apparent stimulation of tuber formation in monoecious hydrilla treated at 0.05 mg/L after 6 months based on measurements of number of tubers (Figure 1c). The tubers produced in the 0.05 mg/L treatment were much smaller, however significantly more tubers were formed, thus the total tuber weight in this treatment was similar to tuber weight in untreated plants (Figure 1b). Furthermore, laboratory tests indicated no differences in germinability between these smaller tubers collected from the bensulfuron methyl treatments and those from untreated plants (data not shown).

Untreated dioecious hydrilla began to form tubers 1 month after planting, reaching a maximum number of 444 tubers per pan in April (Figure 1f). Tuber production in dioecious hydrilla apparently ceased from April to June however, as the tuber curves remained flat during these summer months. This seasonal pattern of tuber production in dioecious hydrilla in Florida was consistent with earlier findings by Haller et al. (1976) and Sutton et al. (1992). In the 0.05 mg/L bensulfuron methyl treatment, tubers were formed from February to April, but again there was no evidence of tuber production from April to June (Figures 1e and 1f). As a result, tuber formation in dioecious hydrilla was still reduced by 84% or more after 6 months in all bensulfuron methyl treatment rates tested. These results suggest that proper timing of bensulfuron methyl applications according to the seasonal tuber production in dioecious hydrilla could increase the herbicide performance in this biotype.

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Potential Use of Bensulfuron Methyl for Sediment Application in Irrigation Systems in Australia[1]

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ABSTRACT

The use of bensulfuron methyl as a soil-residual herbicide in irrigation channels was investigated by treatment of empty channels about a week before the start of irrigation water flows in spring. Assessments in the late summer, some 4 to 5 months after treatment, showed poor control of common watermilfoil (*Myriophyllum papillosum*) Orchard, sp. nov.), fair control of elodea (*Elodea canadensis* Rich.), moderate control of ribbonweed (*Vallisneria gigantea* Graebner) and excellent control of floating pondweed (*Potamogeton tricarinatus* F. Muell. & A. Benn. ex A. Benn (1892)). Floating pondweed exhibited a 96% reduction in freshweight biomass 4 months after treatment with only 100 g/ha of bensulfuron methyl, and substantial control continued for at least 15 months. Even though plot length was limited (13 to 50 m) there was no evidence of plot-to-plot movement, suggesting that bensulfuron methyl is rapidly immobilized in sediment or weeds.

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Key words: Myriophyllum, Elodea, Vallisneria, Potamogeton, drawdown.

INTRODUCTION

In Australia, the management of submerged aquatic weeds in irrigation channels is mainly dependent on the use of acrolein which is applied by injection into flowing water (Bowmer and Sainty 1977, Bowmer and Smith 1984). Ribbonweed and elodea, the two most important submerged weeds, are effectively and rapidly controlled with acrolein, while floating pondweed with both submerged juvenile leaves and floating waxy leaves, is less easily controlled. The effect of acrolein on all these plants is short-term, and two applications are often required each 6 month irrigation season. Also, only limited effects are obtained on the semi-emergent complex of milfoil species. Acrolein has several other disadvantages. It is extremely toxic to fish and other aquatic organisms; and its handling, transport, storage and application require special facilities and training.

Bensulfuron methyl (Methyl 2-[[[[[(4,6 dimethoxy pyrimidin-2-yl) amino] carbonyl] amino] sulfonyl] methyl] benzoate) is very effective in controlling broad-leaved weeds in rice when applied into the flood water (Takeda *et al.* 1986). Its safety and rapid adoption in the rice industry in Australia and California prompted our interest in its efficacy for submerged weed control in irrigation distribution channels. We investigated the potential of the herbicide for use in drained channels by application to the sediment in a series of replicated small-plot trials. The prospect for longer-term management of weeds was investigated. The economy and logistics of weed control and water supply would be improved if a single annual treatment applied during the drawdown period was effective through the following irrigation season.

