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WRC Project W-727

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SUMMARY

WRC project W-727 focuses on evaluating the capacity of selected aquatic plant species for low concentrations of herbicide and nitrate removal from nursery waste waters. Two nurseries in the Sacramento area were selected as test sites. From June 1988 through October 1989, water samples from inflow and outflow water from both nurseries were collected and analysed for inorganic constituents and herbicides. Of the herbicides analyzed (simazine, oryzalin, oxyfluorfen and pendimethalin), only oryzalin and oxyfluorfen were present in measurable quantities. Pendimethalin was never detected and simazine appeared in detectable quantities only twice. Both nitrate and ammonia nitrogen concentrations were consistently high in outflow from both nurseries, except for the period of about three months during the winter. Soluble reactive phosphorus was relatively low.

Two species of aquatic macrophytes, *Ludwigia peploides* and *Myriophyllum aquaticum* were able to sustain high growth rates in herbicide concentrations up to 50 ppb as tested in greenhouse experiments. Both species grew well in nursery waste water for an extended period of time (June through September 1989). *Ludwigia peploides* was most effective in nitrate removal because of its high growth rate (30 g dry weight/m^2/day) and very high nitrogen tissue concentration (4.0%). *Ludwigia peploides* , being a native plant in California is recommended for water treatment rather than *Myriophyllum aquaticum* , an introduced species and potential noxious aquatic weed. *Ludwigia peploides* is an amphibious herb which indicates that it can survive short periods with low ground water levels -- a favorable characteristic for Californian climate.

Assuming the daily production of 30 g dry weight per meter square, and 4% nitrogen in dry weight, then one meter square of *Ludwigia peploides* can remove 1.2 g of nitrogen per day. To keep the production high, plants have to

native Californian macrophyte, *Ludwigia peploides* (HBK) Raven (syn. *Jussiaea californica, J. repens,* var. *peploides*), water primrose (Fig. 1) , with respect to its capacity for use in waste water treatment. *L. peploides* occurs in pools, small streams and ditches at lower altitudes. It grows very vigorously as a weed in nutrient rich drainage canals (Fig. 2) which is why it caught our attention as a potential candidate for our project. Because *Ludwigia peploides* has negatively geotropic upward-growing roots (Ellmore 1981), which provide a conduit for atmospheric gasses into nodes submerged in an anaerobic substrate, it is well adjusted to waterlogged conditions. *Ludwigia peploides* achieves its high production because of its canopy architecture which results into a high leaf area index (LAI). High LAI is usually correlated with high productivity (Collins and Jones 1986).

Our research involved evaluating the capacity of selected aquatic plant species for low concentrations of herbicide and nitrate removal from nursery waste water.

Methods

1. Study site selection and description

In early summer of 1988 we selected two nurseries in the Sacramento area as study sites for our project. These were:

1) Oki Nursery Inc. Bradshaw Branch, Sacramento, CA 95826
2) Haight Nursery, Roseville, CA 95678

Oki Nursery is a 260 acre wholesale nursery. Most of the nursery runoff water runs into Elder Creek. Haight Nursery is a 65 acre wholesale nursery. All the nursery runoff water is collected in a small (ca 0.5 acre) holding pond, with an overflow which eventually runs into Dry Creek. Both nurseries use mostly well water as their water source. Fertilizers are applied in both nurseries with the irrigation water in concentrations about 140 ppm of nitrogen and 6.5 ppm of phosphorus in Oki and 235 ppm of nitrogen and 12.5 ppm of phosphorus in Haight. The average flow rate in the outflow canal is approximately 1,000 gal/day in Haight nursery. For Oki nursery we have only a short term estimate for July 1989, i.e., for the time of very intensive irrigation. The flow rate at that time was very close to 1,000,000 gal/day.

filliculoides. For the emergent plants the apical stem cuttings of respective plant species were rooted in vermiculite. After the roots had developed, the cuttings were placed in plastic foam plugs and transferred to 500 ml Erlenmeyer flasks with 1/2-strength Hoagland solution plus the respective herbicide. The floating plants were grown in Petri dishes. The typical length of the herbicide experiment was 2 to 3 weeks. Distilled water was used to replenish water lost through evapotranspiration. Shoot length of plants for emergent and number of fronds for floating plants were recorded and dry biomass was assessed. These data were used to evaluate the effect of a herbicide as compared to a control with no herbicide added to the solution. The results were mostly expressed as relative growth rate (RGR, g/g/day).

To determine the dependence of growth of *Ludwigia peploides* and its tissue nitrogen concentration on the concentration of nitrogen in water, a growth chamber experiment was conducted. Plants were grown in 500 ml Erlenmeyer flasks in 1/2-strength Hoagland nutrient solution with 1.4, 7, 14, 35, 70, and 140 ppm of nitrogen added as $CaNO_3$. The nitrogen solution was changed daily. Growth chamber conditions included 12-hour photoperiods with day/night temperatures of 25/20 ^oC. Photosynthetically active radiation was approximately 0.25 Em^{-2} sec^{-1}. A similar experiment was set up in the greenhouse (max./min. temperatures of 32/20 ^oC and natural sunlight. Plants from this experiment were used for measuring the photosynthetic CO_2 assimilation using a LI-COR Portable Photosynthesis System, LI-6200.

Nitrogen changes in the nutrient solution were measured using the ORION nitrate ion selective electrode. The amount of nitrogen in plant biomass was determined on a Perkin Elmer CHN analyzer.

4. Outdoor experiments

A) Transplant experiment

A transplant experiment was established in both nurseries to evaluate the long term effect of nursery waste water containing the herbicide residua on the two selected plant species: *Ludwigia peploides* and *Myriophyllum aquaticum.* In the experiment, rooted cuttings about 15 cm long were held in a plastic foam plug that was placed in styrofoam holders (See Fig. 3) which floated on the water surface of either the wastewater canal (Elder Creek) in Oki nursery or the holding pond in Haight nursery . A wire-net sleeve around each holder prevented plants from intertwining. Control plants in the same holders were grown in an outdoor plastic container in Hoagland nutrient solution. At two week intervals, five replicates were harvested from each nursery and the control, and the biomass was dried and weighed. The experiment continued for ten weeks.

B) Harvesting experiment

For the harvesting experiment, plants were grown in individual pots submersed in 1/2 strength Hoagland nutrient solution in large metal containers, placed in the greenhouse. All plants were grown to the stem length of approximately 40 cm before the treatment started. At the beginning of the experiment, 25, 50, 75, and 95% of the length of each stem was cut. A series of uncut plants was left as a control. Four plants of each treatment were harvested at five day intervals until day 45, the length of all branches was recorded, and the plants were dried and weighed.

C) Density dependent growth and carrying capacity

To assess the dependence of growth characteristics on initial plant biomass, plants were grown in 50 by 50 by 50cm outdoor plastic containers . Hoagland nutrient solution was added in amounts necessary to keep the NO_3-N concentration at approximtely 50 ppm. Water lost through evapotranspiration was compensated daily. Plants in containers with the initial biomass corresponding to 100, 200, 300, 400, 500, 600, 700 and 800 g/m^2 were grown for 10 days, harvested, dried and weighed.

The above described containers were also used for estimating the maximum carrying capacity of *Ludwigia peploides*. In this experiment, 1, 2, 4, 6, 8, 10, and 16 plants were placed in individual containers and let grow for two months. Nutrient solution was added in amounts necessary to keep the NO_3-N concentration at about 30 to 40 ppm. Wire net enclosures were fixed around each container when the plants grew taller than the container wall. Losses of water through evapotranspiration were compensated for once every two days. At the end of the experiment, plants were harvested, subsamples divided into leaves, stems and roots, dried and weighed.

Results and Discussion

Water analyses

Table 1 and 2 summarize the data on water analyses from the nurseries. Figures 4 and 5 show the seasonal changes in concentrations of the main inorganic pollutants, NO_3-N, NH_4-N and PO_4-P in outflows from both nurseries. Haight nursery does not have any natural inflow, the inflow to Oki nursery has low concentrations of both, nitrogen and phosphorus, averaging 0.57 and 0.49 ppm respectively. Both nitrate and ammonia nitrogen concentrations in the outflow from Haight nursery were high, ranging from 11 to 63 ppm and 2.9 to 30 ppm respectively. Average NO_3-N was 29.9, average NH_4-N was 15.3 ppm. The average PO_4-P concentartion was 0.88 ppm. The outflow from Oki nursery averaged 26.6, 12.8, and 2.0 ppm for nitrate nitrogen, ammonia nitrogen and phosphate respectively. Such high nitrogen concentrations justify a need for water treatment. Total suspended solids (TSS) content in the outflow water was about the same for both nurseries, and averaged 9.07 ppm and 8.72 ppm for Oki and Haight nursery respectively. Higher TSS values usually indicated either rainy periods or intensive irrigation. Particulate organic matter contributed to the TSS by about 50%.

Fig. 6 and 7 show the respective herbicide concentrations in the outflow water samples from each nursery. The waste water from Haight nursery contained relatively high concentration of oryzalin throughout most of the sampling period with one smaller peak and one large peak corresponding to December 1988 and March 1989 treatments. The first large peak (September 1988) most probably reflects a treatment, which was not included in the information on treatment dates that we obtained from the nursery. Simazine was detected in only two samples. Oki nursery used exclusively OH-2, which is 2:1 mixture of oxyfluorfen and pendimethalin. Oxyfluorfen was present in low concentrations for most of the sampling period. The other component of OH-2, pendimethalin, was always below a detection limit, i.e., lower than 0.5 ppb. All major peaks of oxyfluorfen follow the treatment, except for two peaks in July and August 1989.

The growth of *Ludwigia peploides* in the transplant experiment in Oki nursery wastewater did not show any significant difference in comparison to the control growth in a nutrient solution with about the same concentration of nitrogen and without any herbicides (Table 3, Fig. 8). The average relative growth rates (RGR) for the duration of the whole experiment did not differ significantly and corresponded to 0.078 g/g/d and 0.077 g/g/d for Oki and control respectively. The transplant experiment in wastewater pond in Haight nursery had to be terminated two weeks earlier because the pond was invaded by a thick growth of *Azolla* spp. , which strongly interfered with the experimental setup. RGR of *Ludwigia peploides* for the period of 7/7 through 9/5 1990 was 0.089 g/g/d. The growth of *Myriophyllum aquaticum* was slower than that of *Ludwigia* in both treatments and the control with the average RGR equal to 0.042 g/g/d, 0.046 g/g/d and 0.042 g/g/d for Oki nursery, Haight nursery and control respectively.

The aim of the above experiment was to verify whether nursery wastewater with its high nitrogen content, variable herbicide content and possible unknown residua of pesticides other than those we analysed the water for, would have any unfavorable long term effect on the test plants. The conclusion is that growth rates were not significantly different from those obtained in a control and the tested plant species could therefore be used for wastewater treatment.

