0.50
0.08 g l^{-1} $CuSO_4 \cdot 5\,H_2O$		Zn	0.05
0.02 g l^{-1} $H_2MoO_4 \cdot H_2O$		Cu	0.02
		Mo	0.01

Effect of different nitrogen levels on the growth of water hyacinth

Plants used were 20–25 cm high, having three leaves and a well-developed root system. The composition of the culture solution used is given in Table 4. Nitrogen in the form of $NH_4\,NO_3$ was given at four levels: 0, 21, 210 and 420 mg l^{-1}. The plants were harvested after 3 weeks.

Effect of different phosphorus levels on the growth of water hyacinth

The plants were subjected to 7 different phosphorus levels: 0.00, 0.62, 3.10, 7.74, 15.49, 30.98 and 61.95 mg l^{-1} in respect to solution I–VII in Table 5. The salt concentrations in treatment VI were equivalent to 100% Hoaglands solution. The concentrations of the elements K, Mg, S, Fe and the microelements B, Mn, Zn, Cu and Mo were kept constant, as recommended by Hoagland (1952). Small changes in the concentrations of Ca and N were unavoidable in order to vary phosphorus and to keep K constant (phosphorus was given as KH_2PO_4).

Table 5. Composition of the modified Hoaglands' solutions used for growth of water hyacinth under different phosphorus concentrations.

Element	Final concentrations of elements in mg l^{-1} treatments						
	I	II	III	IV	V	VI*	VII
K	234.60	234.60	234.60	234.60	234.60	234.60	234.60
Mg	48.64	48.64	48.64	48.64	48.64	48.64	48.64
S	64.13	64.13	64.13	64.13	64.13	64.13	64.13
P	0.00	0.62	3.10	7.74	15.49	30.98	61.95
N	196.11	196.95	197.51	199.61	203.12	210.12	224.13
Ca	160.32	161.12	164.33	170.34	180.36	200.36	240.48
Fe	0.60	0.60	0.60	0.60	0.60	0.60	0.60
B	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Mn	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Zn	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Cu	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Mo	0.01	0.01	0.01	0.01	0.01	0.01	0.01
P and Ca	Final concentration as % of P and Ca concentration in the original Hoagland-solution						
P	0.00	2.00	10.00	25.00	50.00	100.00	200.00
Ca	79.85	80.42	82.02	85.02	90.02	100.00	119.78

* Treatment VI is equivalent to the original Hoagland nutrient solution.

The solutions were changed weekly. The experiment continued for a period of 4 weeks. A weekly record of number of mother plants leaves, daughter plants and their leaves was made. At the end of the experiment total fresh and dry weights of the mother and daughter plants were determined.

Effect of different iron levels on the growth of water hyacinth

The water culture used is 50% Hoagland strength solution. Ironchelate (ferric-sodium-ethylenediaminetetra-acetate, 12% Fe) as a source of iron was used. Iron concentrations are given in Table 6.

Table 6. Final Fe concentrations in mg l^{-1} used to study effects on the growth of water hyacinth.

Treatment	Stock solution Fe-EDTA g l^{-1}	Volume of stock solution added per l of final solution ml	Fe-EDTA concentration in mg l^{-1}	Fe* concentration in mg l^{-1}
I	50	0.0	0.0	0.0
II	50	0.5	2.5	0.3
III	50	1.0	5.0	0.6
IV	50	5.0	25.0	3.0
V	50	10.0	50.0	6.0

* Calculated as 12% of molecular wt of the used compound as given by the producing firma (Firma Feluka, Switzerland).

After 6 weeks of growth the plants were harvested for fresh and dry weights, number of leaves of mother and daughter plants and number of daughter plants produced.

Results

Effect of nutrient level, time and origin of plants on growth

The mean reproduction rate for each of the three factors studied – time, origin and nutrient level – are given in Table 7. The differences in reproduction rates due to nutrient level and time were found to be significant. Those due to origin were not significant ($P \leqslant 0.01$) (Table 8).

After 4 weeks it was observed that plants in treatments with the highest concentration (200% Hoagland) were not healthy. A brown colour developed and almost all leaves died. The plants in the lower concentrations (10% Hoagland) showed signs of deficiency but they recovered in the 6th week.

Production of daughter plants was not recorded after the 9th, 7th, 5th week in treatments 50%, 100% and 200% respectively. The results obtained for fresh and dry weight showed a pattern of increase and decrease similar to that of the variations in numbers of daughter plants (Table 7).

