Proceedings 1978 British Crop Protection Conference - Weeds

THE EFFECT OF 2450 MHz RADIATION ON THE GERMINATION OF SOME WEED AND CEREAL SEEDS

Dr. M.F. Diprose
Dr. R. Hackam
Professor F.A. Benson

Department of Electronic and Electrical Engineering, The University of Sheffield, Mappin Street, Sheffield, S1 3JD, U.K.

Summary Microwave radiation has been suggested as a suitable energy source for some aspects of agriculture i.e. weed control and the breaking of seed dormancy. After considering the benefits of microwaves, their effects on seed germination are discussed together with the factors that influence the interaction between the seeds and the radiation, the adsorption of energy by the seeds and their consequent increased temperature. Finally some experiments are described which demonstrate the possibility of the reduction of *Avena fatua* seed viability when mixed with cereal seeds, by exposure to 2450 MHz radiation. The measurements of seed temperature resulting from the microwave treatment are presented and discussed, and it is shown that for wheat, values of 153°C can be reached.

Résumé Il a été suggéré que le rayonnement micro-ondes serait une source énergétique qui conviendrait á certains aspects de l'agriculture, c'est-à-dire le contrôle des mauvaises herbes et la provocation de la germination. Après avoir considéré les bien-faits des micro-ondes, on discute leurs effets sur la germination des graines, ainsi que les facteurs qui influencent l'interaction entre les graines et le rayonnement, l'adsorption d'énergie par les graines et la hausse de température qui en suit. Finalement on decrit des expériences qui démontrent la possibilité de réduire la viabilité de la graine d'*avena fatua* melangée a des graines céréaliers, par l'exposition à un rayonnement de 2450 MHz. Les températures de graines (dans le cas du blé une valeur de 153°C) obtenues grâce au traitement par micro-ondes sont presentées et discutées.

INTRODUCTION

Microwave radiation is put to a wide variety of uses including civil and military aviation, telecommunications, industrial processes and food preparation both domestic and commercial and it has become well established as a flexible and powerful energy source. Although a variety of uses have been proposed it has not, however, been widely employed in agriculture (Fanslow and Saul 1971, Bosisio et al 1970, Hightower et al 1974, Borchers et al 1972).

Electromagnetic radiation has several advantages, the chief one being the rapid penetration of non-metallic loads. Travelling near the speed of light the energy is rapidly dissipated throughout the bulk of the irradiated object. This is unlike the normal thermal conduction process where the centre of the object is usually the last place to be heated. The microwave radiation is converted to heat so there is no residue and this is important as pollution issues become more sensitive. It can also be directed at the load, through a variety of applicators and is not affected by winds. If used as a weed control device over open ground, the penetration properties of the radiation ensure that the treatment is to a depth of several centimetres resulting in surface weeds and buried seeds being killed (Wayland et al 1973; Davis, F.S. 1974).

Nelson (Nelson 1965, Nelson et al 1970, 1976; Stone 1973) has made an extensive study of the effect of microwave and other frequency radiation upon seed germination. Hard seed in alfalfa has been reduced by 2450 MHz radiation from 40-60% down to 5-15% (Nelson 1976) and the lower the moisture content of the seeds the more effective the treatment. The most important factor was the final temperature attained, and 75°C, was found to be the optimum; above this the germination decreased again. The effectiveness of the treatment with radiation lasted up to four years.

Kashyap and Lewis used 2450 MHz radiation to increase the germination of white and red spruce tree seeds by 15% to 30% with exposures of 20 to 35s in a 500W cavity. Twelve species of dry seeds and samples imbibed for 4h and 46h were exposed to 600W of 2450 MHz radiation (Davis et al 1971). In general dry seeds were less susceptible than imbibed seeds. When tests were carried out with dry and imbibed seeds planted in both wet and dry sand during the irradiation period, the seed moisture content was found to be more important than the sand-water content. Shafer and Smith report similar effects when dry and imbibed seeds of <u>foxtail millet</u> were exposed to 1kW of 2450 KHz radiation. Reduction of germination to 50% took 30 mins. for dry seed, and 35s and 25s for 4h and 16h imbibed seeds respectively. Whatley et al (1974) found that variations in the frequency of radiation were less important than the seed moisture content, and when the seeds were planted the maximum effect of the radiation occurred whtn the seed moisture was high, and the soil moisture was low.

