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GROWTH OF *SALVINIA MOLESTA* AS AFFECTED BY NUTRITION AND WATER TEMPERATURE

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ABSTRACT

Biological control investigations of *Salvinia molesta* D.S. Mitchell require a knowledge of its growth and behaviour under various environmental conditions. Consequently, this aquatic weed has been studied under varying water temperatures and levels of N and P of different chemical species. Four experiments have been carried out in a glasshouse using controlled temperature water baths at 16, 19 or 22^oC. In experiments 1, 2 and 3 initial plant propagules had four leaves, a terminal and an axillary bud, and a dry weight of about 20 mg; in experiment 4 the dry weight was only 7 mg, and propagules had not developed axillary buds. Over periods of 18 to 32 days, little growth occured at 16^oC, even if luxury levels of N and P were supplied. The highest relative growth rates and total dry matter production occurred at 22^oC when plants were supplied with 20 mg 1^{-1} N as NH_4^+ and 2 mg 1^{-1} P as $H_2PO_4^-$. Under these conditions the time taken for plants to double their number of leaves was as short as 2.2 days, which is equivalent to the shortest time reported in Australia for a tropical lake in north Queensland. In one experiment for plants receiving the lowest N treatment (0.02 mg 1^{-1} N as NH_4^+) the total dry matter at harvest was 82, 206 and 232 mg at 16, 19 and 22^o, respectively. In contrast, for plants receiving 20 mg 1^{-1} NH_4-N the production was 97, 416 and 892 mg, respectively. The NH_4^+ ion was markedly superior to the NO_3^- ion or urea as a source of N, but was not significantly better than N supplied as NH_4NO_3. Responses to P supplied as $H_2PO_4^-$ were not significantly different to those from P supplied as $HPO_4^=$ or $PO_4^{\equiv}$ions. Effects of treatments on various plant parameters, and on levels of N, P, K, Ca, Mg and Na in plant dry matter, also are reported.

INTRODUCTION

Salvinia molesta D.S. Mitchell is a free-floating aquatic fern that is native to South America. Salvinia is a vascular plant with no true roots. Instead it has hairy submerged leaves or axes which are considered to function as roots, absorbing nutrients and acting as a stabilizer (Gaudet 1973). Salvinia goes through three distinct morphological stages. In the preliminary stage, which occurs during the initial period of colonization, the leaves lie flat on the surface. In the second stage, the leaves fold up along the midrib. As space becomes limiting, this folding continues until the two halves of the leaf come into contact. In this third stage infertile sporocarps develop on modified segments of submerged leaves. For convenience hereafter in this paper the submerged leaves are called 'roots'.

Through the agency of man, salvinia is now widely distributed in tropical areas throughout the world (Mitchell 1979a, b). While it may be a desirable and attractive plant when grown under control in an aquarium or a small pond, it can be thoroughly obnoxious when growing under optimum conditions in warm fresh waters. Salvinia is capable of explosive growth, covering large areas of water, blocking waterways, hindering or preventing fishing, and, in extreme cases as in Papua New Guinea, removing the main source of livelihood for the native population living along the banks of the Sepik River (Mitchell *et al.* 1980).

Clearly, ecologically sound and efficient measures need to be developed to prevent and control extensive growth of this notorious aquatic weed in the warm fresh waters of Australia. To achieve this objective, a knowledge of the growth and behaviour of salvinia under various environmental conditions is required.

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This paper briefly reports some of the more important findings obtained from series of experiments carried out in a glasshouse at Griffith in New South Wale The experiments tested the effects of varying the levels and sources of N and and the water temperature on the growth, chemical composition and dry matt production of salvinia. These experiments will be discussed in greater detail in series of papers currently being prepared for publication.

Information gained from these studies should help in predicting the potenti hazards likely to arise from the accidental introduction of this aquatic weed in the inland waters and irrigation systems of Australia. Also, a knowledge of tl levels of nutrients that will promote specific growth rates at certain temperatur will form a basis for predicting the plant's capacity to recover from control b biological or other means. This knowledge will also provide a target for mai taining nutrient levels well below the minimum critical levels for satisfactor growth of salvinia.