Table 7. Number, fresh and dry weights of daughter plants produced weekly per country, nutrient level and time.

Factor	Mean		
	No. of daughter plants	Fresh weight in g	Dry weight in g
Country			
Sudan	0.84	13.39	0.84
Egypt	0.63	10.35	0.61
U.S.A.	0.69	10.05	0.67
South America	0.72	11.17	0.76
Philippines	0.80	11.73	0.72
Nutrient level			
10% Hoagland solution	0.82	12.77	0.93
50% Hoagland solution	0.95	15.42	1.06
100% Hoagland solution	0.74	11.06	0.65
200% Hoagland solution	0.43	6.11	0.93
Time			
1st week	0.27	2.85	0.29
2nd week	0.62	6.42	0.75
3rd week	0.74	12.62	0.78
4th week	0.75	12.89	0.56
5th week	1.27	19.07	1.08
6th week	0.83	15.14	0.85
7th week	0.76	11.99	0.78
8th week	0.89	13.73	0.50
9th week	0.63	9.45	0.52
10th week	0.60	9.22	0.08

Effects of nutrient level. The highest average reproduction rate of 0.95 offspring · wk^{-1} and the lowest 0.43 offspring · wk^{-1} were recorded in treatments 50% and 200% respectively. These had 15.42 and 6.11 g fresh weight and 1.06 and 0.23 dry weight respectively (Table 7).

Plants collected from Sudan and Egypt showed highest reproduction rates on treatment (50% Hoagland solution) while plants collected from all other areas had their highest rates in treatment with 10% Hoagland solution (Table 9). Reproduction rate of plants from all origins decreased with increasing nutrient levels from 50% to 200% Hoagland solution, but statistically significant differences were found only between the highest nutrient level (200%) and the lower two levels (10% and 50%) (Table 7).

Once can conclude from these results that water hyacinth can grow in a wide range of nutrient levels, but reproduces at high rates only when grown in optimum nutrient concentrations. These findings are in agreement with those of Boyd & Scarsbrook (1975).

Table 8. Analysis of variance for data of Table 7.

Source of variation	F-ratio Offspring	Fresh weight	Dry weight	$P \leq 0.05$	$P \leq 0.01$
Nutrient concentration	23.40*	18.03*	61.07*	2.61	3.80
Time	12.40*	9.84*	31.41*	1.89	2.41
Country	2.66	1.65	2.87	2.88	3.34
Interaction					
nutrient × time	3.73*	2.55*	5.47*	1.47	1.71
nutrient × country	1.09	1.44	2.58*	1.76	2.20
time × country	0.92	0.72	1.46	1.41	1.61
nutrient × time × country	0.81	0.70	1.67*	1.19	1.20

* Differences significant.

Effects of time. The mean reproduction rate per week showed a tendency of increase with time, reaching a maximum at the 5th week and then a gradual decline, reaching a minimum in the 10th week (Table 7).

The weekly reproduction rates can be looked at as additional replicates, since after cutting the offsprings there remains only the mother plants. But these rates were not regular from week to week.

Table 9. Effect of different Hoagland concentrations on growth of water hyacinth.

	Hoagland solution				
	10%	50%	100%	200%	L.S.D.*
A. Daughter plants production/week					
Sudan	1.06	1.23	0.76	0.37	0.50
Egypt	0.60	0.75	0.70	0.26	0.47
U.S.A.	1.03	0.91	0.54	0.29	0.46
South America	1.06	0.91	0.76	0.25	0.50
Philippines	1.04	1.01	0.75	0.38	0.47
B. Mean fresh weights of produced daughter plants/week					
Sudan	17.58	21.35	11.33	4.27	9.99
Egypt	8.70	15.82	9.81	3.14	10.35
U.S.A.	15.87	12.15	8.67	3.65	7.99
South America	18.03	14.43	11.82	2.96	10.00
Philippines	15.53	14.56	11.64	5.07	8.36
C. Mean dry weight of produced daughter plants/week					
Sudan	1.02	1.46	0.62	0.27	0.60
Egypt	0.54	1.04	0.64	0.21	0.69
U.S.A.	1.00	0.90	0.57	0.22	0.53
South America	1.17	0.95	0.73	0.17	0.63
Philippines	0.90	0.96	0.72	0.30	0.20

* Least Significant Difference.

Table 10. Effect of element deficiencies on growth of water hyacinth.