The efect of herbicides

Table 4 shows results of the experiments in which we evaluated the tolerance of emergent (*Ludwigia peploides, Myriophyllum aquaticum*) and floating (*Lemna minor, Azolla filiculoides*) species to herbicides applied in the two nurseries. The results in Table 4 are expressed as percent of control. *Ludwigia peploides* seems to be tolerant to all the herbicides used. Its growth is usually over 80% of control up to 50 ppb of the respective herbicide concentrations. *Myriophyllum aquaticum* shows very similar tolerance except for OH-2, which decreases its growth markedly at 5 ppb. The floating plants, *Lemna minor* and *Azolla filliculoides*, were evaluated only for their tolerance to oryzalin and diquat. The production of these plants compared to the emergent species is lower (see following section) which decreases their potential for wastewater treatment. This is why we decided to eliminate them from further experiments and to concentrate on the emergent species. The changes of relative growth rates (RGR) of individual plant species dependent on different herbicide concentrations are expressed in Figs. 9 and 10.

Of the plant species tested, *Ludwigia peploides* has the highest transpiration rate, probably as a result of its large leaf area. In the conditions of both the greenhouse and the outdoor experiment, it looses about 20 ml of water per gram of dry biomass per day, compared to 13 ml for *Myriophyllum aquaticum*. Water losses of floating species are lower because they have generally much smaller leaf area than emergents.

Plant Density

A photograph of *Ludwigia peploides* from a drainage canal (Fig. 2) shows that this plant grows in very dense stands. An experiment conducted in outdoor cultivation containers confirmed that both crop growth rate and relative growth rate stay high over a broad range of plant densities (Fig.11). Crop growth rate (CGR) of over 40 $g/m^2/day$ is comparable to that of water hyacinth (Reddy and DeBusk 1987). The highest CGR values for *Lemna* species are about four times lower than those for *Ludwigia peploides* (Rejmankova 1979). Crop growth rate of 12.3 $g/m^2/d$ was found for *Myriophyllum aquaticum* by Sytsma (1989).

Relative growth rate (RGR) of *Ludwigia peploides* stays positive even at very high densities which would substantially decrease RGR of floating macrophytes such as *Lemna* or *Azolla* (Rejmankova, 1981). The reason for *Ludwigia peploides* being able to grow well at high densities is its high leaf area index -- usually between 4 to 6. Leaf area index is usually positively correlated with production, expressed as crop growth rate (Collins and Jones 1986) in plants the canopy architecture of which allows them to spread in vertical space. LAI for both *Lemna* and *Azolla* is very close to 1 when they cover the whole water surface (Rejmankova 1979), because these plants are limited to one horizontal layer. Increase in LAI over 1 results in overcrowding and mutual shading. We did not assess LAI for *Myriophyllum aquaticum*. Although its feather-like leaves would be very difficult to measure, we believe that LAI of this species is lower than that of *Ludwigia peploides*.

Nitrogen

Figure 12 shows the changes in biomass of individual plants of *Ludwigia peploides* as a function of nitrogen concentration in water. An increase of NO_3-N in water over 20 ppm did not significantly increase biomass production. Biomass does not decrease even at a concentration of 140 ppm. Such a high nitrogen concentration causes reduced growth in some plants. Sytsma (1989) recorded reduced growth of *Myriophyllum aquaticum* in the nitrogen concentration of 88 ppm.

The concentration of tissue nitrogen from the same experiment is presented in Fig. 13. Compared to other aquatic macrophytes, tissue nitrogen concentration of *Ludwigia peploides* is very high. Its relative, *Ludwigia repens*, from a natural marsh contained only 1.7 to 2.0 % of N in biomass (Terry and Tanner 1986) which probably reflects relatively low nitrogen concentration in water in the marsh. Although the tissue nitrogen curve has a similar course to that of biomass, tissue nitrogen increases between 20 and 80 ppm of nitrogen in water, which indicates the luxury consumption in this range of concentrations. Luxury nitrogen consumption is characteristic for aquatic plants used for waste water treatment (Reddy and DeBusk 1987).

The allocation of nitrogen into individual plant parts at different nitrogen concentrations in water is summarized in Fig.14. The allocation pattern of nitrogen is similar to that of biomass. Except for the lowest nitrogen concentration, in all other concentrations about 70% of nitrogen is allocated into leaves. At low nitrogen concentration , slightly over 50% of available nitrogen is translocated into leaves. Increased allocation of nitrogen to leaves with increasing nitrogen concentration was reported also for *Myriophyllum aquaticum* (Sytsma 1989).

Values for photosynthetic rate of individual leaves of *Ludwigia peploides* plotted against the amount of nitrogen in leaves (Fig. 15) show that photosynthetic assimilation decreases when nitrogen concentration in leaves exceeds 5.5 %. Fig. 16 shows the regression of leaf chlorophyll on leaf nitrogen. Contrary to photosynthetic assimilation, chlorophyll amount does not decrease with increasing leaf nitrogen concentrations. So far we can only speculate on why this is happening and more research needs to be done.

Carrying capacity

Results of the carrying capacity experiment are shown in Fig. 17. The carrying capacity value for *Ludwigia peploides*, close to 2000 g/m2, seems to be somewhat overestimated, as a result of the experimental set-up. Wire enclosures kept plants growing vertically rather than spreading horizontally, as they probably would in their natural environment. Data from field sampling indicate, that when *Ludwigia peploides* plants have sufficient space to spread, the average biomass is in the range of 500 to 700 g/m2. The fact that plants in our experiment were able to keep positive RGR even at the highest density and that the highest density did not show any signs of senescence means, that *Ludwigia peploides* is capable of growing at high densities.

In natural stands, the biomass allocation between submersed tissues (shoots and rhizomes) and emersed tissues (shoots and leaves) is usually close to range of 1.7 : 1. In our experiment, more biomass was allocated to the emersed tissues, with the ratio submersed : emersed being 0.5 : 1. Increased allocation to emersed tissues is advantageous for increased production. We do not have sufficient data to explain how much of the allocation is determined simply by different water depth and spatial limitation and how much it is caused by other factors. Further experiments are needed to determine this aspect.

Harvesting

One of the requirements for a "good" plant for treating wastewater is its ability to regenerate rapidly after harvesting. Fig. 17 shows that even when 95% of the stem length is removed, *Ludwigia peploides* is able to regenerate relatively rapidly regaining a similar biomass to the uncut control in 45 days. *Ludwigia peploides* plants react to cutting by increased production of lateral branches.

Data on harvesting together with the carrying capacity experiment and nutrient uptake data will be used for calculation of optimal harvest strategy based on the Elizarov-Svirezev harvesting model as it has recently been applied to duckweeds (Rejmankova et al. 1990). The model is based on discrete harvests. For *Ludwigia peploides* the model will be more complicated than for duckweeds because of its more complicated growth form. Compared to duckweeds, the harvesting intervals for *Ludwigia peploides* can be much longer because of its high carrying capacity. While duckweeds have to be harvested in 2 to 4 days intervals for maximum production, we expect the harvest intervals for *Ludwigia peploides* to be much longer (about 30 days).

Treatment potential of *Ludwigia peploides*

If we assume the daily production of 30 g/m^2 and the average tissue nitrogen content of 4 %, then 1 m^2 of *Ludwigia peploides* can remove 1.2 g of nitrogen per day. If we use data from the Haight nursery as an example, then the average concentration of total inorganic nitrogen leaving the nursery in the otflow is 45.2 ppm. The average flow rate in the outflow is approximately 1,000 gallons (Bill Jordan, personal communication), which means that 171 g of nitrogen is leaving the nursery per day. To remove this amount of nitrogen, we would need 143 m^2 of actively growing *Ludwigia peploides*.

Conclusions

1. Seventeen months of sampling of the outflow water from the two commercial nurseries in the Sacramento area revealed that of the herbicides analyzed (simazine, oryzalin, oxyfluorfen and pendimethalin) only oryzalin and oxyfluorfen were present in measurable quantities. Both nitrate and ammonia nitrogen concentrations were consistently high in the outflow from both nurseries, except for a period of about three months during the winter. Soluable reactive phosphorus was relatively low.

2. Of the plant species tested for the sensitivity to the presence of herbicides in water, *Ludwigia peploides* and *Myriophyllum aquaticum* were able to sustain high growth rates in herbicide concentrations up to 50 ppb.

3. *Ludwigia peploides* is a fast growing aquatic plant that can produce an average of 30 gm^{-2}d^{-1} in nursery drain waters . In natural stands its average

biomass is usually in the range of 500 to 700 gm^{-2}. In cultivation it attained positive growth rate even at densities about 2000 gm^{-2}.

4. *Ludwigia peploides* grows well in a broad range of nitrogen concentrations. Its biomass production stays approximately the same through the range of 20 to 140 ppm of nitrogen in water. The whole plant nitrogen content is high (up to 4.5%), while leaf nitrogen may reach up to 6.8%. Rate of photosynthesis decreases in leaves with nitrogen concentrations higher than 5.5%.

5. *Ludwigia peploides* regenerates well after partial harvest (up to 95%). When the main stem is cut, lateral branches develop rapidly and continue growing.

6. *Ludwigia peploides* is native to California and therefore its use for wastewater treatment would be more acceptable than the use of potentially noxious species, such as *Eichhornia crassipes* or *Myriophyllum aquaticum.* Another advantage of *Ludwigia peploides* is its amphibious character, which may be essential for survival in periodically drying water bodies.

Use of Research Data by Water Resources Agencies

There has been a lot of interest in the results of this project. Two participating nurseries as well as California Department of Water Quality will be able to use the data on annual changes of the outflow water chemistry. California Association of Nurserymen and Pesticide Impact Assesment Program have consulted the potential of aquatic plants for nursery wastewater treatment with us.

Several consulting companies, such as Zetner & Zetner, and Jones & Stokes expressed their interest in our research dealing with the potential use of higher wetland and aquatic plants for water treatment.

Publications and presentations resulting from this grant

A poster was presented at the Annual Meeting of the Ecological Society of America in Snowbird, Utah:

Rejmankova, E., and D. Bayer. 1990. 1990. Ludwigia peploides -- a new candidate for wastewater treatment. Bull. ESA, 71: 298.

(A representative from Bioscience Journal was present at the meeting, she was interested in the project and a short article about the project should appear in the November issue of Bioscience)

A paper is being prepared for submission to Aquatic Botany.

Acknowledgements

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Table 1 Water quality data from the Haight nursery. Site 1 = ouflow before the pond, Site 2 = Pond, Site 3 = Main outflow from the nursery, Site 4 = small canal draining mostly greenhouses.