Measurements of the electrical properties of various seeds (Nelson 1973a, 1973b) have shown the dielectric constant and the dielectric loss factor of the material are important when determining the amount of power absorbed by the seeds from the external electric fields. One of the equations governing this power level is

$P_{abs} = 55.6\ E^2 f\varepsilon''$ (Nelson 1976)

where P_{abs} = Power adsorbed per unit volume ($W.m^{-3}$)
55.6 = A numerical constant depending upon the seed
E = Electric field inside load (Vm^{-1})
f = Frequency of radiation (Hz)
ε'' = Loss factor of the seed

Both the numerical constant and the electric field inside the load depend upon the electrical properties of the load, the shape of the seeds and the strength of the electric field outside the load. Thus, the relationship between the energy dissipated in the seed and the microwave radiation is complex.

Davis et al (1973) report that the susceptibilities of 15 seed spcies treated in a microwave oven were correlated with mass per seed, volume per seed and ther soluble content as well as the previously mentioned moisture contents.

With such a large number of variables determining the extent of reaction of a seed to 2450 MHz signals, different seed species will react differently in a common electrical environment, and the possibility of selective treatment of one species when mixed with others arises. Bhartia et al (1977) found that a sample of <u>Avena fatua</u> seeds had their germination rate reduced from 50% to 10% whilst torch rape seed was unaffected by a similar exposure (360s) to microwaves at 2450 MHz. This led the authors to investigate the possibilities of selectively killing <u>Avena fatua</u> seeds, when mixed with cereal seeds, and the work completed to date is reported here.

METHODS AND MATERIALS

The seed samples were placed in open 6cm petri dishes at the centre of a stainless steel microwave oven cavity measuring 46cm x 30cm x 34.5cm (length x height x depth). The microwave power was supplied by a magnetron at a frequency of 2450 MHz ± 30 MHz. Due to the complex energy distributions that arise in rectangular cavities, a rotating fan blade was used as a mode stirrer to regularise the electric and magnetic fields. Power density measurements were determined by measuring the initial rate of rise of temperature of a 40ml water load in an open 6cm petri dish in the centre of the oven.

Fifty seeds of each species (wheat, oats, Avena fatua and Chrysanthemum segetum) were placed in petri dishes and exposed to 1kW 2450 MHz radiation ($11 Jcm^{-3}s^{-1}$ in a 40ml water load) for varying time periods - each successive period being increased by 10s. After exposure each group of seeds was planted in a tray of Levington compost and kept in the greenhouses at the University's Experimental Botanical Gardens. Germination was determined by counting the number of seedlings that had emerged after 14 days.

Seed temperature measurements were made by using standard calorimetry methods. A known weight of seeds was irradiated and then quickly transferred to a copper calorimeter containing water - both of known weight. By measuring the temperature changes of the water with a thermocouple an assessment was made of the seed temperature. The specific heat of the seeds was found by heating them to a known temperature in a 50 Hz power oven and then using the same calorimetric technique described. The temperatures of barley, oats, wheat and Avena fatua were found for exposures of 90s and 210s to 1kW of 2450 MHz radiation and, in addition, the temperatures of wheat and Avena fatua were measured for exposures of 30, 45 and 60s.

RESULTS

The results of exposing seeds to 1kW of 2450 MHz radiation are shown in Figure 1. A dip in the germination of Avena fatua for moderate exposures can be seen at 20s and is a reduction from 58% to 26% whilst wheat and oat seeds show high germination rates after this time. Subsequently the germination of wheat decreases rapidly after 50s whilst that of oat seeds still shows at 50% after treatments in the order of 150s. Chrysanthemum segetum shows a varied response to microwaves with a broad band of increased (compared to 0s) germination centred around 130s.

Table 1 gives the specific heats of four seed species and also the temperatures to which they are raised by the 2450 MHz radiation. Barley and Oats only have two temperature values given, and these are both high - in excess of 100°C for both treatment times. The temperatures obtained from the wheat and Avena fatua measurements are shown with a maximum temperature of 153°C for the wheat, but Avena fatua are cooler than the other cereal seeds. The temperatures rise fairly rapidly to approximately 100°C, and then the rate of rise slows down. This is due to the incoming energy not only being adsorbed by the seed material but also by the seed moisture. Measurements in seeds before and after irradiation, showed that wheat exposed for 210s loses 69.2% of its moisture whilst Avena fatua lose 40% in the same period. The evaporating water after the seeds reach 100°C needs extra energy - the latent heat of vapourisation.

The influence of moisture content on seed temperature for various exposure times is shown in Figure 2 for wheat and Avena fatua. For both of the species, as the moisture content rises, so do the temperatures attained, but the higher moisture content values (40% for wheat and 56% for Avena fatua) result in lower temperatures. This is reasonable as the electrical properties of seeds first rise and then fall with increasing moisture content as Nelson has shown for maize (Nelson 1978) and this would lead to a rise and fall of the power dissipated in the seeds.

