Chemical control of *Salvinia molesta*: glasshouse and lake experiments

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Summary

Changes in fresh weight, chlorophyll and percentage cover of the tertiary form of salvinia in response to treatment with diuron at 4.8 kg ha^{-1}, hexazinone powder at 2.7 kg ha^{-1} and hexazinone liquid at 3.0 L ha^{-1} both sprayed onto the foliage and injected into the water, AF 100 (kerosene plus surfactant) at 112 L ha^{-1}, AF 100 plus hexazinone at 112 L ha^{-1} (equivalent to 100 g hexazinone ha^{-1}), and AF 101 (kerosene plus surfactant and diuron) at 112 L ha^{-1} (equivalent to 280 g diuron ha^{-1}) were examined in glasshouse and lake experiments in north Queensland. AF 100 and AF 101 had the most immediate effects on the chlorophyll content and leaf integrity of salvinia in both the glasshouse and the lake. The powdered form of hexazinone had the greatest effect on the fresh weight of salvinia in the glasshouse and both diuron and hexazinone killed plants in the lake more quickly than the kerosene-based mixture, although the cost was higher. The results are discussed in relation to the cost-effectiveness of each treatment and other constraints on their use.

Introduction

The aquatic fern salvinia (*Salvinia molesta* Mitchell) is found in many subtropical and tropical parts of the world (Harley and Mitchell, 1981). The plant was first noticed in Lake Moondarra (the major water supply for the city of Mount Isa, Queensland) in October 1975 and despite attempts at manual removal it continued to spread throughout the lake (Farrell, 1978). A spraying programme using paraquat was initiated during January 1976 but, despite the expenditure of \$88 000 by the following November, the plant continued to spread and full scale spraying was suspended. Due to the lack of success of this programme, paraquat was discounted as a practical control treatment.

The cessation of chemical control measures led to a rapid increase in area of the weed and by December 1977 60 to 70% of the riverine area of the lake was covered with salvinia (Figure 1). Spraying then recommenced using the kerosene-based spray AF 101 (Diatloff *et al.*, 1979). This programme was initially very successful and a considerable reduction in salvinia biomass was achieved. However, after the onset of hot weather in January the rapid growth of the plant outstripped the spraying programme, which was again stopped, after the expenditure of \$50 000 (Farrell, 1978). Plans were made to spray during the cooler months of the year using the cheaper but seemingly equally effective (A.C. Julian, personal communication) kerosene-based spray AF 100. The results of this and later spraying programmes will be reported in a further publication.

In view of the problems being experienced with chemical control of salvinia in Lake Moondarra, a quantitative comparison of various herbicides was undertaken. AF 100, diuron and hexazinone were included with AF 101 in a series of glasshouse and lake experiments. Both diuron and hexazinone have been shown to be effective against salvinia in other areas, at 4.8 kg ha^{-1} and 2.7 kg ha^{-1} respectively (P. James, personal communication) but they had not previously been quantitatively compared to the kerosene-based herbicides. This comparison was therefore undertaken to

Figure 1 Distribution of *Salvinia molesta* on Lake Moondarra in December 1976.

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determine which of these herbicides was the most effective against salvinia in the warmer conditions of northern Queensland.

Materials and methods

Glasshouse experiments

The herbicides diuron (as Karmex), hexazinone (as Velpar and Velpar L) and AF 101 were tested for their effectiveness against salvinia between April and August 1978 at the rates shown in Table 1. The herbicides were made up in 25 mL of distilled water and, whilst being continuously agitated, were sprayed directly onto 34 g fresh weight tertiary form salvinia in 2.5 L polyethylene containers. The containers were wrapped in aluminium foil to exclude light and reduce algal growth, and were filled with Townsville tap water. Additional water was added every 2 to 3 days to replace that lost by evapotranspiration. The effect of injecting hexazinone directly into the water was also tested, while unsprayed plants were used as controls. At approximately 7-day intervals three containers from each treatment, but not the controls, were cleared and the plants separated into the emergent parts (floating leaves and stems) and submerged leaf or root-like structures prior to weighing. The chlorophyll *a* content of plants was measured from 90% acetone extracts using the formula of Jeffrey and Humphrey (1975) and expressed on a fresh weight basis. The water temperature in the containers varied from 20°C to 35°C throughout the experiments, with the lower values being more common.