	A	B	C	D	E	F	G	H	I	K
1	DATE	SITE	CONDUCT.	PH	TSS	POM	NO3	NH4	PO4	TOC
2			[umhos/cm]		[ppm]	[ppm]	[pmm]	[pmm]	[ppm]	[ppm]
3	6/28/88	1	1200	7.20	7.20	4.20	50.94	45.58	1.40	8.96
4	6/28/88	2	1100	7.40	8.00	5.00	52.18	29.22	1.40	
5	6/28/88	3	1000	7.40	10.66	7.33	56.87	24.30	1.31	9.72
6	6/28/88	4	1200	7.60	14.66	8.00	58.23	6.12	1.18	
7	7/12/88	1	1200	7.00	8.66	4.66	48.67	26.83	2.25	9.90
8	7/12/88	2	1200	7.20	12.00	7.43	56.04	33.47	1.87	
9	7/12/88	3	1000	7.20	14.33	8.50	41.45	19.72	1.73	11.04
10	7/12/88	4	900	7.10	52.00	17.00	30.63	12.84	1.06	
11	7/28/88	1	1400	6.80	11.00	4.00	44.64	56.66	1.89	11.16
12	7/28/88	2	1000	7.20	23.00	14.00	45.91	28.82	2.06	10.44
13	7/28/88	3	1000	7.20	15.30	14.00				
14	7/28/88	4	760	6.90	6.50	4.50	23.53	5.73	1.45	
15	8/19/88	1	2000	6.70	7.00	4.00	54.28	81.77	1.59	13.09
16	8/19/88	2	1200	7.20	10.00	8.00	22.91	9.14	1.30	
17	8/19/88	3	1000	7.20	7.86	6.43	41.01	23.26	2.18	10.35
18	8/19/88	4	800	6.80	6.50	4.66	34.19	11.95	0.83	
19	9/9/88	1	1200	7.10	10.00	4.66	49.01	18.14	0.74	15.41
20	9/9/88	2	1300	7.30	14.00	10.50	36.29	20.98	1.09	
21	9/9/88	3	1200	7.20	10.66	7.60	63.24	30.44	1.69	17.48
22	9/9/88	4	800	7.10	9.33	5.33	39.22	5.82	1.60	
23	9/29/88	1	1100	7.40	7.00	3.50	24.90	15.93	0.75	9.98
24	9/29/88	2	1200	7.30	9.30	6.00	24.36	17.91	1.04	
25	9/29/88	3	1200	7.60	10.00	5.30	26.82	17.08	1.24	12.82
26	9/29/88	4	700	8.30	4.50	3.50	18.57	7.48	0.80	
27	10/21/88	1	800	6.80	4.00	3.33	34.05	13.86	1.97	12.05
28	10/21/88	2	1100	7.20	5.50	4.50	32.04	30.14	1.74	
29	10/21/88	3	1100	7.10	5.00	4.50	31.18	30.00	1.74	11.25
30	10/21/88	4	600	7.40	14.66	8.00	12.29	9.17	0.96	
31	11/8/88	1	1200	7.00	2.50	2.50	53.24	26.74	2.11	16.83
32	11/8/88	2	1100	7.00	6.00	6.00	57.24	26.36	1.63	
33	11/8/88	3	1200	7.10	10.00	10.00	50.62	26.94	1.46	18.78
34	11/8/88	4	900	7.10	42.00	29.00	36.59	6.30	3.80	
35	12/1/88	1	700	6.90	7.30		27.68	24.29	0.09	
36	12/1/88	2	680	7.30	12.00		16.00	11.73	0.07	
37	12/1/88	3	530	7.60	7.00		15.28	8.82	0.04	
38	12/1/88	4	740	8.20	11.40		27.00	21.23	0.17	
39	1/4/89	1	1000	7.90	5.30		16.78	4.45	0.37	
40	1/4/89	2	420	7.60	6.00		13.26	3.01	0.36	

Table 1 - cont.

	A	B	C	D	E	F	G	H	I	K
	DATE	SITE	CONDUCT.	PH	TSS	POM	NO3	NH4	PO4	TOC
			[umhos/cm]		[ppm]	[ppm]	[pmm]	[pmm]	[ppm]	[ppm]
41	1/4/89	3	380	7.40	7.60		13.58	4.44	0.45	
42	1/4/89	4	500	8.00	18.30		10.25	3.78	0.68	
43	2/3/89	1	400	6.30	8.50		7.50	3.78	0.44	
44	2/3/89	2	400	6.40	11.50		16.72	6.38	0.70	
45	2/3/89	3	420	6.40	12.10		12.93	3.58	0.65	
46	2/3/89	4	360	6.50	10.60		7.89	2.24	0.41	
47	2/24/89	1	560	8.30	4.50		14.90	5.90	0.85	
48	2/24/89	2	630	7.80	8.70		23.95	14.25	1.01	
49	2/24/89	3	610	7.70	6.50		22.98	15.45	0.95	
50	2/24/89	4	380	7.70	12.30		5.80	3.26	0.75	
51	4/5/89	1	1600	6.50	14.50		53.00	22.06	0.89	
52	4/5/89	2	680	8.20	10.00		22.98	10.11	0.44	
53	4/5/89	3	600	8.20	9.80		21.99	9.93	0.93	
54	4/5/89	4	500	7.70	10.50		14.55	5.65	0.74	
55	4/25/89	1	420	6.80	9.20		19.17	4.78	0.76	
56	4/25/89	2	680	5.40	5.70		47.54	5.99	0.93	
57	4/25/89	3	740	6.20	6.60		50.91	5.04	0.90	
58	4/25/89	4	520	6.60	5.50		37.62	0.02	0.72	
59	5/18/89	1	1100	6.00	11.40		38.43	21.21	0.74	
60	5/18/89	2	1000	6.90	8.90		47.13	19.65	0.53	
61	5/18/89	3	1000	6.70	10.30		46.95	20.99	0.41	
62	5/18/89	4	580	7.10	15.40		24.34	9.53	1.01	
63	6/20/89	1	1800	7.50	4.60		37.12	20.13	0.36	
64	6/20/89	2	680	7.90	7.40		35.10	14.25	0.35	
65	6/20/89	3	660	6.60	8.50		34.00	13.19	0.40	
66	6/20/89	4	680	7.50	12.00		43.18	19.72	0.71	
67	8/4/89	1	1500	7.10	6.60		30.63	17.40	0.55	
68	8/4/89	2	760	7.30	5.90		27.18	15.30	0.38	
69	8/4/89	3	770	7.50	10.00		25.00	12.00	0.45	
70	8/4/89	4	760	7.20	7.80		32.47	16.50	0.86	
71	8/17/89	1	1000	7.40	6.50		22.98	14.90	0.15	
72	8/17/89	2	680	7.60	5.30		14.68	9.26	0.10	
73	8/17/89	3	660	7.60	3.50		15.29	6.30	0.07	
74	8/17/89	4	600	7.50	4.50		23.15	10.18	0.85	
75	9/5/89	1	1200	6.70	12.00		59.23	46.12	1.20	
76	9/5/89	2	900	6.90	10.50		56.93	29.18	1.03	
77	9/5/89	3	850	6.90	11.60		46.68	26.20	0.98	
78	9/5/89	4	570	7.50	7.80		23.65	12.45	0.73	
79	9/19/89	1	900	6.40	14.70		9.38	4.26	0.41	
80	9/19/89	2	750	6.40	6.50		10.12	5.13	0.53	
81	9/19/89	3	750	6.50	7.00		11.01	2.90	0.50	
82	9/19/89	4	500	7.30	9.30		15.12	6.44	0.95	
83	10/11/89	1	1000	6.80	6.30		24.15	12.60	0.27	
84	10/11/89	2	700	7.20	5.00		18.93	7.50	0.39	
85	10/11/89	3	680	7.20	5.50		17.00	6.20	0.37	
86	10/11/89	4	720	7.70	10.00		32.17	15.80	0.78	

Table 2 Water quality data from the Oki nursery. Site 1 = inflow, Site 2 and 4 = small outflows, Site 3 = Main outflow (Elder Creek).

	A	B	C	D	E	F	G	H	I	J
1	DATE	SITE	CONDUCT.	PH	TSS	POM	NO3	NH4	PO4	TOC
2			[umhos/cm]		[ppm]	[ppm]	[ppm]	[ppm]	[ppm]	[ppm]
3	6/28/88	1	240	7.80	1.33	1.00	0.29	0.26	0.45	12.98
4	6/28/88	2	560	9.20	21.25	13.75	0.23	0.67	1.04	
5	6/28/88	3	580	7.40	6.00	3.70	36.70	14.23	2.62	7.46
6	6/28/88	4	1200	7.60	11.33	8.66	54.98	45.21	2.12	
7	7/13/88	1	260	7.20	2.50	1.65	0.35	0.25	0.59	12.37
8	7/13/88	2	560	8.00	50.00	32.00	0.40	0.54	1.27	4.33
9	7/13/88	3	750	7.10	26.66	18.00	27.36	43.21	4.50	23.2
10	7/13/88	4	420	7.10	9.00	4.00	14.38	7.23	1.80	
11	7/28/88	1	270	7.60	2.00	1.33	0.61	0.68	0.64	11.54
12	7/28/88	2	580	7.80	42.85	38.57	0.24	0.78	0.91	
13	7/28/88	3	260	7.30	8.00	4.66	41.43	10.38	1.91	11.33
14	7/28/88	4	900	7.00	5.50	3.00	10.18	13.07	1.46	
15	8/19/88	1	260	7.10	0.50	0.25	1.94	1.35	0.79	17.77
16	8/19/88	2	620	7.20	28.00	18.00	2.49	2.50	1.32	
17	8/19/88	3	260	7.00	8.00	5.33	8.90	1.93		18.07
18	8/19/88	4	850	7.20	80.00	10.00	34.64	32.25	2.07	
19	9/9/88	1	260	7.70	2.00	1.33	0.45	0.52	0.29	11.46
20	9/9/88	2	600	8.10	3.30	2.00	12.68	2.39	1.40	
21	9/9/88	3	650	7.90	9.00	4.00	34.53	15.82	2.56	7.49
22	9/9/88	4	700	7.50	15.00	8.00	0.46	0.26	0.21	
23	9/29/88	1	270	8.20	1.50	1.50	0.25	0.31	0.78	14.85
24	9/29/88	2	520	9.00	40.00	6.70	0.05	0.25	0.06	
25	9/29/88	3	700	8.50	12.00	5.30	12.24	14.12	2.57	9.06
26	9/29/88	4	660	8.00	12.60	7.30	20.43	5.14	1.71	
27	10/21/88	1	360	8.00	3.50	3.50	0.61	2.49	1.32	18.55
28	10/21/88	2	540	8.30	7.00	1.50	15.18	9.76	0.63	
29	10/21/88	3	660	8.10	6.50	6.50	22.24	15.26	3.48	11.66
30	10/21/88	4	1200	7.80	4.50	4.50	40.29	23.95	3.29	
31	11/8/88	1	260	7.40	3.50	3.50	0.19	0.51	1.38	21.28
32	11/8/88	2	860	7.80	4.50	4.00	46.62	28.24	0.19	
33	11/8/88	3	890	7.30	5.50	5.00	45.15	22.07	1.71	14.69
34	11/8/88	4	1400	7.10	4.50	4.00	62.96	35.92	3.33	
35	12/1/88	1	340	8.00	9.20		0.24	0.06	0.09	
36	12/1/88	2	140	7.80	0.70		5.25	N.D.	0.23	
37	12/1/88	3	560	7.70	6.60		24.32	10.07	0.31	
38	12/1/88	4	1400	7.80	5.50		47.30	36.48	0.43	
39	1/4/89	1	330	7.10	1.30		0.11	0.24	0.11	
40	1/4/89	2	180	6.90	2.00		6.03	0.23	1.11	

Table 2 - cont.