METHODS AND MATERIALS

Experiments 1 and 2.

Propagules of salvinia at the primary stage were selected from uniform clon material. Each propagule had four leaves, with a terminal and an axillary bu The average dry weight of a propagule was 23.2 mg (s.e.m. ±7.2) in experime 1 and 21.4 mg (s.e.m. ±6.2) in experiment 2. The experiments were carried ou in three pairs of controlled temperature baths located in a glasshouse. The fir pair was maintained at 16°C, the second at 19°C, and the third at 22°C. T allow for any possible microclimatic differences between one side of the glas house and the other, one bath of each pair was located on the eastern side, an the other on the western side. The glasshouse was heated during the wint months (May to September) to a minimum temperature of 16°C. During th summer months (October to April) temperatures were kept as low as possible b ventilation and shading; thus air temperatures, varying from 19° to 42°C closely followed outside ambient conditions. Rectangular metal baths (3.0 x 1. x 0.2 m) were used; each bath contained 32 10-l pots, and each pot was fille with 8 l of nutrient solution. The baths were filled with water to a height c 180 mm, and the water surface was covered with a 20 mm layer of polyethylen beads (7 to 10 mm diameter) to minimize evaporation losses and inhibit growt of algae. As it was not possible to prevent algal growth in the nutrient solutio contained within each 10-l plastic pot, the salvinia plants were provided wit fresh nutrient solution every 84 hours. Thus at any given time in each bath onl 16 pots were used for growing the salvinia plants. After each 84-hr period th plants were gently washed to remove algae and then transferred to identical pot which had been thoroughly washed clean of algae and filled with fresh nutrien solution. This way competition from algae was kept to a minimum.

In experiment 1, four N levels (0.02, 0.20, 2.00 and 20.00 mg l^{-1}) wer tested; and in experiment 2 the levels tested were 0.02, 2.0, 20.00 and 60.00 m l^{-1}. Four chemical species also were compared, viz. N supplied as NO_3^-, NH_4^+ NH_4NO_3, and urea. A total of 96 salvinia propagules of uniform vigour wer used for each experiment. One propagule was placed into each 10-l plastic po previously filled with 8 l of nutrient solution. This solution was made up fron water supplied from a nearby irrigation channel, but enriched with the nutrient Ca, Mg, K, Na, N (as NH_4^+ and/or NO_3^-) and P (as HPO_4^-) to a total exchang capacity of 3.62 mequiv. l^{-1} for experiment 1, and of 13.42 mequiv. l^{-1} fo experiment 2. The nutrient solutions also contained the elements Fe, B, Mn, Zn, Cu and Mo at levels of 1.60, 0.20, 0.20, 0.06, 0.02 and 0.03 mg l^{-1}, respectively. Each bath thus contained 16 salvinia propagules in 16 plastic pots which included one pot at each nutrient level for each of the four chemical species tested. Experiment 1 commenced on 21 June 1979 and a harvest was obtained 19 days later on 10 July 1979. Experiment 2 commenced on 13 July 1979 and a harvest was obtained 26 days later on 8 August 1979. The plants were harvested when salvinia plants receiving the most effective nutrient treatment had almost covered the surface area of water within the 10-l pot (about 0.045 m^2). As a measure of growth rates numbers of leaves in each pot were counted at 84-hr intervals during the progress of the experiments. Relative growth rates ($\overline{RGR}_N$ day^{-1}) were calculated using the formula:

$$\overline{RGR}_N = \frac{\ln N_1 - \ln N_o}{t_1 - t_o}$$

where N_o and N_1 represent the leaf numbers at the initial (t_o) and final (t_1) time periods, respectively. Doubling times (days) were obtained by dividing ln2 by $\overline{RGR}_N$. At harvest, the fresh plant material from each pot was cut up and separated into 'roots', stems, leaves and buds. The material was then dried at 75°C in a forced draught oven, and weighed to obtain dry matter yields. Samples of the dried material were analysed for the elements Ca, Mg, K, Na, N and P.