Table 1

The seed temperatures attained and moisture losses for various irradiation periods of 1kW 2450 MHz and the seed specific heat values

	Exposure Time (s)	Barley	Oats	Wheat	Avena fatua
Seed Temperatures ^{o}C	0	-	-	18	18
	30	-	-	67	51
	45	-	-	86	52
	60	-	-	116	68
	90	120	116	137	65
	210	142	120	153	87
Moisture losses during irradiation (%)	120	23	31	39	28
	240	48	51	69	41
Specific Heat $Jkg^{-1}{}^{o}C^{-1}$		1138	882	1125	1085

DISCUSSION

The initial experiments have shown that the possibility exists of selectively controlling wild oats when mixed with cereal seeds. The germination of Avena fatua seeds was reduced by half of the control value by irradiating with 1kW of 2450 MHz energy in a microwave oven for 20s whilst wheat and oat seeds remain almost unaffected.

The effects on the seeds are most likely to be thermal - especially in view of the high temperatures to which the seeds were raised by the microwaves e.g. 153^{o}C for wheat (at 12% moisture content) exposed to 1kW of 2450 MHz for 210s, and that temperatures of 100^{o}C were reached by the same seeds in under 60s. Reports have been made of non-thermal effects of microwaves in biological tissue (Bigu-Del-Blanco et al 1977), but these are at very low power levels - just a few $mW.cm^{-2}$ and the authors believe that the high powers for short periods used in these experiments will completely mask any subtle effects. Further confirmatory evidence comes from an experiment of the authors in which wheat seeds were irradiated for 180s, and a separate sample was exposed to the same power levels for six periods of 30s with an hour between each process. In the former the germination was very low, just 6% but the latter treatment resulted in 92% growth. It is believed that this is due to the fact that the multi exposed seeds had time to cool down between each treatment. Had any non-thermal effects been present, it is believed they would have been cumulative and the germination correspondingly lower than measured.

The experiments are to be repeated, with refined germination techniques, to make the latter compatible with those practised by the Official Seed Testing Stations, but the authors do not believe that the results will be substantially different.

Microwave radiation has been applied to a variety of problems in agriculture, but for several reasons it appears that not many of the systems seem to go into practice. Nelson (1976) believes that, even when a method can be shown to be more efficient and cost comparable, i.e. the reduction of hard seed in alfalfa, the farming community find the idea of a brand new technology is difficult to accept, especially investing in completely new types of equipment when market prices are so variable.

The more uses that are found, however, the more likely it will be that the equipment will be used. This will be especially true, if several uses can be found for one machine, i.e. the same microwave generator with a selection of adaptors could perhaps be used by greenhouse operatives to partially sterilise soil, keep frost off delicate plants at another time, and treat insect pests in seeds (and prepare hot lunches in winter!).

In conclusion, diverse applications of microwaves in agriculture have been suggested, including the possibilities of selective treatment of Avena fatua in cereal seeds. Further work needs to be done on this and the other related topics, before microwaves will take place in agriculture and the full benefits of this exciting new technology are obtained.

Acknowledgements

The authors would like to acknowledge the help and advice and access to facilities given by Dr. K. Holly of the Weed Research Organisation, Oxford and the assistance and guidance given by Dr. A. Booth and Professor A.J. Willis of the Department of Botany, The University of Sheffield. We should also like to thank the Agricultural Research Council for their grant to support the work.

References

BHARTIA, P., LEBELL, M. BARON, J. (1977) Weed control with electromagnetic fields, Journal of Microwave Power, 12(1), 52-54.

BIGU-DEL-BLANCO, J., BRISTOW, J.M., ROMERA-SIERRA, C. (1977) Effects of low level microwave radiation on germination and growth rate in corn seeds, Proceedings of the I.E.E.E., 65(7), 1086-1088.

BORCHERS, R., MANAGE, L.D., NELSON, S.O., STETSON, L.E. (1972) Rapid improvement in nutritional quality of soybeans by dielectric heating, Journal of Food Science, 37, 333-334.

BOSISIO, R.G., BARTHAKUR, N., SPOONER, J. (1970) Microwave protection of a field crop against cold, Journal of Microwave Power, 5(1), 47-52.

DAVIS, F.S. (1974) New techniques in weed control via microwaves, Presented to Southern Nurseryman's Association, July 17, Nacogdoches, Texas, pp.5.

DAVIS, F.S., WAYLAND, J.R., MERKLE, M.G. (1971) Ultra high frequency electromagnetic fields for weed control : Phytotoxicity and selectivity, Science, 173, 535-537.