	A	B	C	D	E	F	G	H	I	J
	DATE	SITE	CONDUCT.	PH	TSS	POM	NO3	NH4	PO4	TOC
			[umhos/cm]		[ppm]	[ppm]	[ppm]	[ppm]	[ppm]	[ppm]
41	1/4/89	3	310	7.10	2.50		9.69	0.86	1.32	
42	1/4/89	4	330	8.30	4.60		6.20	0.10	0.65	
43	2/3/89	1	560	5.70	12.00		14.55	1.38	0.38	
44	2/3/89	2	210	6.30	14.60		8.86	2.11	1.67	
45	2/3/89	3	320	6.00	19.00		10.96	2.56	2.17	
46	2/3/89	4	700	6.10	16.00		30.00	12.63	5.85	
47	2/24/89	1	440	6.90	5.30		0.11	0.39	0.56	
48	2/24/89	2	1100	7.10	2.00		38.25	43.27	0.84	
49	2/24/89	3	220	6.50	6.00		7.75	2.48	1.54	
50	2/24/89	4	3000	4.50	36.00		24.40	13.65	0.92	
51	4/5/89	1	215	6.70	19.30		4.07	0.58	0.43	
52	4/5/89	2	740	6.60	7.30		42.00	19.64	1.16	
53	4/5/89	3	510	6.70	7.70		37.74	6.53	1.27	
54	4/5/89	4	1200	6.90	5.10		50.15	17.52	1.50	
55	4/25/89	1	200	6.10	12.00		2.37	1.45	0.22	
56	4/25/89	2	810	4.60	2.50		43.38	22.41	1.25	
57	4/25/89	3							-	
58	4/25/89	4	1200	6.60	26.00		48.60	19.91	1.38	
59	5/18/89	1	240	6.30	4.00		0.37	0.97	0.29	
60	5/18/89	2	1000	3.10	3.50		45.84	19.63	2.12	
61	5/18/89	3	800	6.00	6.50		43.55	17.94	2.43	
62	5/18/89	4	1500	6.50	9.00		44.75	19.54	3.13	
63	6/20/89	1	340	7.60	5.20		0.35	1.38	0.65	
64	6/20/89	2	800	6.50	2.70		38.30	12.40	0.95	
65	6/20/89	3	540	6.50	3.50		30.12	16.50	1.12	
66	6/20/89	4	400	6.70	12.50		47.20	18.70	2.05	
67	8/4/89	1	440	7.10	12.00		0.72	1.02	0.35	
68	8/4/89	2	85	6.40	1.50		42.12	10.60	1.97	
69	8/4/89	3	400	7.00	5.00		37.80	15.30	1.11	
70	8/4/89	4	820	7.30	16.00		47.30	18.70	2.16	
71	8/17/89	1	380	6.60	3.10		1.23	1.01	0.16	
72	8/17/89	2	630	6.50	2.00		25.16	13.60	1.71	
73	8/17/89	3	300	6.60	4.20		23.70	10.07	1.50	
74	8/17/89	4	1100	6.80	18.50		44.20	28.40	2.05	
75	9/5/89	1	270	6.90	5.50		0.75	0.31	0.78	
76	9/5/89	2	700	7.10	4.00		24.40	11.50	0.96	
77	9/5/89	3	280	6.50	6.30		15.30	9.70	1.00	
78	9/5/89	4	900	6.00	19.00		32.50	12.60	2.13	
79	9/19/89	1	250	6.80	13.50		1.28	1.23	1.22	
80	9/19/89	2	660	6.80	20.40		12.42	8.65	0.95	
81	9/19/89	3	270	6.90	19.80		8.45	3.72	1.11	
82	9/19/89	4	900	6.50	10.40		23.18	10.12	0.79	
83	10/11/89	1	300	6.60	6.00		0.84	0.59	0.96	
84	10/11/89	2	520	6.30	10.11		37.03	15.40	2.15	
85	10/11/89	3	330	6.00	12.30		55.82	23.12	3.40	
86	10/11/89	4	1200	6.70	5.40		48.11	30.30	3.16	

Table 3 Growth of *Ludwigia peploides* in wastewater canal (Oki), wastewater pond (Haight) and control. W_0 and W_1 = initial and final biomass per plant (g of dry weight), RGR = relative growth rate (g/g/day)

Location	Duration days	NO3-N ppm	Oryzalin ppb	Oxyfluorfen ppb	Ludwigia			Myriophyllum		
					Wo	W1	RGR	Wo	W1	RGR
Oki	73	21.3	-	1.63	0.13	37.9	.078	0.22	4.6	.042
Haight	60	24.5	34.5	-	0.18	38.9	.089	0.18	2.92	.046
Control	73	36.2	-	-	0.12	36.0	.077	0.18	3.74	.042

Table 4 The effect of herbicides on the growth of *Ludwigia peploides, Myriophyllum aquaticum, Lemna minor* and *Azolla filliculoides* expressed as a percentage of biomass of the control.

1		Conc. [ppb]	Ludwigia	Myriophyllum	Azolla	Lemna
2						
3	Oryzalin	0	100	100	100	100
4	Oryzalin	0.05	89.2	107.6	75.6	89.9
5	Oryzalin	0.5	84.9	89.8	62.5	85.4
6	Oryzalin	5	86.3	90.6	57.3	81
7	Oryzalin	50	77.2	80.8	59.9	78.1
8	Oryzalin	500	26.2	58.7	53.3	53.3
9	Oryzalin	1000	31.7	57	-	-
10						
11	Diquat	0	100	100	100	100
12	Diquat	0.05	87.9	83.5	108.2	145.6
13	Diquat	0.5	87.1	94.6	112	127.9
14	Diquat	5	89.7	93.3	100	59.7
15	Diquat	50	80.4	68.7	43.2	dead
16						
17	OH-2	0	100	100		
18	OH-2	0.5	75.2	74.4		
19	OH-2	5	85.6	53.8		
20	OH-2	50	87	49.6		
21	OH-2	500	80.1	50.4		
22	OH-2	1000	64.6	56.4		
23						
24	Simazin	0	100	100		
25	Simazin	0.05	87.4	98.6		
26	Simazin	0.5	83.3	100		
27	Simazin	5	90	97.3		
28	Simazin	50	87	82.2		
29	Simazin	100	51.9	98.6		
30	Simazin	500	10.46	62.16		

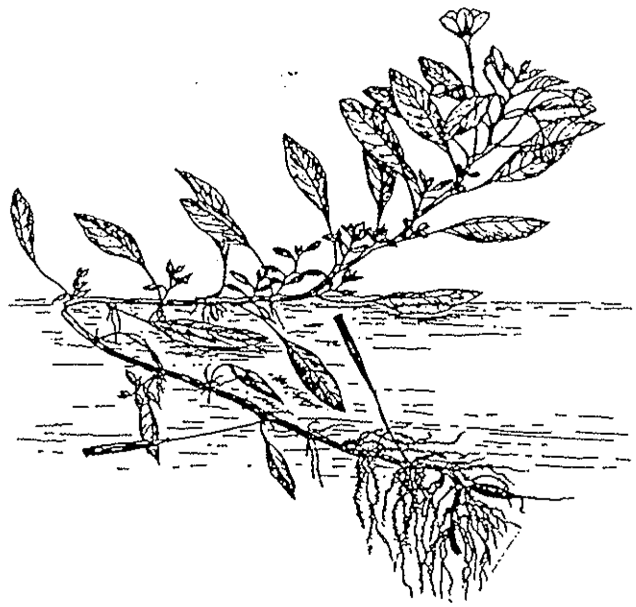


Fig. 1 *Ludwigia peploides* (HBK) Raven, water primrose

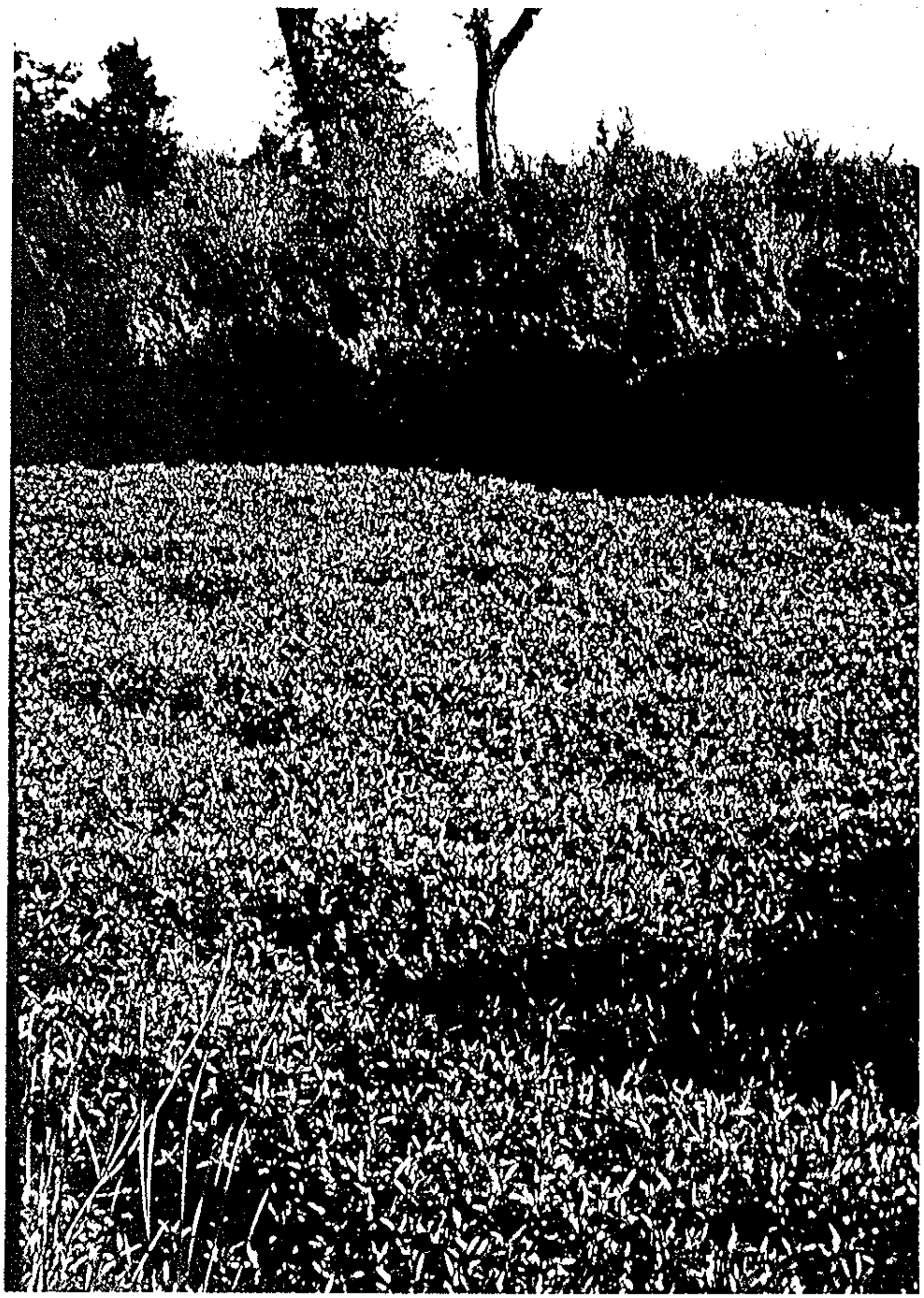


Fig. 2 *Ludwigia peploides* in an agtriculture drain water canal. August 1989.