Experiments 3 and 4.

With the exception of differences in nutrient treatments, the procedures for experiments 3 and 4 were very similar to those used for experiments 1 and 2. In experiment 3, four P levels (0.02, 0.20, 2.00 and 20.00 mg l^{-1}) were tested, and in experiment 4 the levels were 0.01, 0.10, 1.00 and 10.00 mg l^{-1}, exactly half of those for experiment 3. Three different chemical species ($H_2PO_4^-$, $HPO_4^=$ and $PO_4^{\equiv}$) also were compared. In both experiments basal N (as NH_4^+) was supplied at the level of 20 mg l^{-1}. The nutrient solutions contained the elements Ca, Mg, K, Na, N (as NH_4^+) and P (as $H_2PO_4^-$, $HPO_4^=$ or $PO_4^{\equiv}$) at a total exchange capacity of 6.71 mequiv. l^{-1} in experiment 3, and of 5.60 mequiv. l^{-1} in experiment 4. The elements Fe, B, Mn, Zn, Cu and Mo were also supplied at the levels described previously for experiments 1 and 2. A total of 72 propagules were used for each experiment. Some difficulty was found in experiment 3 in obtaining propagules with P levels low enough for significant responses to be obtained from the applied P treatments. It is known (Gaudet 1973) that salvinia plants have a capacity to store luxury levels of P which can be used later when P levels in the nutrient medium are low or limiting. Thus, for experiment 4 it was necessary to propagate a sequence of sub-cultures of salvinia plants in a P-deficient nutrient medium to obtain propagules inherently low in P and able to respond significantly to the P treatments applied. One disadvantage arising from this procedure was that propagules for experiment 4 were of much poorer vigour than those used in experiment 3; for instance, the average dry weights were 16.7 mg (±3.3) and 6.7 mg (±1.6), respectively. Also, in propagules for experiment 4 the axillary buds were not visible to the naked eye. However, some were observed to develop a few days after the propagules had been growing in a high N P nutrient medium.

Experiment 3 commenced on 7 September 1979 and a harvest was obtained 20 days later on 27 September 1979. Experiment 4 commenced on 26 October 1979 and a harvest was obtained 32 days later on 27 November 1979.

RESULTS AND DISCUSSION

Experiments 1 and 2

Since experiment 2 was a partial repeat of experiment 1, except for the subsitution of the 0.20 mg l^{-1} N level by the 60 mg l^{-1} N level, it is convenient to discuss these two experiments together. The effects of temperature and N level on relative growth rate and doubling time of salvinia plants are presented in Table 1. These results are based on the increase in leaf number over the period day 1 to 18 for experiment 1 and day 1 to 25 for experiment 2. Moreover, the results are those for plants receiving the NH_4-N source, which was markedly superior to NO_3-N and urea sources (Table 2). In general, growth was poor at 16°C, particularly in experiment 2 where the N level had no effect on growth even when increased 3000-fold from 0.02 to 60 mg l^{-1}. Some responses to increasing the N level were evident at 19°C, but were most marked at 22°C where significant increases ($P = 0.01$) in relative growth rates were obtained by raising the N level from 0.02 to 2.00 mg l^{-1}. Increasing the N level above 2.00 mg l^{-1} did not significantly increase growth rate or reduce doubling time. The lowest doubling time was obtained in experiment 1 at 22°C from the 20.00 mg l^{-1} level of N. However, doubling times lower than 2.9, and down to 2.2 days were obtained from this treatment during the course of the experiment. Propagules immediately after being placed in a high nutrient solution tended to suffer a slight shock lasting several days. Thus, these propagules did not exhibit their maximum growth potential until about 10 days after the commencement of the experiment. This period of adjustment was even more marked in experiment 2

Table 1. Effects of temperature and N level on relative growth rate and doubling time of *Salvinia molesta* in experiments 1 and 2. The results are those for plants receiving the NH_4-N source.