Growth measure	Weeks	Complete Hoaglands solution	Distilled water	N	K	P	Ca	Mg
No. of mother plants leaves	2nd	9.3	6.3	7.0	6.3	8.3	4.5	7.3
	3rd	8.5	3.0	8.3	8.0	5.5	2.0	6.8
No. of daughter plants produced	2nd	3.3	0.0	2.5	2.8	3.0	0.0	3.3
	3rd	8.3	0.0	3.3	3.0	4.5	0.0	3.5
No. of daughter plants leaves	2nd	14.4	0.0	9.3	10.3	11.5	0.0	11.0
	3rd	34.8	0.0	14.0	14.0	19.8	0.0	11.5
Total of leaves (mother and daughter plants)	2nd	24.1	6.3	16.3	16.6	19.8	4.5	18.3
	3rd	43.3	3.0	22.3	22.0	25.3	2.0	18.3
Dry weight	3rd	32.3	19.7	19.7	19.9	27.0	15.2	18.6

Their irregularity is related to many factors:

1. The mother plants increase weekly in size during the study period.
2. The detaching of the newly formed daughter plants has effects on the physiology of reproduction of plants.
3. The variation in climatic conditions from one week to another, humidity, air temperature, length of the day, and light intensity that changes with cloudiness.

Table 11. Effect of different nitrogen levels on growth of water hyacinth.

	Time in in weeks	Nitrogen concentration in mg l^{-1}				L.S.D.* between treatments
		00	21	210	420	
Mother plants leaves	1	5.75	6.75	7.00	5.75	1.53
	2	4.00	7.50	7.75	5.50	1.51
	3	5.25	12.25	9.75	5.75	2.88
	L.S.D. between weeks	1.25	2.09	2.19	1.48	
No. of daughter plants	1	1.75	1.50	1.00	1.50	1.02
	2	2.50	3.75	2.75	3.25	0.90
	3	2.50	5.00	5.00	3.00	1.06
	L.S.D.	0.80	0.76	0.93	0.91	
Leaves of daughter plants	1	4.75	3.00	2.25	3.50	2.44
	2	12.50	19.00	13.75	14.50	4.53
	3	12.25	25.00	22.75	17.75	4.41
	L.S.D.	3.69	3.69	3.24	2.86	
Total leaves	1	10.50	9.75	9.25	9.25	1.57
	2	16.50	26.50	21.50	20.00	4.18
	3	17.50	35.00	32.50	23.50	3.13
	L.S.D.	2.68	3.32	2.35	2.45	
Dry weight (g)	3	6.48	9.45	6.95	4.75	1.09
Fresh weight (g)	0	48.90	54.45	39.88	45.40	5.36
	1	78.33	85.00	64.33	59.98	9.12
	2	102.65	132.98	101.48	83.85	15.37
	3	123.25	193.25	151.00	101.25	24.25

* Least Significant Difference.

Effect of geographical origin. Variations linked to origin did not show any significant effect on the growth of water hyacinth. Some variations of maximum growth at different nutrient levels were recorded, e.g. plants collected from Sudan and Egypt showed maximum growth at 10% Hoagland solution, while all other grew best at 50% solution (Table 9).

Effect of elemental deficiencies

The results obtained 3 weeks after the start of the experiment are shown in Table 10. Plants grown in complete Hoagland solution showed maximum growth. Plants grown in solutions lacking one element showed vigorous inhibition of growth, reaching up to 50% of growth in complete Hoagland solution. No new plants were produced in distilled water or solution lacking calcium.

Effect of different nitrogen levels

The effects of different nitrogen levels on growth of water hyacinths are given in Table 11. Maximum growth was recorded in a treatment with 21 mg l^{-1} nitrogen. The difference between treatment 21 mg l^{-1} N and 210 mg l^{-1} is not significant in number of daughter plants produced, their leaves and the leaves of the mother plants. But the difference in fresh and dry weights is significant. The treatment with 420 mg l^{-1} showed the lowest values for fresh and dry weights, and even lower than those obtained in distilled water.

Effect of phosphorus levels

With increasing phosphorus (0.0, 0.62, 3.10, 7.74, 15.49, 30.98 and 61.95 mg l^{-1} P), growth increases (Table 12) were recorded.

Table 12. Effect of P in mg l^{-1} (as % of P concentration on Hoagland solution) on growth and reproduction of water hyacinth.