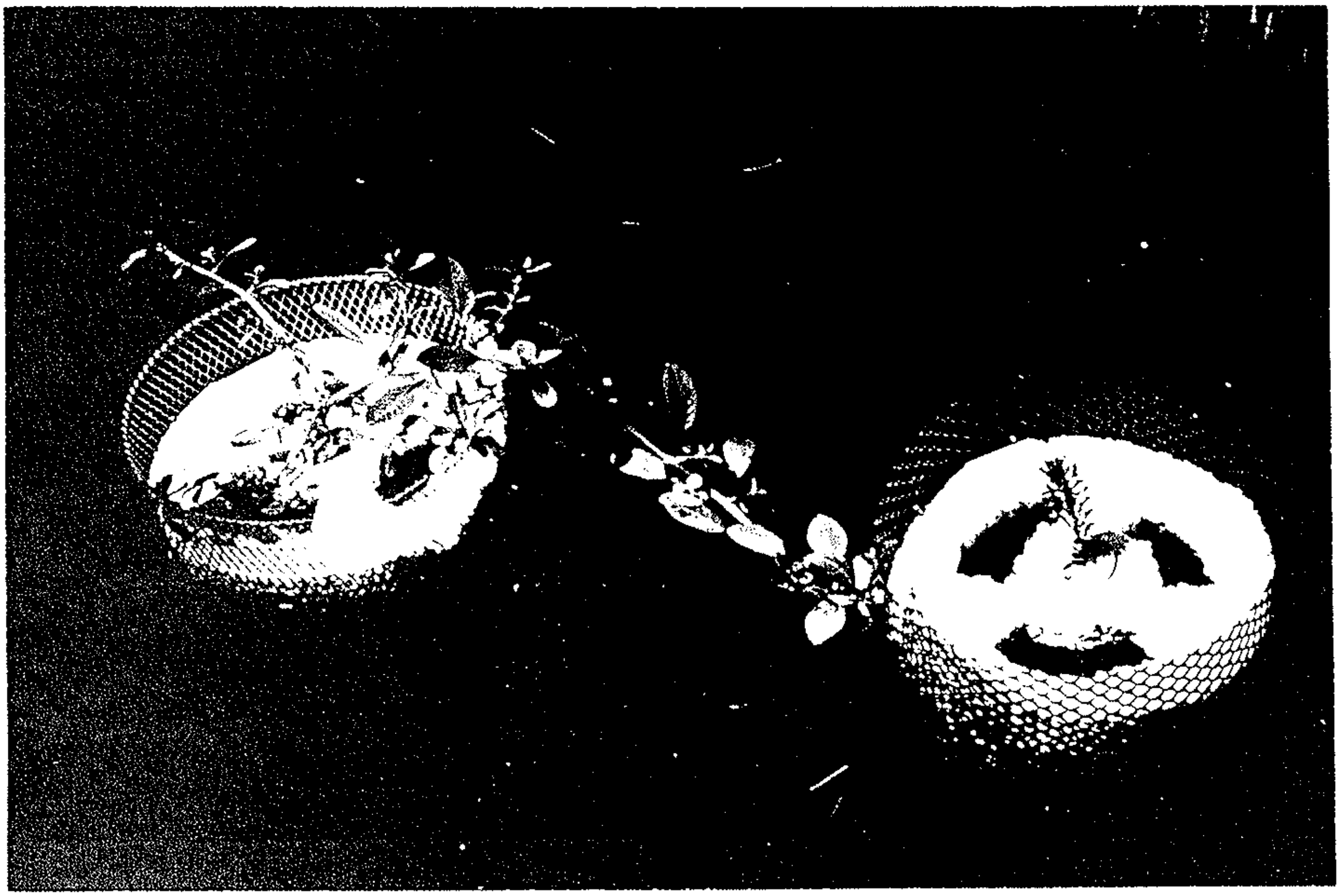


Fig. 3 *Ludwigia peploides* (left) and *Myriophyllum aquaticum* (right) in styrofoam floating plant holders in a nursery wastwater canal. August 1989.

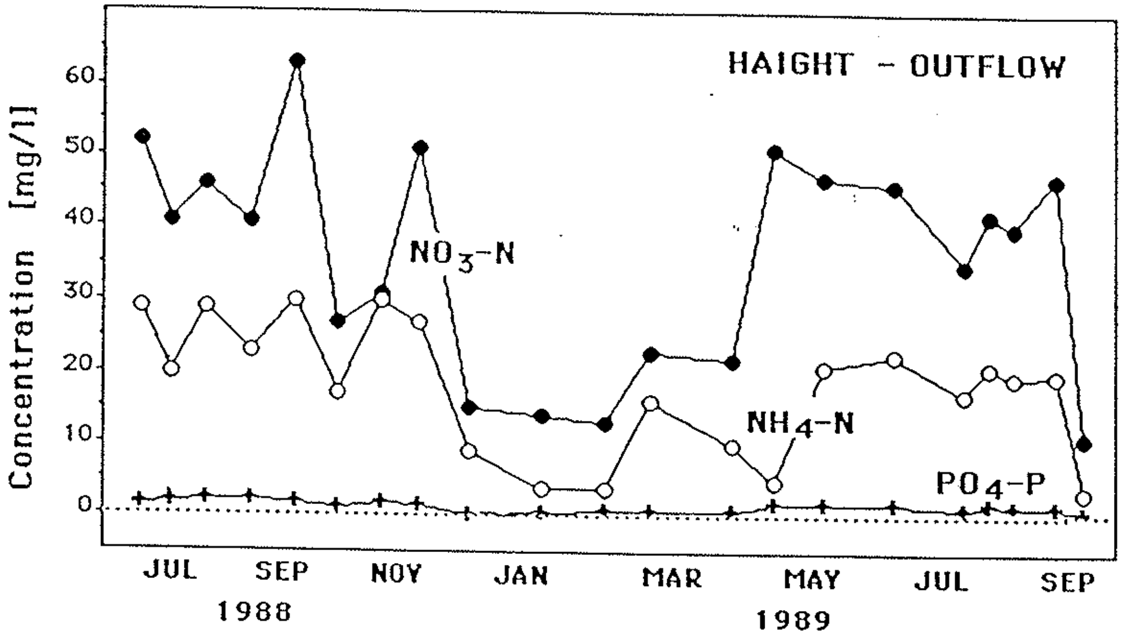


Fig. 4 Seasonal changes of NO_3-N, NH_4-N, and PO_4-P in the outflow water from Haight nursery.

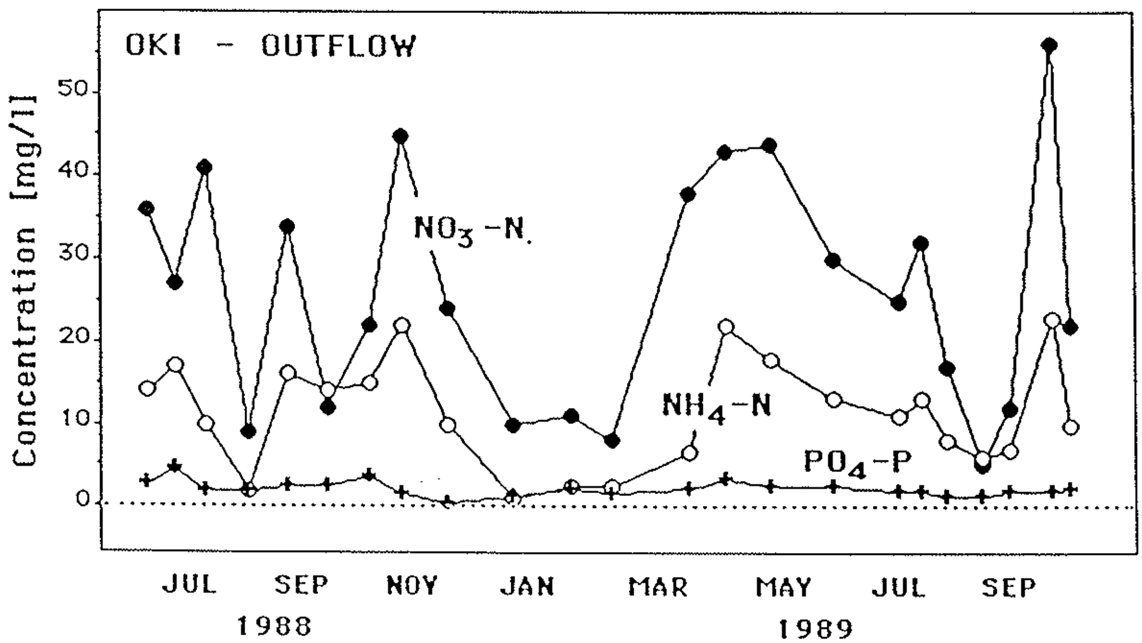


Fig. 5 Seasonal changes of NO_3-N, NH_4-N, and PO_4-P in the outflow water from Oki nursery.