Temperature (°C)	Nitrogen level (mg l^{-1})	Relative growth rate ($RGR_N \times 10^3$)		Doubling time (days)	
		Expt 1	Expt 2	Expt 1	Expt 2
16	0.02	48	46	14.5	15.1
	0.20	82	–	8.5	–
	2.00	118	48	5.9	17.4
	20.00	115	45	6.0	16.3
	60.00	–	45	–	16.3
19	0.02	64	77	11.3	8.9
	0.20	133	–	5.3	–
	2.00	150	110	4.7	6.3
	20.00	159	115	4.4	6.0
	60.00	–	114	–	6.0
22	0.02	111	126	6.3	5.5
	0.20	168	–	4.2	–
	2.00	219	198	3.2	3.5
	20.00	238	197	2.9	3.5
	60.00	–	190	–	3.6
l.s.d. $P = 0.05$		59	48	2.9	3.5
$P = 0.01$		80	64	3.9	4.7

Table 2. Effects of N level and source on leaf number and total dry matter at harvest of *Salvinia molesta* in experiments 1 and 2. The results are those for the 22°C temperature treatment, expressed on a per pot basis.

Nitrogen source	Nitrogen level ($mg\ l^{-1}$)	Leaf number		Total dry matter (mg)	
		Expt 1	Expt 2	Expt 1	Expt 2
NO_3	0.02	22	51	156	237
	0.20	82	–	290	–
	2.00	114	104	277	488
	20.00	106	111	284	489
	60.00	–	146	–	462
NH_4^+	0.02	30	56	140	232
	0.20	87	–	313	–
	2.00	218	216	523	866
	20.00	319	258	760	892
	60.00	–	182	–	726
NH_4NO_3	0.02	25	46	112	230
	0.20	90	–	284	–
	2.00	257	155	671	674
	20.00	355	195	710	826
	60.00	–	206	–	746
UREA	0.02	31	46	100	256
	0.20	57	–	195	–
	2.00	122	96	304	523
	20.00	182	100	399	496
	60.00	–	122	–	550
l.s.d. P = 0.05		105	62	141	177
P = 0.01		140	83	189	237

when little growth occurred during the first seven days. It is noteworthy that the doubling time of 2.2 days found during the peak growth period in experiment 1 is equivalent to the shortest time reported in Australia for a tropical lake in north Queensland (Farrell 1979).

The effects of N level and source on leaf number and total dry matter at harvest of the salvinia plants are presented in Table 2. The results are those for the 22°C temperature treatment which produced the most vigorous growth (Table 1). N as NH_4^+ was the most effective nutrient source, producing the highest total dry matter yields at the 20 $mg\ l^{-1}$ N level in both experiments 1 and 2. Increasing the N level from 20 to 60 $mg\ l^{-1}$ in experiment 2 tended to reduce yields, but this effect was not significant. The leaf number of plants receiving the NH_4^+ source was similarly reduced by this increase in N level; however, leaf number was increased slightly for plants receiving the three other N sources. NH_4NO_3 was not significantly different from NH_4^+ as a source of N, but both sources were significantly better ($P = 0.01$) than NO_3^- or urea at N levels above 0.20 $mg\ l^{-1}$ in experiment 1, and at the 20.00 $mg\ l^{-1}$ N level in experiment 2.

The effects of temperature and N level on leaf number and total dry weight of the salvinia plants are presented in Table 3. The results are expressed as the average of the four N sources. In both experiments the highest number of leaves

Table 3. Effects of temperature and N level on leaf number and total dry weight of *Salvinia molesta* in experiments 1 and 2. The results are expressed on a per pot basis as the average of the four N sources.