METHODS

Bensulfuron methyl, (MARINER®[3], a dry flowable formulation provided by DuPont (Australia) Ltd.) was applied in four experimental sites in early spring (September, 1989). The sites were selected for homogeneity and uniform weed populations. Experiments on common watermilfoil and ribbonweed were located in the Murrumbidgee Irrigation Areas near Griffith, floating pondweed near Murrami, and the elodea experiment near Deniliquin in the Murray Valley, New South Wales.

The taxonomy of the *Myriophyllum* (milfoil) complex has recently been revised. Our trial was conducted on *M. papillosum*, a species previously described as *M. variifolium* (Orchard 1985, p. 214). The previously described species *Myriophyllum propinquum* is now revised into three species, *M. variifolium, M. crispatum* and *M. papillosum,* all of which are superficially similar in morphology.

The experiments were each divided into at least 3 blocks, with treatments randomized within the blocks. The five treatments were 100, 200 and 300 g/ha of bensulfuron methyl, with two untreated controls in each block to improve the assessment of weed variability along the channel. Plot lengths varied from 13 to 50 m depending on the length of channel available at each site.

Bensulfuron methyl was applied near the end of the 3-month drawdown period and at least 4 days before channels were refilled with water in the spring. Water status at the sites varied at time of application. The elodea and common watermilfoil sites had pockets of free water 2 to 3 cm deep with saturated sediments throughout. The ribbonweed site was well-drained, but the floating pondweed site was completely covered with static water 30 cm deep.

The above-ground plant cover in the elodea experiment was negligible though underground biomass was substantial. Sediments in the common watermilfoil experiment were about 50% exposed and plants were actively growing with new shoots up to 2 cm long. In the ribbonweed experiment, there was a thick cover of senescent leaves over most of the sediment, with only about 10% of the sediment exposed. In the floating pondweed experiment, floating leaves provided cover over about 90% of the water surface.

Where there was minimal free water at treatment, in the elodea and ribbonweed experiments, applications of herbicide were followed by a water spray (2500 L/ha) to simulate rainfall in an attempt to fix the herbicide in the sediment. Channels were filled with water 4 to 15 days after treatment and held full for 6 to 9 days before draining and refilling. Sediment texture was fine grey clay except in the common watermilfoil experiment where sediment was a loamy clay. Sediment pH (1:5 in 0.01 M $CaCl_2$) and further details are presented in Table 1.

Six quadrats (0.25 m^2) were harvested from the untreated plots before treatment and five quadrats from all plots in mid to late summer (Jan/Feb 1990). Additional measurements for ribbonweed were made including plant numbers, leaf length and numbers of flowers to investigate any changes to growth and reproductive biology. Visual scores of floating pondweed were made six times after treatment using a linear scale based on the area covered by floating leaves.

The movement of bensulfuron methyl downstream was investigated by plotting the summer biomass in untreated plots against the accumulated upstream dose of herbicide. It was assumed that an inverse trend could reflect herbicide transport downstream.

RESULTS AND DISCUSSION

Before treatment there was a consistent distribution of weeds in all experiments, reasonable homogeneity being reflected in the coefficients of variation which were less than 40% (Table 2).

Stunting of elodea was evident early in the season, but regrowth occurred later. Bensulfuron methyl at 300 g/ha reduced biomass by about 34% when observed in late summer some 5½ months after treatment, and water authority officers considered that this suppression provided a worthwhile increase in channel flow capacity (Table 3). Application immediately after the autumn drawdown onto ex-

[3]An EPA experimental use permit for MARINER® evaluations in aquatic systems was obtained in the USA in January 1988.

TABLE 1. DESCRIPTION OF EXPERIMENTAL SITES, THE TIME OF APPLICATION OF BENSULFURON METHYL TO CHANNELS, AND SUBSEQUENT WATER MANAGEMENT.