Table 1 Herbicides used in the glasshouse and lake experiments. The cost estimates are based upon the landed price in Mount Isa in 1978.

Herbicide	Spray composition[1]	Application rate	1978 cost per hectare
hexazinone	a) 900 g kg^{-1} powdered Velpar 0.2% v/v BS 100 surfactant	2.7 kg hexazinone ha^{-1} in 3000 L of water	$141.65
	b) 250 mL L^{-1} liquid Velpar 0.2% v/v BS 100 surfactant	2.7 kg hexazinone ha^{-1} in 3000 L of water	$195.00
diuron	800 g kg^{-1} powdered Karmex 0.2% v/v BS 100 surfactant	4.8 kg diuron ha^{-1} in 300 L of water	$40.20
AF 100	1 part v/v Caldec surfactant + 45 parts kerosene	112 L AF 100 ha^{-1}	$23.19
AF 100 plus	1 part v/v Caldec surfactant + 45 parts kerosene + 900 mg L^{-1} Velpar	112 L AF 100 ha^{-1} 100 g hexazinone ha^{-1}	$27.91
AF 101	3 parts v/v of 1.25 kg diuron in 20 L acetone + 2 parts Caldec + 55 parts kerosene	112 L AF 100 ha^{-1} 280 g diuron ha^{-1}	$28.92

[1]The surfactant Caldec, used in the AF 100 formulation, is hydrophobic and miscible with kerosene, whereas the water miscible BS 100 was used with hexazinone and diuron.

Lake experiments

A quantitative comparison of the effects of diuron (as Karmex), hexazinone (as Velpar), AF 101, AF 100 and AF 100 plus hexazinone was conducted in Lake Moondarra during November 1978 using the same application rates as in the glasshouse trials (Table 1). Approximately 1 kg fresh weight of the tertiary form of salvinia was placed into floating 0.25 m^2 PVC quadrats. Suspended beneath these were 100 L (approx.) plastic bags that were used to prevent plants escaping, and fish and water goannas entering the quadrats. The herbicides were applied to three replicate quadrats by spraying directly onto the plants by the method used for the glasshouse experiments. Unsprayed control quadrats were also established. Fresh weight changes were recorded and percentage vegetation cover of each quadrat estimated after 7 and 14 days. Fresh weight decay rate coefficients over 14 days were calculated using the formula of Jewell (1971).

Results

Glasshouse experiments

When sprayed onto the plants, powdered hexazinone caused a greater reduction in the fresh weight of the floating leaves and stems than when added to the water, where a greater reduction occurred in the weight of the submerged structures (Figure 2). The liquid hexazinone did not show the same pattern with similar weight changes occurring as a result of both treatments. The weight changes following treatment with AF 101 were somewhat erratic and visible breakdown of the plant material was considerably slower with this mixture. The breakdown that did occur was more pronounced in the submerged structures, as was also the case with diuron. The decay rate coefficients show quantitatively the differences in effectiveness of these herbicides (Figure 2). At the conclusion of the experiments the fresh weights were all significantly ($P < 0.05$) less than the control plants with the greatest reduction caused by powdered hexazinone (Table 2).

The most immediate effect on the plants was caused by AF 101. As the spray was administered the characteristic wetting of the leaves occurred, followed by the sinking of the plants. Approximately 5 hours after application the leaves showed the first signs of chlorosis and the plants began to disintegrate. After 7 days only 35% of the original chlorophyll content of the plant tissue remained, compared with more than 87% under the other herbicide treatments (Table 2). Liquid hexazinone was particularly slow acting, with an actual increase in chlorophyll content. However, by 14 days after application all the treatments had caused complete chlorosis of the plants.