Temperature (°C)	Nitrogen level (mg l^{-1})	Leaf number		Total dry matter	
		Expt 1	Expt 2	Expt 1	Expt 2
16	0.02	11	10	90	98
	0.20	17	—	130	—
	2.00	27	11	216	154
	20.00	31	11	252	121
	60.00	—	11	—	135
19	0.02	16	26	112	210
	0.20	34	—	173	—
	2.00	58	42	251	412
	20.00	66	42	295	373
	60.00	—	41	—	351
22	0.02	27	50	128	239
	0.20	79	—	271	—
	2.00	178	143	444	638
	20.00	241	166	538	676
	60.00	—	164	—	621
l.s.d. P = 0.05		83	39	99	104
P = 0.01		111	53	132	139

and total dry matter were obtained from plants receiving the 22°C temperature and 20.00 mg l^{-1} N treatment. However, these results were not significantly better than those from plants receiving the same temperature but the lower 2.00 mg l^{-1} N treatment. This suggests that for plants receiving a basal 2 mg l^{-1} level of P the optimum N level is likely to be somewhere between 2 and 20 mg l^{-1}.

The effects of N level on leaf number, average 'root' and stem length, and average dry weight per pot at harvest of salvinia leaves, stems, 'roots' and buds are presented in Table 4. The results are those for the superior NH_4-N source, and are expressed as the average of the three temperature treatments. Leaf number was increased by increasing the N level up to 20 mg l^{-1}, but in experiment 2 it was decreased when the N level was increased from 20 to 60 mg l^{-1}. The average 'root' length decreased with increasing N, but this effect was only significant (P = 0.01) when comparing results for the 0.02 and 0.20 mg l^{-1} levels in experiment 1, and between the 0.02 and 2.0 mg l^{-1} levels in experiment 2. The average stem length was not significantly affected by increasing the N level. In both experiments dry weights of leaves, stems and buds were highest in pots receiving the 20 mg l^{-1} N level. However, in experiment 2, these weights tended to be reduced by increasing the N level from 20 to 60 mg l^{-1}. In experiment 1 the highest 'root' weight was obtained at the 20 mg l^{-1} N level, but in experiment 2 this occurred at the 2 mg l^{-1} level. However, in experiment 1 the 'root' weight was not significantly higher in pots receiving the 20 mg l^{-1} N level than in pots only receiving the 0.20 mg l^{-1} level, and in experiment 2 the 'root' weight was significantly reduced (P = 0.01) by raising the N level above 2 mg l^{-1}. This suggests that there is much less need for salvinia plants to

Table 4. Effects of N level on growth parameters and dry weight at harvest of *Salvinia molesta* in experiments 1 and 2. The results are expressed on a per pot basis as the average of the three temperature treatments.

Experiment	Nitrogen level (mg l^{-1} NH_4-N)	Leaf number	Average 'root' length (mm)	Average stem length (mm)	Leaf dry weight (mg)	Stem dry weight (mg)	'Root' dry weight (mg)	Bud dry weight (mg)
1	0.02	18	58	18	70	70	38	8
	0.20	50	43	19	117	20	57	27
	2.00	105	33	16	211	37	58	58
	20.00	141	34	20	267	42	66	78
	l.s.d. P = 0.05	42	10	3	40	8	16	14
	P = 0.01	57	13	4	54	11	22	19
2	0.02	30	61	14	66	14	80	13
	2.00	91	38	17	255	45	119	61
	20.00	103	28	18	271	45	76	76
	60.00	77	24	18	241	36	60	72
	l.s.d. P = 0.05	32	14	4	70	10	29	18
	P = 0.01	42	19	5	93	14	39	24

Table 5. Effects of N level on nutrient contents of *Salvinia molesta* in experiments 1 and 2. The results are expressed as the average of the three temperature treatments.

Experiment	Nitrogen level (mg l^{-1} NH_4-N)	Nutrient concentration (per cent plant dry matter)					
		N	P	K	Ca	Mg	Na
1	0.02	1.74	0.395	4.24	0.563	0.308	–
	0.20	2.55	0.420	4.03	0.438	0.295	–
	2.00	3.67	0.522	3.54	0.363	0.288	–
	20.00	4.53	0.612	3.56	0.277	0.285	–
	l.s.d. P = 0.05	0.32	0.059	0.50	0.052	0.024	
	P = 0.01	0.43	0.078	0.66	0.070	0.032	
2	0.02	1.46	0.335	3.86	0.593	0.361	0.792
	2.00	3.82	0.487	3.04	0.412	0.319	0.600
	20.00	4.27	0.605	3.04	0.338	0.322	0.487
	60.00	4.86	0.648	3.32	0.292	0.313	0.482
	l.s.d. P = 0.05	0.34	0.047	0.55	0.129	0.031	0.096
	P = 0.01	0.45	0.063	0.74	0.173	0.040	0.129