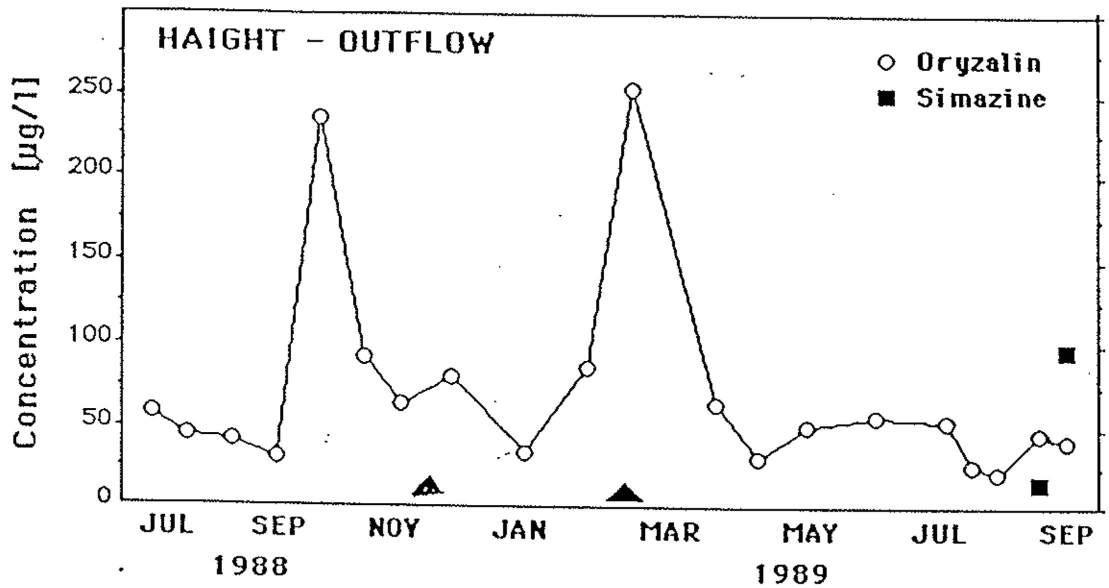


Fig. 6 Seasonal changes in concentration of oryzalin in the outflow water from Haight nursery. Simazine was detected only twice. Black arrow indicates the application date.

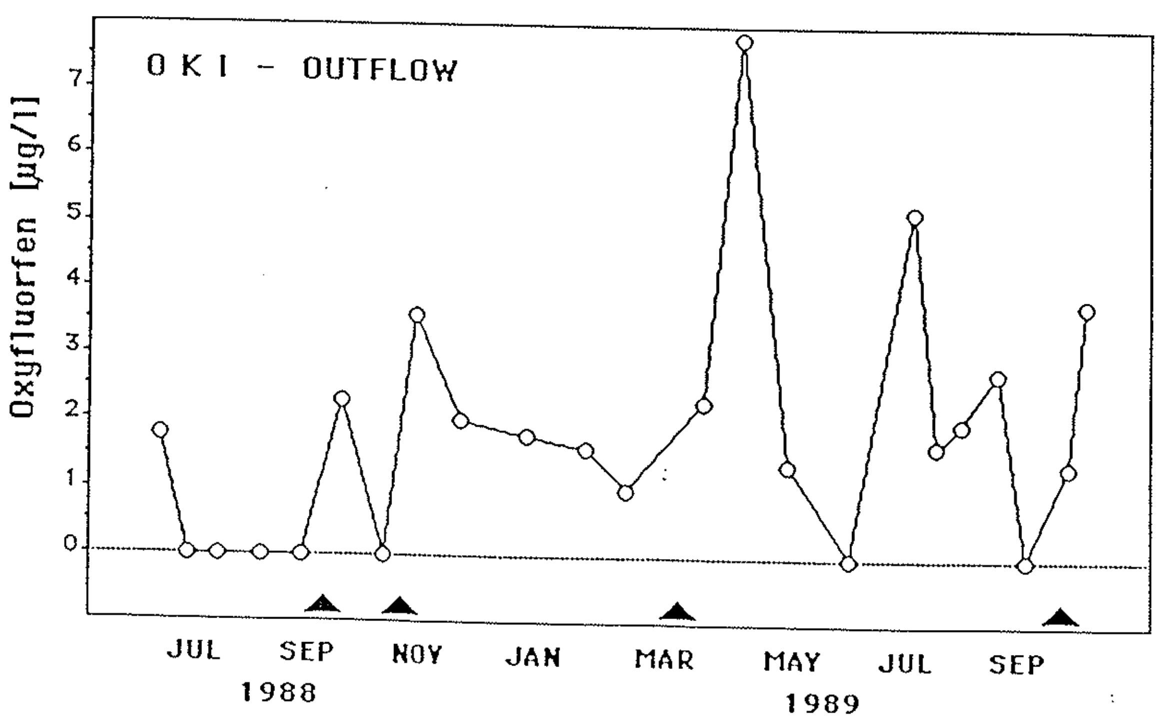


Fig. 7 Seasonal changes in concentration of oxyfluorfen in the outflow water from Oki nursery. Black arrows indicate the application dates.

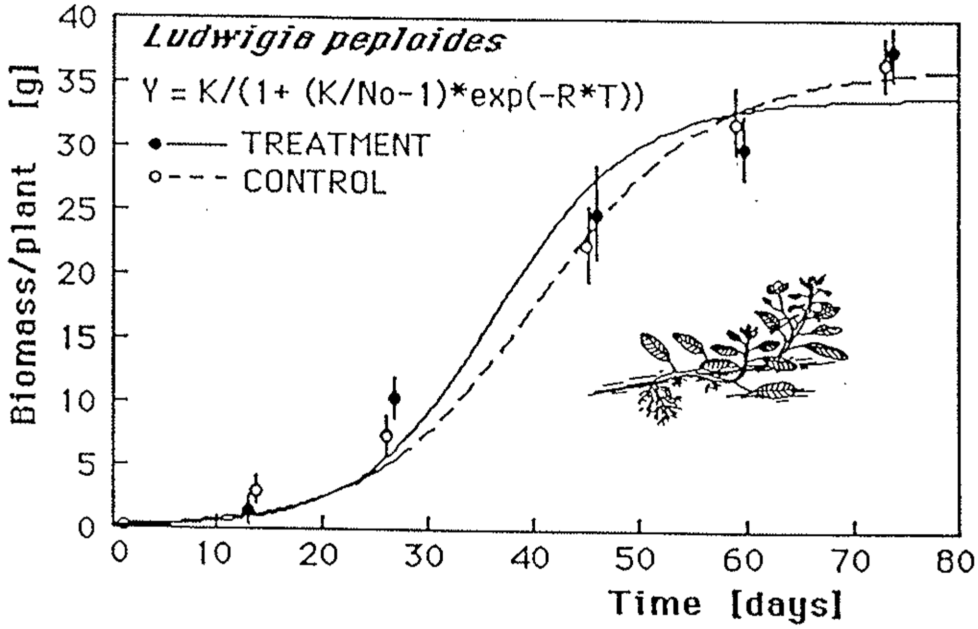


Fig. 8 Growth of *Ludwigia peploides*, expressed as biomass per plant (g dry weight) in Oki nursery waste water (treatment) and in nutrient solution (control). July - September 1989.

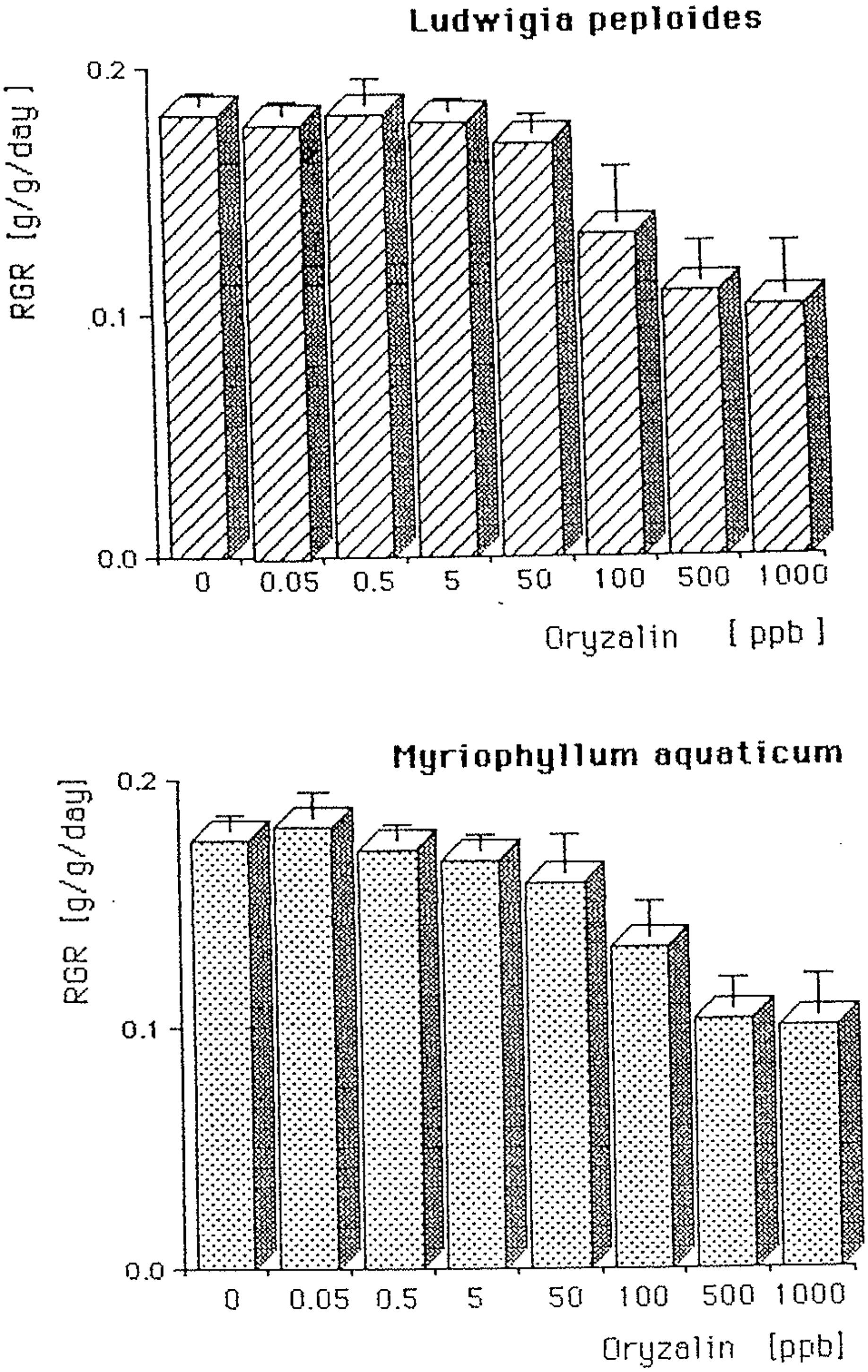
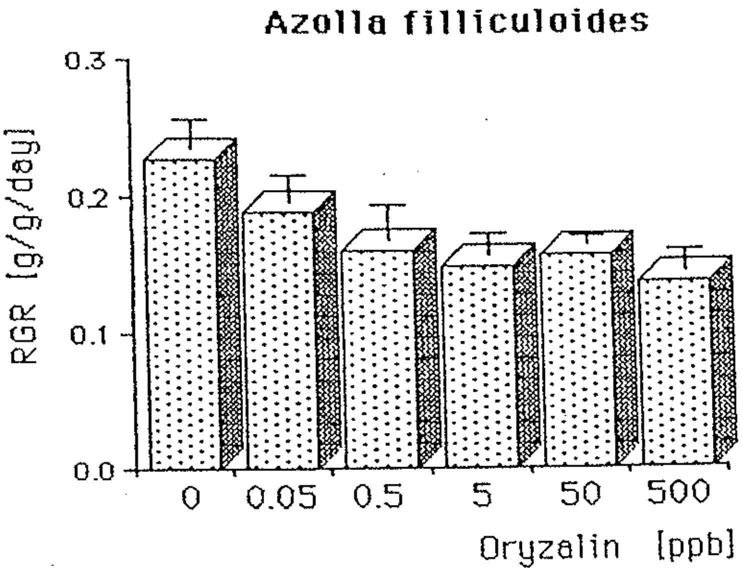


Fig. 9 The effect of oryzalin on the relative growth rate (RGR) of *Ludwigia peploides* (a), and *Myriophyllum aquaticum* (b).