DAVIS, F.S., WAYLAND, J.R., MERKLE, M.G. (1973) Phytotoxicity of a U.H.F. electromagnetic field, Nature, 241, 291-292.

FANSLOW, G.E., SAUL, R.A. (1971) Drying field corn with microwave power and unheated air, Journal of Microwave Power, 6(3), 229-235.

HIGHTOWER, N.C., BURDETTE, E.C., BURNS, C.P. (1974) Investigation of the use of microwave energy for weed seed and wood product insect control, Final Technical Report Project E-230-901 June, Georgia Institute of Technology (Atlanta, U.S.A.), pp.60.

KASHYAP, S.C., LEWIS, J.E. (1974) Microwave processing of tree seeds, Journal of Microwave Power, 9(2), 99-107.

NELSON, S.O. (1965) Electromagnetic radiation effects on seeds, Reprinted from Electromagnetic radiation in agriculture. Proceedings Joint Conference of the Illuminating Engineering Society New York and the American Society of Agricultural Engineers. October 1965, Roanoke, Virginia, p.60-63.

NELSON, S.O. (1973a) Microwave dielectric properties of grain and seed, Transactions of the American Society of Agricultural Engineers, 16, 902-905.

NELSON, S.O. (1973b) Electrical properties of agricultural products - a critical review, Transactions of the American Society of Agricultural Engineers, 16(2), 384-400.

NELSON, S.O. (1976) Use of microwave and lower frequency R.F. energy for improving alfalfa seed germination, Journal of Microwave Power, 11(3), 271-277.

*
NELSON, S.O. NUTILE, G.E., STETSON, L.E. (1970) Effects of radio frequency electrical treatment on germination of vegetable seeds, Journal of the American Society for Horticultural Science, 95(3), 359-366.

NELSON, S.O., BALLARD, L.A.T., STETSON, L.E., BUCHWALD, T. (1976) Increasing legume seed germination by V.H.F. and microwave dielectric heating, Transactions of the American Society of Agrigultural Engineers, 19(2), 369-371.

SHAFER, F., SMITH, D. (1974) Influence of internal and external moisture levels on toxicity of microwaves to seedlings, Abstract No.224, Meeting Weed Science Society of America, N. Texas State University, Denton, U.S.A., p.97.

STONE, R.B., CHRISTIANSEN, M.N., NELSON, S.O., WEBB, J.C., GOODENOUGH, J.L., STETSON, L.E. (1973) Induction of germination of impermeable cotton seed by electrical treatment, Crop Science, 13, 159-161.

WAYLAND, J.R., DAVIS, F.S., MERKLE, M.G. (1973) Toxicity of a U.H.F. device to plant seeds in soil, Weed Science, 21(3), 161-162.

WHATLEY, T.L., WAYLAND, J.R. MERKLE, M.G. (1974) Factors affecting the phytotoxicity of a microwave field, Abstract, Proceedings Southern Weed Science Society, 27, p.344.

*NELSON, S.O. (1978) R.F. and microwave dielectric properties of shelled field corn, Proceedings Microwave Power Symposium, June 28-30, Ottawa, Canada, pp.41-43.

Figure 1

The germination of cereal and weed seeds after varying exposures to 1kW 2450MHz radiation.
The seeds were planted in Levington compost.