produce 'roots' if they are growing in a high N nutrient medium. Further evidence of this behaviour is provided by the shorter average root lengths observed with increasing levels of N (Table 4).

The effects of N level on the nutrient contents of salvinia plants are presented in Table 5. The results are those for plants receiving the superior NH_4-N source. Also, since temperature had no significant effect on nutrient contents, these results are expressed on a whole plant basis as the average of the three temperature treatments. At each increase in N level a significant ($P = 0.01$) increase in N content occurred in both experiments 1 and 2. Moreover, in experiment 2 there was still a significant difference ($P = 0.01$) between the 20 and 60 mg l^{-1} N levels, suggesting that salvinia plants could have N contents even higher than 4.86 per cent. Gaudet (1973) has reported N contents for *S. minima* in sterile culture of the order of 4 per cent, and Steward (1970) has found that such levels are not unusual in several submerged or floating aquatic weeds. What is of particular interest, however, in the results presented in Table 5 is the increase in P contents corresponding to the observed increases in N contents.

In experiment 1 increases in P contents were significantly higher ($P = 0.01$) at each N level above 0.20 mg l^{-1}, and in experiment 2 at each N level above 0.02 mg l^{-1}, but not beyond 20 mg l^{-1}. These increases provide strong evidence of the ability of salvinia plants to accumulate P at luxury levels for later utilization in P deficient conditions. Increasing the N level tended to reduce K, Ca and Mg contents of salvinia plants in experiment 1, and Ca, Mg and Na contents in experiment 2. Significant effects, however, were mainly evident in Ca contents, which in both experiments were significantly lower ($P = 0.01$) in salvinia plants receiving 2 mg l^{-1} N than in plants receiving 0.02 mg l^{-1}.

The effect of the N level on the pH of the nutrient medium 84 hours after the addition of salvinia plants is shown in Table 6. The results are those for the NH_4-N source which, as expected (Gaudet 1973), acidified the nutrient medium; the NH_4NO_3 source had a similar effect. The pH values are those for the 84-hr period ending on day 18 in experiment 1, and on day 24 in experiment 2. At the

Table 6. Effect of N level on pH of nutrient medium 84 hours after addition of *Salvinia molesta* plants for experiments 1 and 2.

Temperature (^oC)	Nitrogen level (mg l^{-1} NH_4-N)	pH Expt 1	pH Expt 2
16	0.02	7.9	8.2
	20.00	7.6	–
	60.00	–	7.6
19	0.02	7.9	8.2
	20.00	7.5	–
	60.00	–	7.0
22	0.02	8.0	8.1
	20.00	7.4	–
	60.00	–	6.6
l.s.d. $P = 0.05$		0.2	0.3
$P = 0.01$		0.3	0.4

beginning of the 84-hr period the pH of the nutrient medium was 7.9 in experiment 1, and 8.1 in experiment 2. Little change in pH was observed in the nutrient medium of plants receiving the lowest 0.02 mg l^{-1} N level. The most marked depression in pH was observed in experiment 2 when comparing the 0.02 and 60.00 mg l^{-1} N levels. It is suggested that this pH reduction could have had a beneficial effect on nutrient uptake, and hence help to explain the superiority of the NH_4^+ and NH_4NO_3 sources as compared to NO_3^- and urea (Table 2). The two latter sources, as expected, had no effect on the pH of the nutrient medium.

Experiments 3 and 4.