	Time in weeks	P concentration in mg l^{-1}							L.S.D.* between treatments
		0.00 (0%)	0.64 (2%)	3.10 (10%)	7.74 (25%)	15.49 (50%)	30.79 (100%)	61.95 (200%)	
Mother plants leaves	1	6.50	6.75	7.50	7.25	7.75	7.75	7.25	0.92
	2	7.75	8.50	9.50	9.50	10.00	9.75	10.50	0.81
	3	8.75	10.25	13.25	14.50	14.00	14.00	14.75	1.43
	4	9.50	11.75	14.50	14.75	16.00	15.25	16.50	1.02
	L.S.D. between weeks	0.80	0.90	1.00	0.85	1.51	1.01	1.25	
No. of daughter plants	1	3.00	2.75	3.25	5.25	4.25	5.00	5.50	0.76
	2	3.00	3.00	3.75	4.75	5.00	5.00	5.75	0.79
	3	3.00	3.00	4.50	5.25	5.75	7.25	8.00	0.81
	4	3.00	4.00	6.00	9.50	9.25	10.00	10.25	1.37
	L.S.D.	0.00	0.56	0.72	0.94	1.39	1.30	1.09	
Leaves of daughter plants	1	11.00	11.25	12.50	13.75	16.50	16.25	18.50	2.81
	2	14.50	15.00	16.25	23.25	32.25	25.50	32.00	3.69
	3	17.50	19.75	28.50	32.50	39.75	43.25	45.50	4.07
	4	19.25	28.25	36.75	58.50	58.25	64.00	65.75	6.66
	L.S.D.	1.57	2.66	4.24	4.69	5.54	7.00	3.87	
Total leaves	1	17.50	20.50	20.00	21.00	24.25	24.00	25.75	3.26
	2	22.25	23.50	25.75	32.75	42.25	35.50	42.50	4.06
	3	26.25	30.00	41.75	47.00	53.75	43.25	60.25	4.78
	4	28.75	40.00	51.25	73.25	74.25	64.00	82.25	6.95
	L.S.D.	2.03	3.01	4.40	5.06	5.92	7.86	4.12	
Total dry weight (g)	4	24.25	31.18	50.20	60.23	76.33	76.68	75.03	4.88
Total fresh weight (g)	4	298.00	410.80	478.80	579.50	626.80	673.50	722.50	55.50

* Least Significant Difference.

Table 13. Effect of Fe-EDTA on growth of water hyacinth.

Growth measure	Treatments					
	I 0.0 mg l^{-1} Fe	II 0.3 mg l^{-1} Fe	III 0.6 mg l^{-1} Fe	IV 3.0 mg l^{-1} Fe	V 6.0 mg l^{-1} Fe	L.S.D.*
Mother plants leaves	8.75	11.25	11.75	8.25	7.00	1.14
No. of daughter plants	7.25	7.75	9.50	1.50	1.00	1.26
Leaves of daughter plants	30.50	47.50	58.50	8.00	5.25	5.83
Total leaves	39.25	58.75	70.25	16.25	12.25	6.10
Dry weight (g)	6.10	21.08	26.10	4.63	3.35	3.25
Fresh weight (g)	117.68	456.78	467.25	56.00	51.93	54.89

* Least Significant Difference.

The lower phosphorus treatments (0.0 and 0.62 mg l^{-1} P) showed a significantly lower growth than all other treatments in all parameters of growth used. Growth at 3.10 mg l^{-1} is significantly different from that at 7.74 mg l^{-1} and at higher concentrations, except for the leaves of mother plants. The differences among the four highest concentrations are not significant, but dry weight at treatment 7.74 mg l^{-1} is an exception (Table 12).

Also, significant differences in the weekly growth are recorded with time over the 4 week period of the experiment, for all treatments.

Effects of different iron levels

Chlorosis of leaves appeared in treatment 0.0 mg l^{-1} Fe, with severe symptoms in the younger leaves. Treatment 0.3 and 0.6 mg l^{-1} Fe showed normal healthy green leaves. Maximum growth was recorded at treatment 0.6 mg l^{-1} Fe (Table 13). In all growth measures taken, the differences between these two treatments are significant (L.S.D.), except for the number of mother plants leaves and fresh weight.

In treatment 3.0 and 6.0 mg l^{-1} Fe signs of toxicity appeared with a brown colour developing on the leaves. High mortality was recorded on older leaves. This toxic effect was most prominent in treatment 6.0 mg l^{-1}, but both 3.0 and 6.0 mg l^{-1} showed poor growth. The differences between them are not significant except for the number of leaves on the mother plants (Table 13).