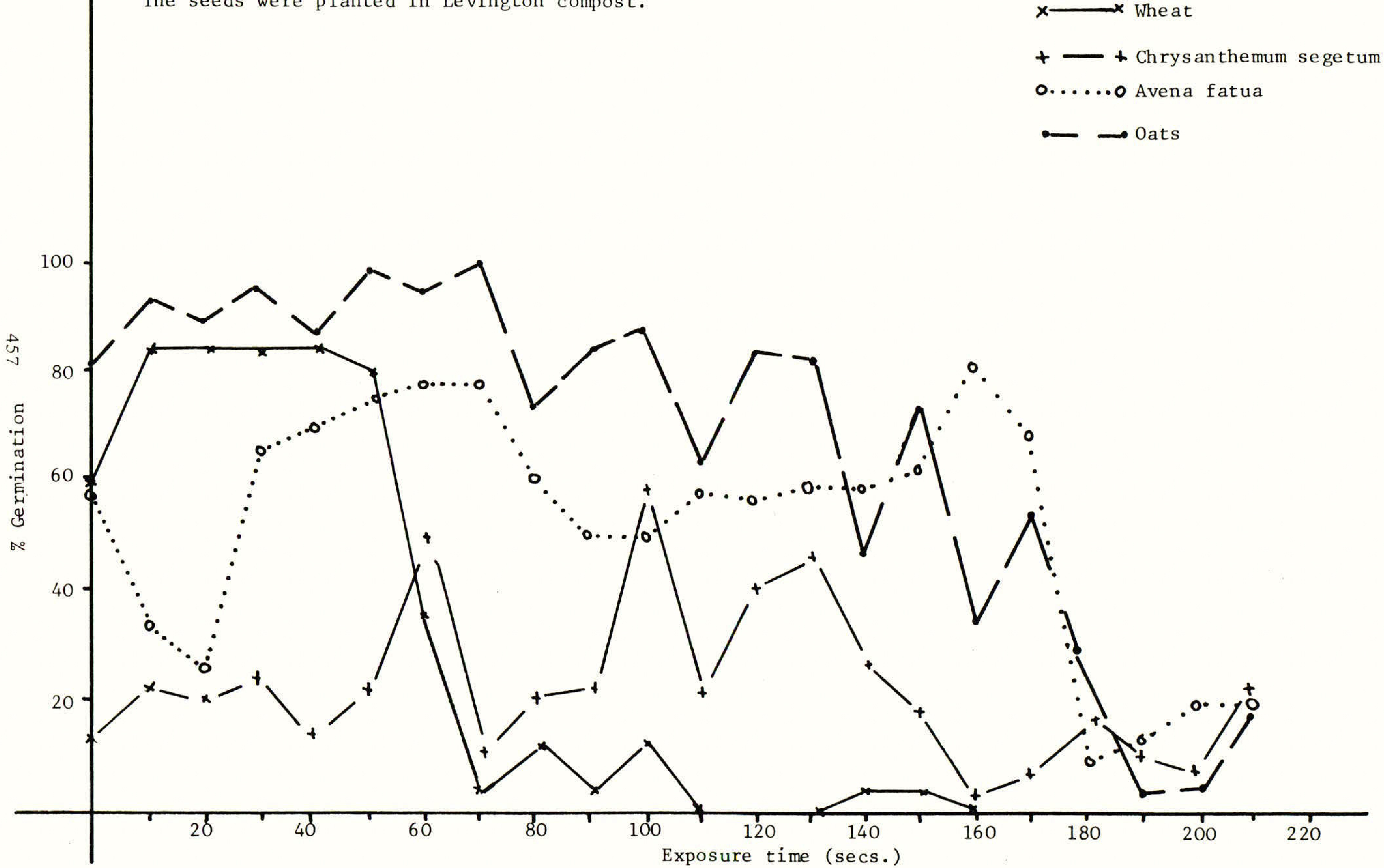
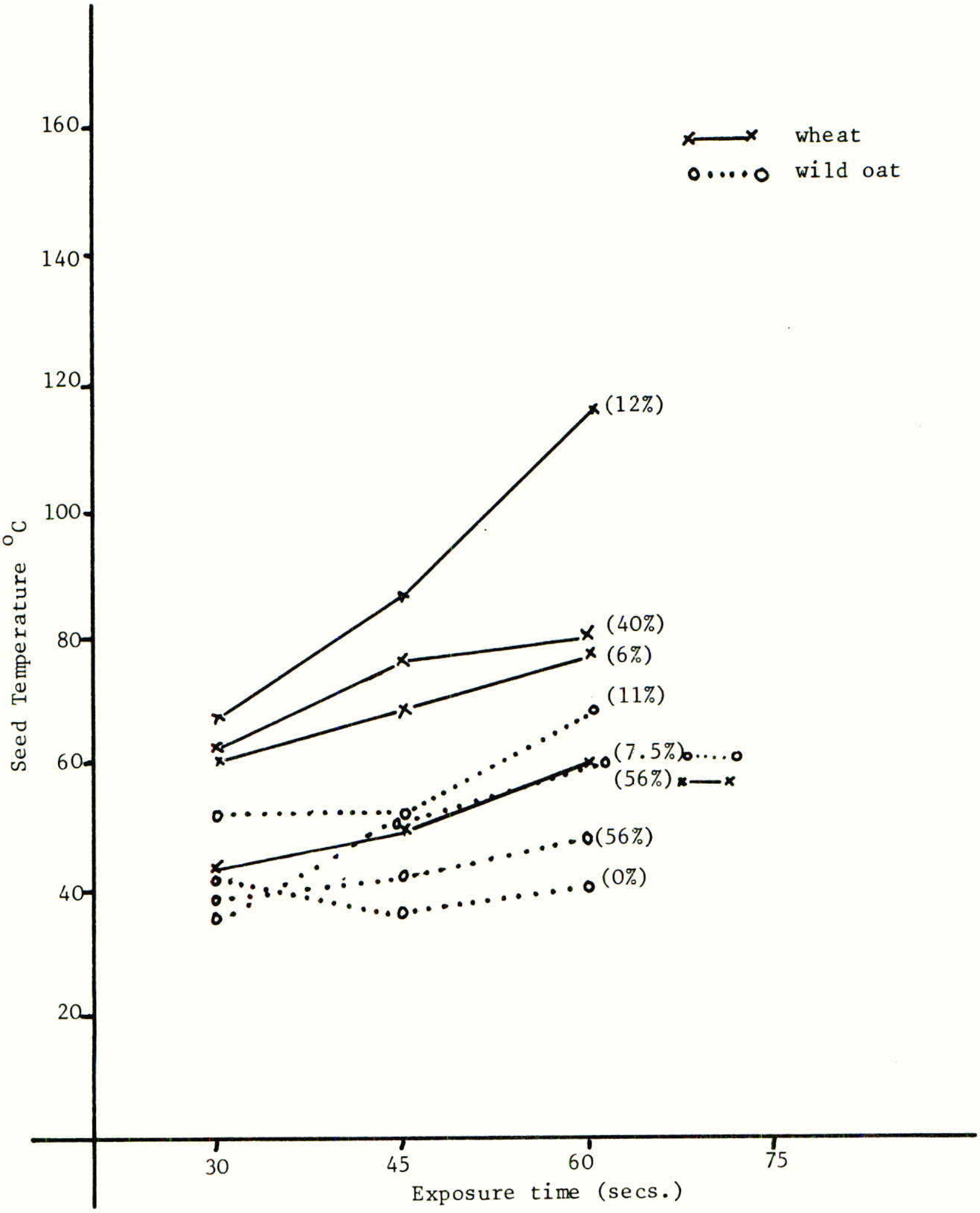