Lake experiments

The most effective herbicides in the lake experiments were diuron (4.8 kg ha^{-1}) and hexazinone (2.7 kg ha^{-1}). The decay rate coefficients (Figure 3) were much greater for these two herbicides than for the formulations based on AF 100. Addition of a low quantity of diuron to AF 100 improved its effectiveness but the addition of hexazinone to AF 100 was not as successful. Hexazinone and diuron by themselves successfully reduced the fresh weight of the plants. It was also clear from visual inspections of the quadrats that both induced rapid breakdown of chlorophyll but the plants retained their basic shape and remained on the water surface. The use of kerosene-based mixtures, however,

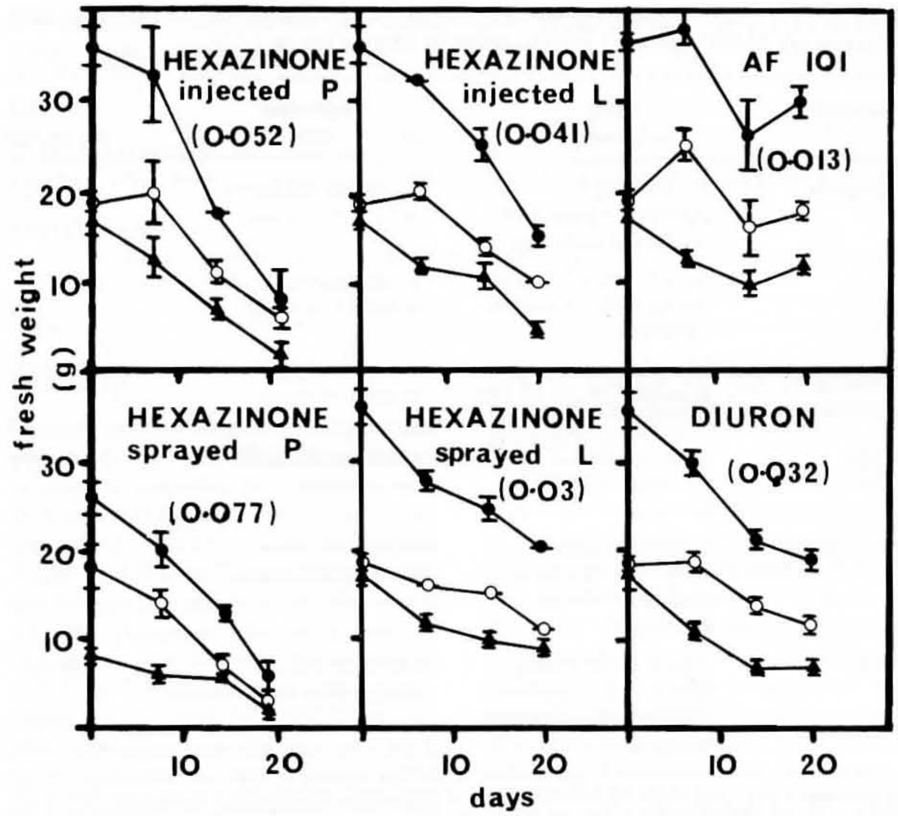

Figure 2 Fresh weight changes of salvinia grown under glasshouse conditions, following treatment with various herbicides (P = powder and L = liquid formulation of hexazinone). The values in brackets are the fresh weight decay coefficients (g g^{-1} day^{-1}). Key: ● total fresh weight; ○ fresh weight of floating leaves; ▲ fresh weight of submerged leaves. Confidence intervals are equal to the standard error.

Table 2 Effect of treatment with various herbicides upon the fresh weight (after 19 to 21 days) and chlorophyll *a* (after 7 days) of salvinia plants maintained under glasshouse conditions, expressed as a percentage of the initial values[1].

Herbicide	Fresh weight (%)	Chlorophyll (%)
AF 101	86.0	34.6
diuron	54.3	87.4
hexazinone liquid		
sprayed	55.9	155.6
injected	42.4	124.9
hexazinone powder		
sprayed	21.8	87.7
injected	21.9	93.6

[1]Control values were not determined after 7 days.

drastically altered the shape of the plants with tissue collapse occurring before extensive chlorophyll degradation became evident.

After 14 days a visual estimate was made of the amount of live plant material remaining in the quadrats. None of the hexazinone or diuron treated quadrats contained live material, whereas the quadrats treated with AF 100 plus hexazinone, AF 101 and AF 100 had approximately 25%, 35% and 70% respectively of their area covered with live plant material. In these cases more than half of the live material appeared to be growth that had occurred since the experiment started. The control quadrats, in contrast, were completely covered with live material of which less than 15% could be visually classed as new growth.