Weed	Sediment pH	Date treated	Channel filled (DAT)[1]	Channel drained and refilled (DAF)[1]	Final assessment		Plot dimensions[2] (m)
					Date	(DAT)[1]	
Elodea	4.9-5.0	4 Sep 89	15	7	19 Feb 90	168	5 × 50
Common watermilfoil	5.9-6.1	20 Sep 89	6	9	–	–	4 × 13
Ribbonweed	6.9-7.0	20 Sep 89	4	8	23 Jan 90	127	4 × 25
Floating pondweed	6.6-7.0	15 Sep 89	8	6	25 Jan 90	132	4 × 30

[1]Days after treatment (DAT); days after first filling (DAF)
[2]Plot dimensions (width × length)

TABLE 2. FRESHWEIGHT BIOMASS OF WEEDS IN IRRIGATION CHANNELS BEFORE TREATMENT OBTAINED BY SAMPLING TWO PLOTS FROM EACH BLOCK (SIX PLOTS IN TOTAL).

Weed	Mean (g/m^2)	C.V. (%)	Range (g/m^2)
Elodea	433	30	296-772
Common watermilfoil	1815	38	972-2552
Floating pondweed	1484	19	1096-1780

posed sediments or onto shallow static remnant water will also be investigated in future experiments.

The common watermilfoil was dense at treatment, and had begun to grow after a mild winter. New shoot tips became chlorotic after treatment but there was no other visible effect of bensulfuron methyl, even at 300 g/ha, when observed towards the close of the irrigation season in autumn. Earlier treatment, before spring growth, should be tried to improve results in future.

Control of ribbonweed was good, with reduction in plant biomass of 71 and 83% at bensulfuron methyl rates of 200 and 300 g/ha, respectively (Table 3). Weeds were thinned rather than stunted as reflected in plant numbers and leaf length measurements (Table 4). Reduction in numbers of female flowers was also evident.

Excellent control of floating pondweed was obtained even at the lowest rate of herbicide used. Bensulfuron methyl at 100 g/ha reduced biomass by 96% when observed in midsummer about 4 months after treatment (Table 3). However, unless a higher rate is used there is a danger that in a mixed stand, repeated treatments could lead to expansion of species more tolerant of the herbicide. Control, as reflected in suppression of leaf water cover by floating leaves, was maintained for at least 15 months after treatment (Figure 1), even though the herbicide was applied into standing water at least 30 cm deep.

TABLE 3. EFFECT OF BENSULFURON METHYL ON FRESH WEIGHT BIOMASS OF WEEDS OBSERVED IN MID TO LATE SUMMER. FIGURES ARE MEANS OF THREE PLOTS EXCEPT FOR UNTREATED CONTROLS WHICH ARE MEANS OF SIX PLOTS. (FIGURES IN BRACKETS GIVE STANDARD DEVIATION).

Bensulfuron methyl (g/ha)	Elodea (g/m^2)	Ribbonweed (g/m^2)	Floating pondweed (g/m^2)
0	2163 (361)	5290 (1583)	3413 (1029)
100	1998 (266)	3564 (1532)	121 (111)
200	2017 (594)	1513 (476)	53 (91)
300	1418 (745)	894 (306)	414 (520)
LSD ($P = 0.05$)	(NS)	1467	571

TABLE 4. EFFECT OF BENSULFURON METHYL ON PLANT DENSITY AND STUNTING OF RIBBONWEED ASSESSED 23 JANUARY 1990 (127 DAT). FIGURES ARE MEANS OF THREE PLOTS EXCEPT FOR UNTREATED CONTROLS WHICH ARE MEANS OF SIX PLOTS.

Bensulfuron methyl (g/ha)	Plant frequency (No/m^2)	Female (No/m^2)	Leaf length (cm)
0	82	75	82
100	100	85	77
200	38	11	78
300	32	6	63

Excellent control of floating pondweed was also obtained with bensulfuron methyl at 100 g/ha by the Rural Water Commission of Victoria in another small plot replicated field trial (K. Sinclair, L. Jackel and J. Wilding, personal communication, 8 November 1990).