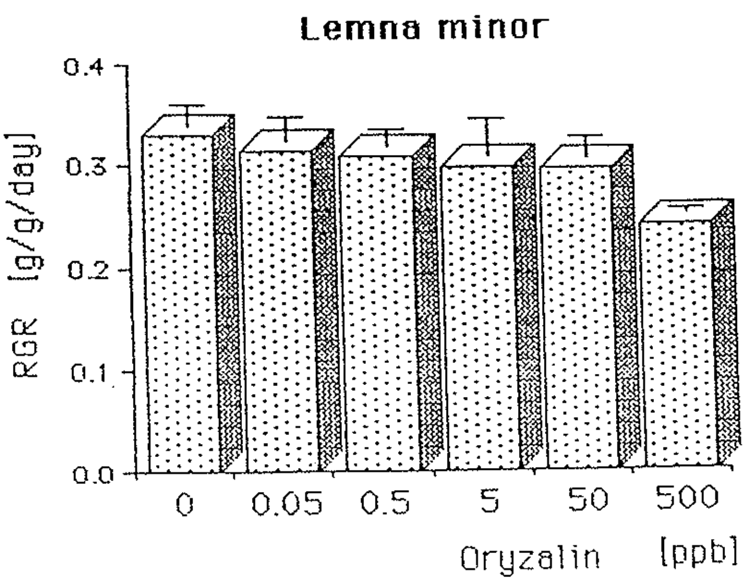


Fig. 10 The effect of oryzalin on the relative growth rate (RGR) of *Azolla filliculoides* (a), and *Lemna minor* (b).

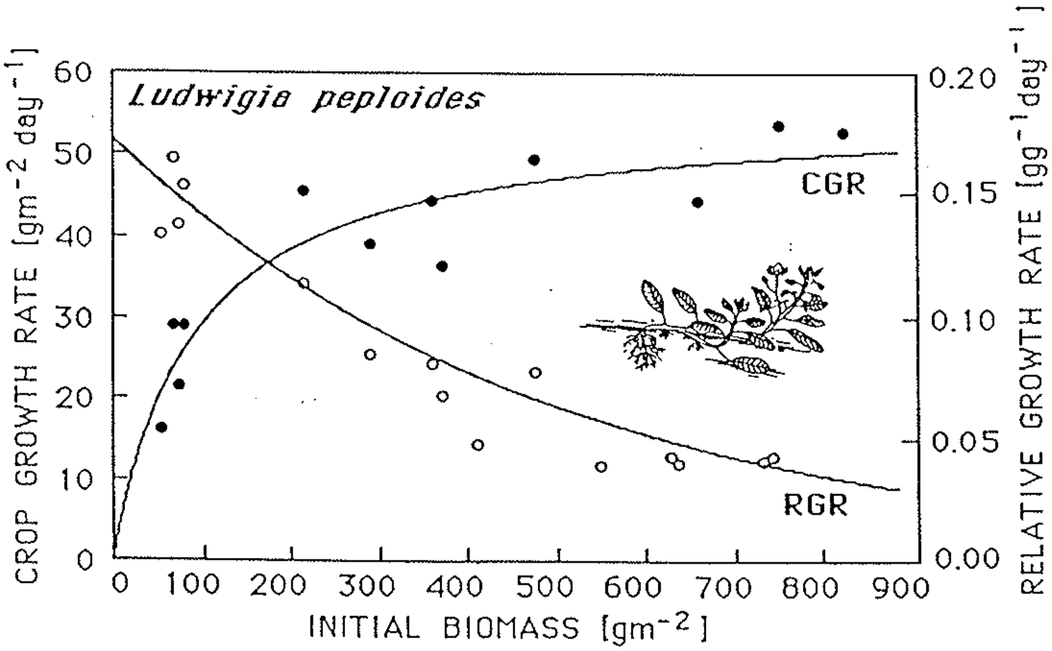


Fig. 11 The dependence of crop growth rate, CGR, (g dry weight/m^2/day) and relative growth rate, RGR, (g dry weight/g/day) on the initial plant biomass (g dry weight/m^2). Outdoor experiment, September 10-20, 1989.

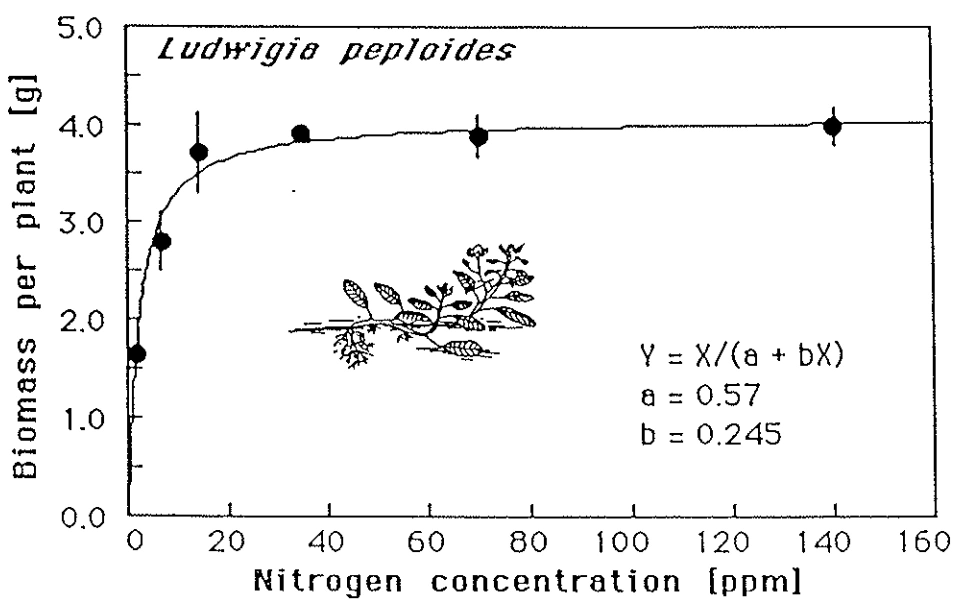


Fig. 12 Changes in biomass (g dry weight per plant) of *Ludwigia peploides* as a function of increasing nitrogen concentration in water. Final values; experiment duration 25 days.

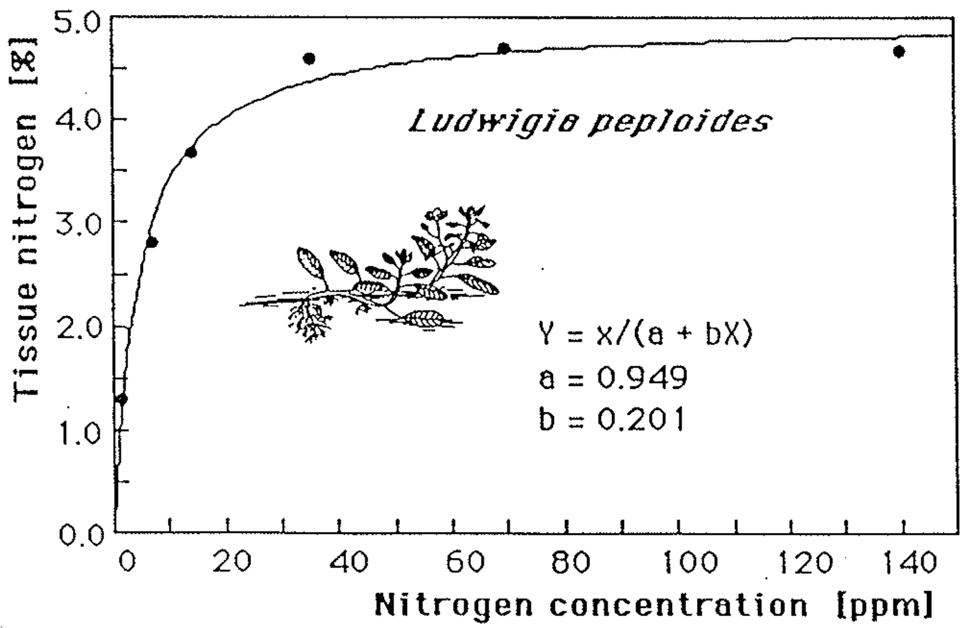


Fig. 13 Changes in tissue nitrogen in *Ludwigia peploides* as a function of increasing nitrogen concentration in water. Final values; experiment duration 25 days.

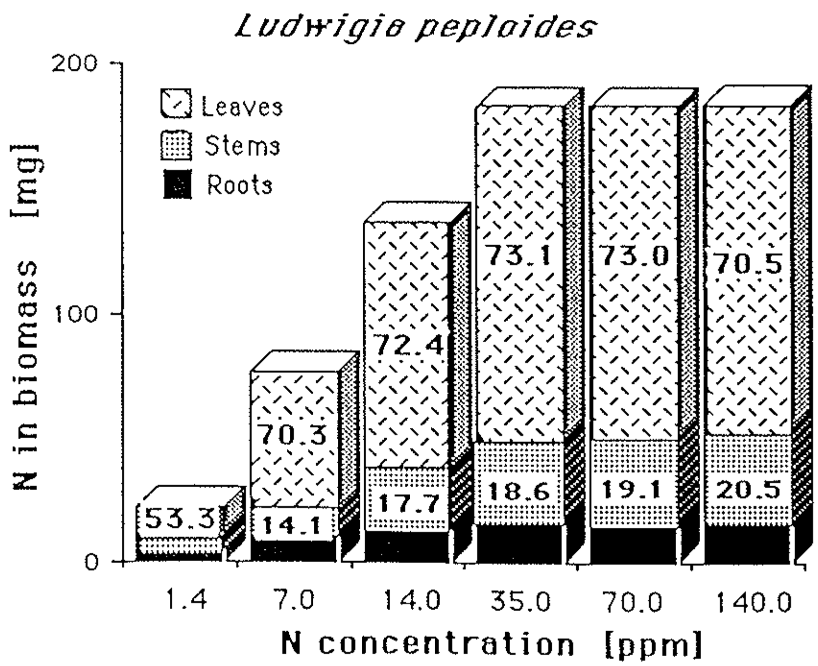


Fig. 14 Allocation of nitrogen to leaves, stems and roots of *Ludwigia peploides* as a function of increasing nitrogen concentration in water.