Discussion

The effectiveness of both hexazinone and diuron in these experiments suggests that they could be more effective than AF 100 or AF 101 for controlling salvinia. The success of hexazinone in degrading salvinia plants in the experiments may be partly attributed to its residual properties, particularly as small containers were used. While the size of the glasshouse containers was considerably less than those used in the lake, hexazinone was effective in degrading the salvinia in both situations. Whether this residual action would be as effective in a lake situation (especially in deeper water) is at present unknown. In Western Australia hexazinone is applied at 2 kg ha^{-1} to control salvinia where the water depth averages 0.5 m and is increased proportionally for each 0.5 m increase in depth (A. J. Tapley, personal communication). This approach may be necessary in all deep water salvinia infestations.

Diatloff *et al.* (1979) found in glasshouse experiments that diuron at 0.15 kg ha^{-1} (applied in AF 101) was effective against this species of salvinia. In the lake experiments reported here, a higher rate of diuron (0.28 kg ha^{-1}) in AF 101 certainly improved the effectiveness of the base formulation. However, an equivalent application rate did not enhance the effectiveness of the basic herbicide mixture when applied during a subsequent full scale spraying in summer in Lake Moondarra, and because of this the diuron was subsequently omitted. Successful control of salvinia was then obtained by the Mount Isa Water Board with AF 100 during the cooler months of winter when regrowth of the plant was comparatively slow. In view of the experimental results and the field successes reported by Julian (1978) in Lake Tinaroo, Queensland, and I. Miller (personal communication) in the East Alligator River, Northern Territory, it would be worthwhile testing the effectiveness of AF 101 in Lake Moondarra during the cooler months.

Farrell (1978) attributed the lack of success of the AF 101 summer programme to the very rapid regrowth that occurred. It was not possible with the equipment available to spray often enough to contain the regrowth. It is worth noting that in Lake Tinaroo motor boats were used to break up the thicker mats of salvinia before spraying with AF 100 at a high rate of 250 L ha^{-1} (Julian, 1978). More attention to the application techniques and rates in field situations may be needed before AF 101 and AF 100 are fully successful in controlling large thick mats of salvinia. These problems may not seriously restrict the effectiveness of these herbicides on smaller and more easily managed infestations. It is imperative therefore that direct and effective steps are taken to prevent any salvinia infestation from reaching a

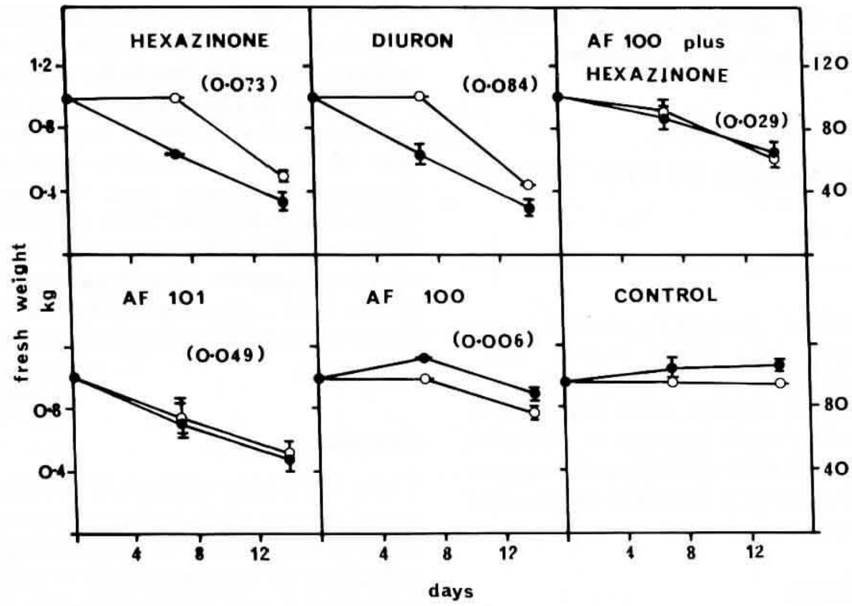

Figure 3 The effect of various herbicides upon fresh weight (●) and percentage cover (○) of tertiary form *Salvinia molesta* plants in floating quadrats in Lake Moondarra. The values in brackets are the fresh weight decay coefficients (g g^{-1} day^{-1}). Confidence intervals are equal to the standard error.

size that is likely to reduce the capacity to spray sufficient herbicide to kill the plants.