The effects of temperature and P level on relative growth rate, doubling time, leaf number and total dry weight at harvest of salvinia plants in experiment 3 are presented in Table 7. There were no significant differences between the three sources. This is not unexpected, because at the pH of the nutrient medium used (pH 7.9-8.0) the predominant species are $H_2PO_4^-$ and $HPO_4^=$ (Stumm and Morgan 1970) irrespective of the orthophosphate species used as the initial source. Although there were significant increases in growth rate, leaf number and yield due to increasing the temperature, as found in experiments 1 and 2, there was almost no response to increasing the P level, even with the 1000-fold increase from 0.02 to 20.00 mg l^{-1}. This lack of response was probably due to the presence of P reserves in the propagules which were sufficient for the duration of the experiment. Chemical analysis of propagules similar to those

Table 7. Effects of temperature and P level on growth rate, leaf number and yield of *Salvinia molesta*. The results are expressed as the average of the three P sources compared in experiment 3. Leaf number and yield are on a per pot basis.

Temperature (°C)	Phosphorus level (mg l^{-1})	Relative growth rate ($\overline{RGR}_N \times 10^3$)	Doubling time (days)	Leaf number	Total dry weight (mg)
16	0.02	79	8.80	17	82
	0.20	78	9.13	17	83
	2.00	80	8.74	17	90
	20.00	82	8.54	18	88
19	0.02	134	5.25	47	164
	0.20	144	4.85	54	173
	2.00	138	5.05	48	160
	20.00	140	4.98	52	151
22	0.02	183	3.86	115	294
	0.20	191	3.63	128	300
	2.00	202	3.44	154	378
	20.00	205	3.38	162	357
l.s.d. P = 0.05		51	1.83	20	48
P = 0.01		69	2.45	26	64

Table 8. Effect of P level on nutrient content of *Salvinia molesta* in experiment 3. The results are expressed as the average of the three temperature treatments.

Phosphorus level ($mg\ l^{-1}\ H_2PO_4$-P)	Nutrient concentration (per cent plant dry matter)					
	N	P	K	Ca	Mg	Na
0.02	3.77	0.135	2.87	0.343	0.375	0.418
0.20	4.40	0.352	2.90	0.328	0.378	0.427
2.00	4.44	0.592	3.36	0.327	0.428	0.513
20.00	4.17	0.890	3.01	0.285	0.435	0.407
l.s.d. P = 0.05	0.32	0.079	0.46	0.055	0.040	0.092
P = 0.01	0.43	0.106	0.62	0.074	0.053	0.123

used in experiment 3 revealed that the P contents were moderately high, being about 0.27 per cent of plant dry matter. Raising the P level in experiment 3, however, did produce significant increases (P = 0.01) in the P contents of plant dry matter, as shown in Table 8, which also provides information on leaf N, K, Ca, Mg and Na contents. Of particular interest is the P content of salvinia plants receiving the 0.02 mg l^{-1} P treatment. At harvest, the P content was only 0.135 per cent of plant dry matter. Since this value is half that of the propagule used at the beginning of the experiment, it strongly suggests that a P level of 0.02 mg l^{-1} is near-deficient and unlikely to facilitate long term vigorous growth of salvinia. In general, raising the P level had little effect on N, K, Ca, Mg and Na contents; there was, however, a tendency for Ca to be reduced and Mg to be increased.

Great care was taken in experiment 4 to produce propagules from salvinia plants grown in a P-deficient nutrient medium for an extended period of about six weeks. This was done to ensure that significant responses to the P treatments could be obtained. Although this objective was successfully achieved, it resulted in propagules being used which were less vigorous than those used in previous experiments. Moreover, these propagules were produced with a terminal bud, but with no visible evidence of an axillary bud. Chemical analysis of propagules similar to those used in experiment 4 revealed that the P contents were low, being about 0.7 per cent of plant dry matter. This value is about 1/4 of that for propagules used in experiment 3. The effects of temperature and P level on leaf number and dry matter yield of salvinia plants in experiment 4 are shown in Table 9; the results are expressed as the average of the three P sources. Despite the low P nutrient contents of the propagules, increasing the P level had little effect at 16°C, and only a slight beneficial effect at 19°C. However, at 22°C leaf number and dry matter yield were both increased significantly (P = 0.01) by raising the P level from 0.01 to 0.10 mg l^{-1}. Also, leaf number was significantly increased (P = 0.01) by raising the P level from 0.10 to 10 mg l^{-1}, and dry matter was significantly increased (P = 0.01) by raising P level from 0.10 to 1 mg l^{-1}, but not beyond 1 mg l^{-1}. This suggests that for plants receiving a basal 20 mg l^{-1} treatment the optimum P level is likely to be somewhere between 1 and 10 mg $^{-1}$, and most likely closer to 1 mg l^{-1} than to 10 mg l^{-1}.