Discussion of experimental results in relation to the growth of the water hyacinth on the White Nile

Water hyacinth was found to grow in 10%, 50%, 100% and 200% Hoagland nutrient solution with an optimum growth at 50% (this corresponds to 105 mg l^{-1} N, 12 mg l^{-1} P, 117 mg l^{-1} K, 100 mg l^{-1} Ca, 24 mg l^{-1} Mg, 32 mg l^{-1} S and 0.30 mg l^{-1} Fe. At 10%, deficiency symptoms developed and at 200% damage effects appeared. The element which caused the deficiency and damage effects at the lower and upper limit concentrations could not be detected from these results. The results merely indicate that an increase of an element or elements in water culture would be followed by an increase in water hyacinth growth, until a certain limit is reached where growth is no longer proportional to the increased element/ elements and growth even starts to decrease. Boyd & Scarsbrook (1975) demonstrated that weekly additions of (N-P_2O_5-K_2O) fertilizer greatly increased biomass of water hyacinth in ponds. Maximum biomass obtained was by addition of 10.8 kg ha^{-1}. The treatment with maximum fertilizer addition (21.6 kg ha^{-1}) did not produce maximum growth.

As expected, the plants' origin showed no significant impact on reproductive rates. This means that, whatever the origin of the plants, they grow at high rates when an optimum nutrient level is available. The world distribution of the plant shows that they grow vigorously in many parts of the world, far away from their origin in South America (Little, 1965).

Elemental deficiency studies demonstrated that deficiency of any macroelement leads to inhibition of growth measured as dry weight or mass production of either leaves or daughter plants. This inhibition of growth reached up to 50% compared to complete Hoagland solution. No new plants were produced in distilled water or solution lacking calcium. Sutcliffe & Baker (1974) related damage of meristematic tissues to Ca deficiency. In the White and Blue Niles these elements are present in concentrations above the complete deficiency level, but their amounts vary from one locality to another.

On investigating the nitrogen level effect on the growth of water hyacinth maximum growth was recorded at 21 mg l^{-1} nitrogen in comparison to 0.0, 210 and 420 mg l^{-1}. Chadwick & Obeid (1966) showed that an increase in N concentrations from 1 to 25 mg l^{-1} increased the number of plants and total dry weight produced. Ueki (1978) differentiated between the requirements of N by mature and immature plants. The latter grew well in 40 mg l^{-1} NH_4-N, while mature plants growth increased with increase of NH_4-N concentration. Nitrogen is present in the White Nile system more as nitrate than as nitrite or ammonia and the few data available on this show that Bahr el Ghazal has higher nitrate and ammonium content than the rest of the White Nile (H.R.U.T., 1973). However, the available data are inconclusive, and in line with the findings of Ueki (1978).

With increasing phosphorus, all measures of growth used (number of mother plant leaves, daughter plants and their leaves, total number of leaves produced, fresh and dry weight) increased (Table 12). The rate of increase was not proportional to the increase in phosphorus, but phosphorus deficiency was found to be a limiting factor of growth and reproduction (Tables 10 and 12). By addition of minute amounts of phosphorus, growth and reproduction could be maintained. Growth was stimulated by adding more phosphorus to the nutrient solution, up to 15 mg l^{-1}. Further additions were not associated with an increase in growth, but amounts as high as 60 mg l^{-1} were not toxic to plants.

Haller & Sutton (1973) found that maximum growth occurred at 20 mg l^{-1} and toxicity occurred at 40 mg l^{-1}. Available data on the phosphorus concentration in the White Nile River (Talling, 1957; Bishai, 1962; H.R.U.T., 1973) showed that phosphorus is always in amount much less than the highest concentrations used in the experiments. The concentrations were so small that they suffice only for sub-optimum growth (in comparison with the experimental results). This contrasts with data by Haller *et al.* (1970) who gave a value of 0.1 mg l^{-1} P as the lower critical level for growth of water hyacinth.

Iron, by deficiency as well as in surplus, affected growth and reproduction negatively (Table 13). Maximum growth was recorded in 0.6 mg l^{-1} followed by 0.3 mg l^{-1}. The few analysis of iron on the White Nile indicate that iron concentrations in Bahr el Ghazal are lower than in the rest of the White Nile. This might suggest that the stunted growth of water hyacinth in that area could be partially or entirely due to iron deficiency. A chlorosis of the plants leaves is noticed here, well comparable to that in iron deficiency treatment. However, absence of repeated and accurate analysis of water from the Nile river system leaves this conclusion questionable until further confirmation, although it does not seem to account for the absence of water hyacinth from the Gezira canals. Other deficiencies, possibly of oligo-elements, might thus be involved as well, and will need further study.

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