In the larger or closely packed mats of salvinia the effectiveness of the kerosene mixtures is further reduced by the lack of free water that allows the herbicide to spread throughout and over the plants. The plants in these mats are principally of the tertiary form that was successfully controlled by hexazinone and diuron in the experiments. It would seem therefore, that both herbicides would be good alternatives to AF 100 or AF 101 control in these situations. Their use, however, is restricted as neither is currently registered in Australia for use in potable water (P. Wade, personal communication). In addition, the use of diuron may be further restricted due to problems with the transport of phytotoxic residues away from target areas (Bowmer and Adeney, 1978).

A further important consideration in the use of herbicides is their cost. While hexazinone and diuron are very effective against salvinia when applied at recommended rates, hexazinone in particular is very expensive when compared with the AF 100 formulations (Table 1). The cost of hexazinone control will also be much greater if the rate of application is increased for use in deeper water. There is some evidence to suggest that the effectiveness of AF 100 can be increased by combining small quantities of diuron and hexazinone with it but the optimum rates still need to be determined. In view of the limited control possible in Lake Moondarra with AF 100 and AF 101 this approach could result in an increase in spraying efficiency while not greatly increasing the cost of application. The use of much smaller quantities of hexazinone or diuron with AF 100 may also overcome the registration problems associated with using these compounds.

The apparent success of the biological control of salvinia in Lake Moondarra (Room *et al.*, 1981) should make further use of herbicides in this lake unnecessary. Whether or not this is the case depends to a large extent on efforts to establish the weevil *(Cyrtobagous singularis)* and salvinia in a dynamic equilibrium at low population densities. At present this does not appear to have occurred. While the longer term success of the biological control programme is being evaluated it may be necessary to use herbicides to contain, if not eradicate an infestation. It is essential therefore that the most effective herbicide available is chosen for the control of each infestation, if the problem of salvinia in Australia is to be contained until an effective and widespread biological control is available. It is particularly important to do this if the successful biological control in Lake Moondarra cannot be repeated elsewhere.

Conclusion

The results of both glasshouse and lake experiments illustrate the effectiveness of diuron and hexazinone on the tertiary form of salvinia. A better combination of low rates of either herbicide with AF 100 may increase the effectiveness of salvinia control and cost less than using them alone at conventional rates. The problems of registration for use in potable water may also be overcome by small additions to the already accepted AF 100.

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References

Bowmer, K. H. and Adeney, J. A. (1978). Residues of diuron and phyto-toxic degradation products in aquatic situations. II. Diuron in irrigation water. *Pesticide Science* **9**:354–64.

Diatloff, G., Lee, A. N. and Anderson, T. M. (1979). A new approach for *Salvinia* control. *Journal Aquatic Plant Management* **17**:24–7.

Farrell, T. P. (1978). The spread and control of *Salvinia molesta* in Lake Moondarra, Mount Isa, Queensland. *Proceedings First Conference Council Australian Weed Science Societies, Melbourne, April 1978*. pp. 179–87.

Harley, K. L. S. and Mitchell, D. S. (1981). The biology of Australian weeds. 6. *Salvinia molesta* D. S. Mitchell. *Journal Australian Institute Agricultural Science* **17**:67–76.

Jeffrey, S. W. and Humphrey, G. F. (1975). New spectrophotometric equations for determining chlorophylls a, b, c_1 and c_2 in higher plants, algae and natural phytoplankton. *Biochemie Physiologie der Pflanzen* **167**:191–4.

Jewell, W. J. (1971). Aquatic weed decay: Dissolved oxygen utilisation and nitrogen and phosphorus regeneration. *Journal Water Pollution Control Federation* **43**:1457–67.

Julian, A. C. (1978). Control of *Salvinia molesta* on Tinaroo Falls Dam with AF 101, an experimental material. *Proceedings First Conference Council Australian Weed Science Societies, Melbourne, April 1978*. pp. 327–31.

Room, P. M., Harley, K. L. S., Forno, I. W. and Sands, D. P. A. (1981). Successful biological control of the floating weed salvinia. *Nature* (London) **294**:78–81.