In summary, experiment 3 gave valuable information on salvinia's ability to use up previously accumulated P reserves and grow satisfactorily without additional P, at least in the short term. This experiment also provided information on the extent of luxury uptake of P that can occur when salvinia plants are grown in a P-enriched nutrient medium. In contrast, experiment 4 gave a clear

Table 9. **Effects of temperature and P level on leaf number and total dry weight of *Salvinia molesta*. The results are expressed on a per pot basis as the average of the P sources compared in experiment 4.**

Temperature (°C)	Phosphorus level (mg l^{-1})	Leaf number	Total dry matter (mg)
16	0.01	7.0	15
	0.10	8.2	16
	1.00	8.0	14
	10.00	8.0	17
19	0.01	8.3	14
	0.10	9.8	17
	1.00	11.5	18
	10.00	13.7	27
22	0.01	9.0	19
	0.10	20.0	63
	1.00	24.5	185
	10.00	28.0	189
l.s.d. $P = 0.05$		4.7	46
$P = 0.01$		6.3	61

indication of the growth responses likely to occur from P-deficient salvinia plants when grown in a P-enriched medium.

General concludions

Our results have shown that temperature is a very important factor affecting the growth of salvinia. It is clearly a warm water plant, with little growth occurring at temperatures below 20°C. Under the experimental conditions we have imposed little growth has occurred, even at 22°C, when the N supply is as low as 0.02 mg l^{-1} and when the P supply is as low as 0.01 mg l^{-1}. Such levels, however, may still be adequate in free flowing natural systems in which relatively low levels are constantly being replenished. We have attempted to minimize the likelihood of this effect being important by supplying a relatively large volume of fresh nutrient solution at 84-hr intervals. Our results have clearly shown that salvinia has a marked preference for the NH_4-N source but does not distinguish between the three P sources we have used. Our results also indicate that salvinia is unlikely to be a major problem in Australia's main irrigation areas in south-eastern Australia, because of relatively low water temperatures and low nutrient supply. Moreover, the organisms being evaluated for biological control are themselves best adapted to warm conditions, and thus their effectiveness also would depend on their growth responses to temperature. Fortunately, if problems with salvinia do occur in these irrigation areas, they are most likely to occur at the tail-end of the irrigation system; e.g., in drainage lakes where water flows are at a minimum and where other appropriate control measures can be most conveniently and efficiently carried out. Severe problems with salvinia are most likely to occur in static or semi-static waterways having relatively high water temperatures. Nutrient enrichment of such water systems must be avoided at all costs if organisms introduced for biological control are to be successful. We are currently studying the effects of various combinations of N and P nutrient enrichment at temperatures of 20°, 25° and 30°C. This work should help in predicting the effects of any nutrient enrichment, be it by accident or by design, into Australia's warm waters and the potential effectiveness of various control strategies. Our present results also suggest that salvinia could be used as a nutrient scavenger. We have shown that salvinia has a potential for relatively high uptake of N (up to 5 per cent of dry matter, see Table 5) and of P (up to 0.9 per cent of dry matter, see Table 8). It is possible that this potential could be used under certain specific and highly controlled conditions to remove undesirably high nutrient levels from waterways contaminated by industrial or agricultural processes. It is interesting that such an approach is being developed at Mt Isa, Queensland (C.M. Finlayson, pers. comm.).

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