In the floating pondweed experiment visual observations of floating leaf cover showed some evidence of downstream transport. The most upstream plot, a 300 g/ha treatment, gave reduced effect compared with its down-

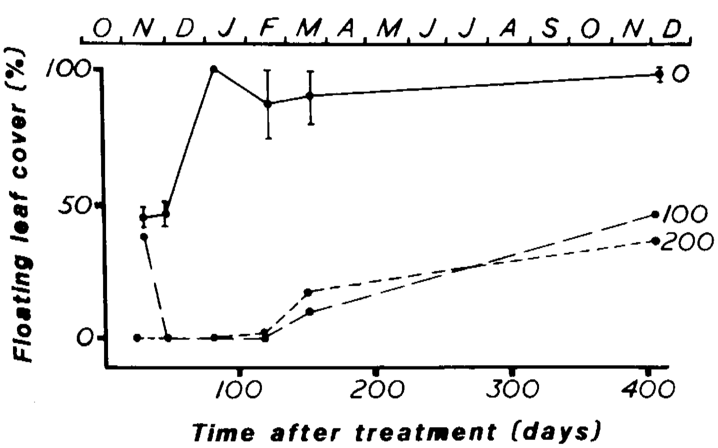

Figure 1. Leaf cover of floating pondweed (visual assessment) with time after application. Each point is the mean of 3 plots for bensulfuron methyl treatments (100 and 200 g/ha) and the mean of 6 plots for untreated controls (0 g/ha). Bars give the range of duplicate series in untreated controls.

stream counterparts and the adjacent untreated downstream plot seemed to be suppressed. The carryover appeared to be restricted to the most upstream two plots although plot length was only 30 m, and bensulfuron was applied into standing water. There were no similar trends reflecting downstream herbicide movement in the elodea and ribbonweed trials, but these trials were drier and simulated rain had been applied following the herbicide. Freshweight biomass of untreated weed stands is plotted against the cumulative upstream application of herbicide in Figure 2.

Overall, results suggest that there is scope for effective and economical use of bensulfuron methyl in localized spot treatment of ribbonweed and floating pondweed. Control of elodea was only moderate but weed suppression which is sufficient to improve water flow is probably better than eradication in many situations.

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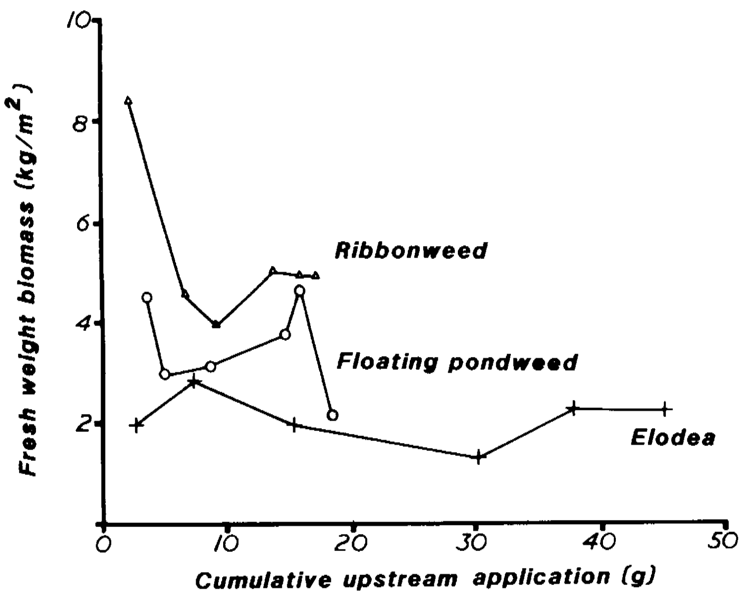

Figure 2. Fresh weight biomass in untreated plots of three weed species in relation to accumulated upstream application of bensulfuron methyl, observed 4-5 months after treatment (for further details see Table 1).

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