Figure 2

The variations in the seed temperatures that are attained, when irradiated with 1kW 2450MHz radiation for various time periods and seed moisture contents.



Figures in brackets ( ) denote the moisture contents of the seeds.

THE INFLUENCE OF DOSE AND INCORPORATION ON THE ACTIVITY AND PERSISTENCE OF METHAM-SODIUM

John G. Davison

ARC Weed Research Organization, Begbroke Hill, Yarnton, Oxford OX5 1PF

Summary Metham-sodium at 125 and 250 kg/ha was applied in May, July and October as a pre-planting treatment for the control of annual weeds. It was incorporated within a minute either by rotary cultivation or irrigation.

All treatments significantly reduced the number of weeds, the main effect being on those germinating shortly after treatment. Survivors developed normally. Matricaria recutita was exceptional in being controlled without incorporation.

Irrigation was the most effective method of incorporation. Delaying incorporation for up to 16 minutes did not affect the control of other weeds.

Metham-sodium reduced the weight of lettuce transplanted 4 and 8 days after treatment in May. There was also a reduction in the emergence of drilled crops. There was no effect on lettuce planted or drilled after the July application or on cress and lettuce bio-assays 4 and 7 days after the October application.

INTRODUCTION

Metham-sodium has been used for many years at 400 kg/ha to control soil-borne pests and diseases in high value crops, usually under glass. It also controls weeds, but this is seldom the main reason for treatment (Fryer and Makepeace, 1972). More recently 125 kg/ha has given promising control of annual weeds in outdoor crops of block-raised lettuce when incorporated by irrigation shortly before planting (Nuyten, 1975). The experiments in this report were designed to investigate some of the factors that might affect its performance, in the hope that it could be used on other high value crops.

METHOD AND MATERIALS

Three pairs of experiments were started, on 6 May, 4 July and 4 October, 1977. On each date metham-sodium was applied at 125 and 250 kg/ha in 1000 and 2000 l/ha respectively using a 51% a.i. commercial product (Vondmetam Nematocide). Application was with a knapsack sprayer fitted with Spraying Systems Tee-Jet 8010 flat fan tips operating at a pressure of 2 bars with carbon dioxide as propellant. Individual plots of 3 x 2 m were randomised in blocks. There were two replicates in May and four in July and October. The metham-sodium was incorporated within one minute, either with a rotary cultivator working at a depth of 5 or 10 cm, or by irrigation with 0.5 cm of water applied from a watering can. In a companion experiment metham-sodium was applied at 125 kg/ha and incorporated at intervals up to 4 hours, either with a rotary cultivator working at a depth of 5 cm (May and July) or with 0.5 cm of water (October).