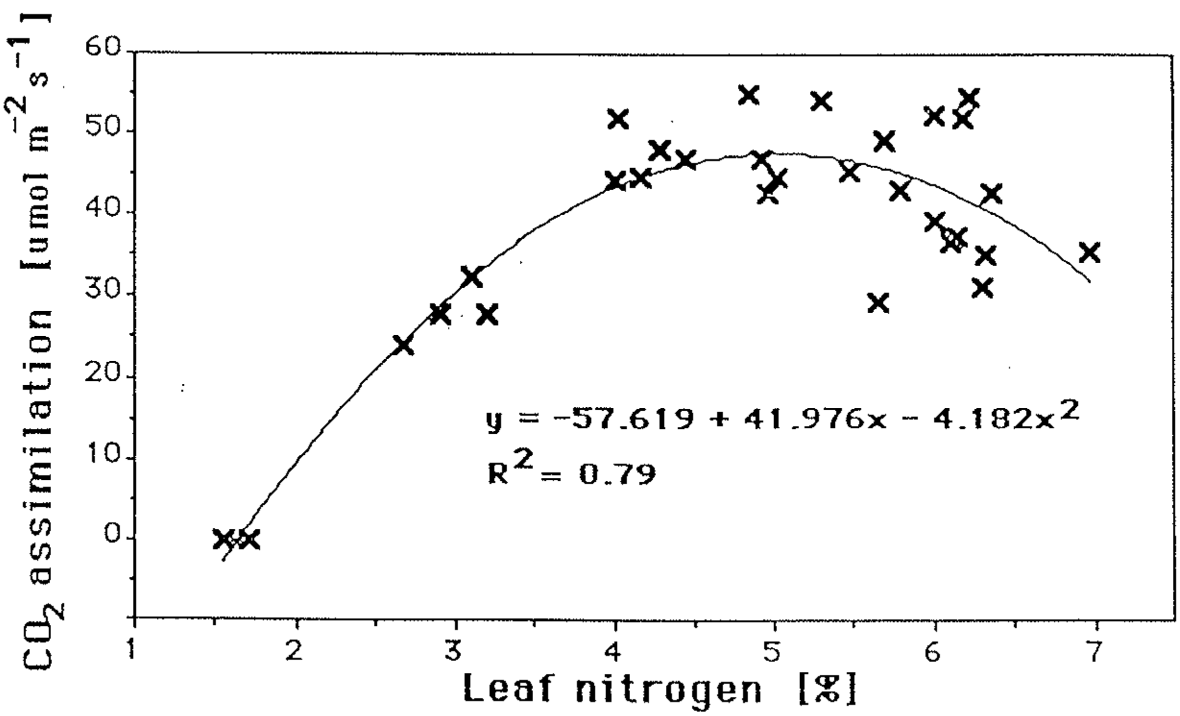


Fig. 15 The relationship between photosynthetic rate of single leaves and leaf nitrogen in *Ludwigia peploides*.

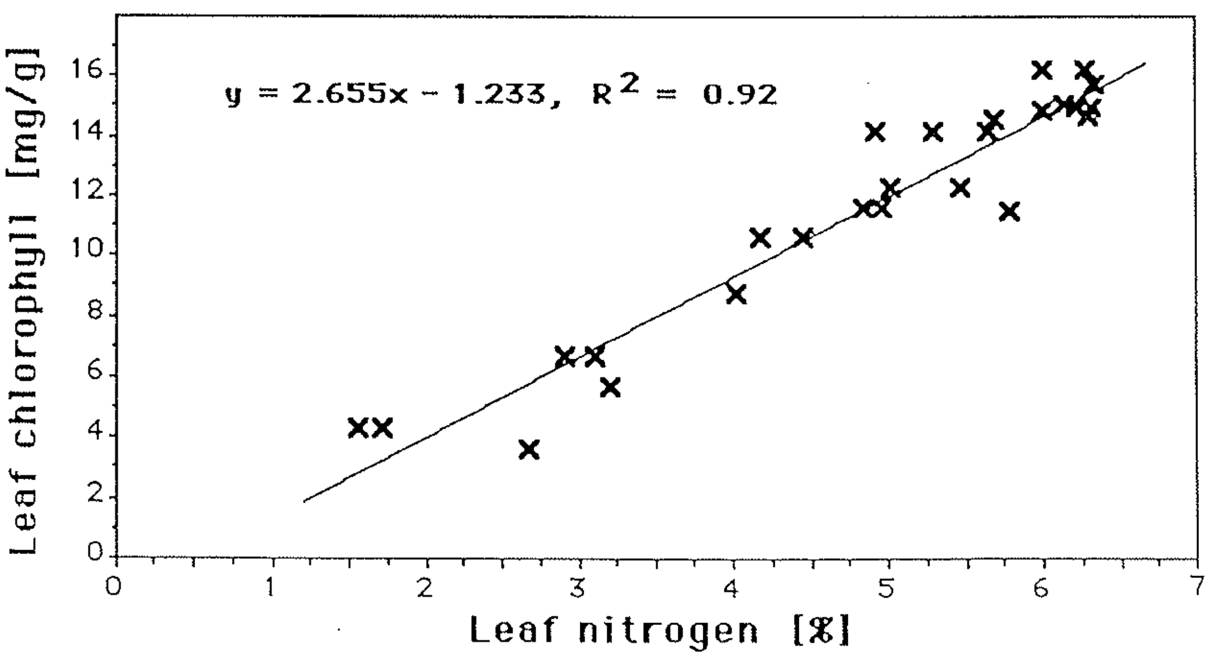


Fig. 16 The relationship between leaf chlorophyll and leaf nitrogen in *Ludwigia peploides*.

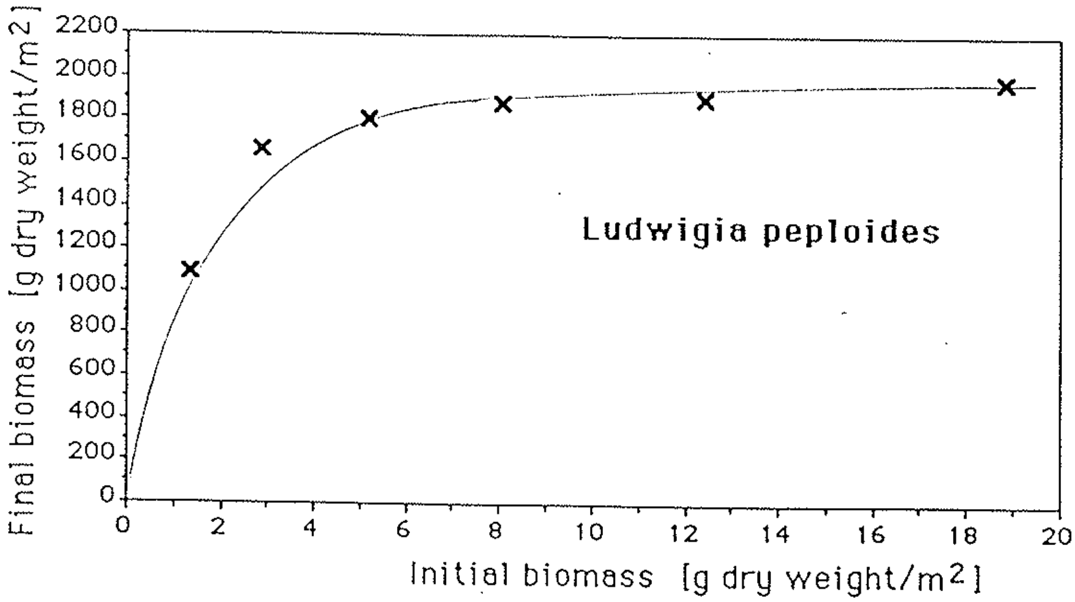


Fig. 17 Carrying capacity of *Ludwigia peploides* expressed as a maximum biomass per square meter at which there is a zero net growth.

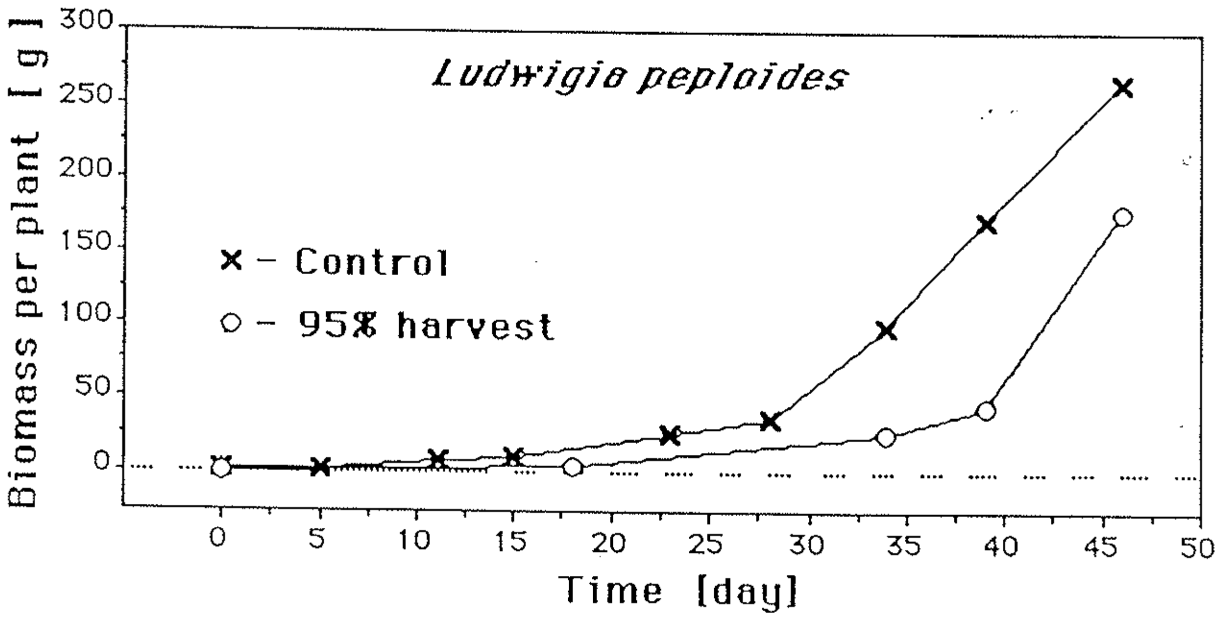


Fig. 18 Growth of *Ludwigia peploides* expressed as biomass per plant (g dry weight) comparing harvested and non-harvested plants.