Table 1

Soil moisture and temperature at treatment

Experiment	Moisture % 0-5 cm	Temperature °C 0.5 cm	Temperature °C 5 cm
May	16	11.5	10.5
July	7	30.0	26.0
October	9	13.4	13.9

Weeds were assessed at intervals either by counting or scoring for percentage ground cover. Lettuce was planted and sown as a test crop 4 and 8 days after treatment (DAT) in May and July. Plants (var Reskia in May and Bellona in July) with 5-6 leaves, growing in 4 x 4 x 4 cm peat blocks, were spaced 20 cm apart in rows 30 cm apart. Seed (var Avondefiance) was drilled in the same plots. Transplants were scored for size (on a 0-10 linear scale with 10 = maximum size) and weighed at harvest. Seedlings were counted, scored for size and singled to approximately 20 cm apart (in rows 30 cm apart) and weighed at harvest.

In the October experiment soil samples were taken from the 0-5 and 5-10 cm layers 4 DAT and bio-assayed with cress. Fifty seeds were sown in beakers containing 100 g moist soil and kept at 20°C in a glasshouse. The tops of the beakers were covered with grease-proof paper to prevent drying out. Lettuce seeds were sown 7 DAT in 7 cm pots 3/4 full of freshly sampled soil from the 0-5 and 5-10 cm layers. These were also placed in a glasshouse at 20°C. The tops were covered with aluminium foil until the seedlings emerged. The number of seedlings of each crop was counted.

Soil moisture at the start of each experiment and soil temperature at the time of application is given in Table 1. In the May experiments each transplant was given 0.3 l water on May 22 and 24 and there was an overall irrigation of 1 cm on 31 May, 1.25 cm on 12 July and 1.5 on 13 July. The July experiments received an overall irrigation of 1.5 cm on 8 July (after planting), 1.25 cm on 12 July (after planting) and 1.5 cm on 13 July.

Where there was no interaction between dose and method of incorporation only the main treatment effects are presented.

RESULTS

Weeds

May application. Weeds were assessed on 16 June and 12 July (6 and 10 weeks after treatment [WAT]). Table 2 shows there were significantly fewer weeds with both doses of metham-sodium on 16 June (6 WAT) but by 12 July (10 WAT) there was an appreciable germination of *Matricaria recutita* on the treated plots and a slight increase in the number of other weeds which included *Aethusa cynapium*, *Anagallis arvensis*, *Poa annua* and *Stellaria media*. The results for 12 July in Table 2 also show that there were fewer weeds where incorporation was by irrigation.

The visual effects were more striking than the counts. On 16 June (6 WAT) there was less than 1% weed cover on all the metham-sodium treated plots whereas there was 10-30% cover on the untreated plots. By 12 July (10 WAT) there was 20% cover on the rotary cultivated plots but only 8% on the irrigated treated plots (sig at P=0.05).

Table 2

Effect of dose and method of incorporating metham-sodium on weed control

assessed	dose (kg/ha) 0	125	250	S.E. ±	LSDø	incorporation: rotary cultivation 5cm	10cm	irrigation 0.5cm	S.E. ±	LSDø
MAY APPLICATION										
	Matricaria recutita - no./m^2									
16 June (6 WAT)	91.2	0.0	0.4	11.00	36.0	30.6	16.7	44.1	11.00	NS
12 July (10 WAT)*	-	37.6	56.9	8.23	NS	51.0	67.1	23.7	10.00	NS
	Polygonum aviculare - no./m^2									
16 June (6 WAT)	84.8	13.0	2.8	8.13	26.5	38.9	35.2	26.5	8.13	NS
12 July (10 WAT)*	-	13.4	7.4	2.50	NS	16.3	9.3	5.6	15.06	NS
	Other annuals - no./m^2									
16 June (6 WAT)	35.8	2.8	0.4	2.17	7.1	15.8	14.5	8.7	2.17	NS
12 July (10 WAT)*	-	8.0	1.9	0.54	2.1	6.5	5.6	2.8	0.69	2.5
JULY APPLICATION										
	All annuals - ground cover (%)									
7 Sept (9 WAT)	10.6	8.3	7.4	0.88	2.6	11.3	7.8	7.3	0.88	2.6
	All annuals - no./m^2									
23 Nov (20 WAT)	50.2	35.2	31.8	3.80	11.1	43.0	40.9	33.3	3.80	NS

ø LSD = Least significant difference (P=0.05)   *excluding nil dose, these plots had been hoed

Table 3

Effect of interval between applying and incorporating metham sodium in May on weed control

Number of weeds/m^2 on 16 June (6 WAT)

Interval between application and incorporation (minutes)

Species	Untreated	Not incorporated	240	16	4	1	S.E. ±	LSD P=0.05
Matricaria recutita	36.1	6.5	7.4	1.0	0.0	0.0	2.10	8.2
Polygonum aviculare	109.3	155.6	102.8	7.4	5.6	19.5	43.53	NS
Other annuals	47.3	20.4	13.0	3.7	5.6	2.8	9.06	NS

LSD = least significant difference
NS = not significant

The results in Table 3 show that on 16 June (6 WAT) there were fewer weeds where incorporation was within 16 minutes of spraying. The only significant difference was with *M. recutita* which was reduced without incorporation.

Table 4

Effect of dose and method of incorporating metham-sodium applied in October on weed control

number of seedlings/m^2 on 30 November (8 WAT)

method of incorporation

		rotary cultivation 5 cm	rotary cultivation 10 cm	irrigation 0.5cm	mean
dose (kg/ha)	0	176.5	175.3	172.4	174.7
	125	92.6	97.1	53.2	81.0
	250	61.8	55.9	19.1	45.7
		S.E. ± 12.6 (LSD=36.7 at P=0.05)			S.E. ± 7.3 (LSD=21.2 at P=0.05)
	mean	110.3	109.5	81.6	
		S.E. ± 7.3 (LSD=21.2 at P=0.05)			

July application. Very few weeds germinated in the first few weeks of the experiment and even the untreated plots were virtually weed free when the transplants were harvested on 16 August (6 WAT). The results in Table 2 show that by 7 September (9 WAT) there was significantly less weed cover with the high dose of metham-sodium and the 5 cm rotary cultivation was the least effective method of incorporation. Shortly afterwards all weeds were killed with paraquat. Counts in November showed both doses of metham-sodium had fewer weeds than the untreated. Varying the interval between spraying and incorporation from 15 seconds to 64 minutes did not affect the level of control.

October application. Table 4 shows that all metham-sodium treatments significantly reduced the number of seedlings on 30 November (8 WAT). The high dose was more effective than the low dose and incorporation by irrigation was more effective than rotary cultivation. As in the May experiment the visual effect was more striking because most weeds on the treated plots were smaller, the early germinating ones having been controlled. There were no differences in susceptibility between the species which included Aethusa cynapium, Aphanes arvensis, Fumaria officinalis, Papaver rhoeas, Poa annua, Stellaria media and Veronica persica. The initial flush of weeds was killed with paraquat but in the following March there was significantly less weed cover with both doses of metham-sodium (13 and 16%) than on the untreated plots (34%).

Delaying incorporation from 15 seconds to 64 minutes after application made no difference to the level of weed control. With all treatments there were 20-30 weeds /m^2 on 30 November (8 WAT) compared with 200/m^2 on untreated plots (Sig at P=0.05).

Crop

May application. Metham-sodium reduced the size of lettuce planted 4 DAT. On 16 June (6 WAT) the scores for 0, 125 and 250 kg/ha were 8.7, 4.3 and 2.7 respectively (S.E. ± 0.39: LSD - P=0.05 = 2.3) but the method of incorporation had not affected size. The weight of heads at harvest on 23 June (7 WAT) is shown in Table 5. There was a clear response to dose but the influence of method of

Table 5

Effect of dose and method of incorporating metham sodium in May on the fresh weight of lettuce planted 4 and 8 days after treatment

weight of heads in g.

		method of incorporation			
		rotary cultivation		irrigation	
		5 cm	10 cm	0.5cm	mean
dose (kg/ha)	0	215	205	155	192
	125	138	124	130	131
	250	69	95	56	73
		S.E. ± 9.1 (LSD=27 at P=0.05)			S.E. ± 5.2 (LSD=16 at P=0.05)
	mean	140	141	114	
		S.E. ± 5.2 (LSD=16 at P=0.05)			

incorporation is confused by the anomalous value for the irrigated control.

The results in Table 6 show that metham-sodium reduced the size and number of lettuce seedlings, the number of plants after singling and head weight at harvest. The high dose was more damaging than the low dose, the latter being safe 8 DAT. There were fewer differences due to method of incorporation.

The sooner the metham-sodium was incorporated the more damage it caused to the lettuce. When the interval between spraying and incorporating was 1, 4 and 16 minutes the weight of lettuce planted 4 DAT was reduced by 65, 50 and 20% respectively. There was also a 40% reduction with the 8 DAT planting when incorporation was 1 minute after spraying.

The results in Table 7 show that the effect on the drilled crop was mainly on the number of seedlings emerging and this affected the number of plants after singling.

July application. Lettuce planted and sown 4 and 8 DAT was not affected in appearance or weight by any of the treatments.

October application. None of the treatments affected either the emergence or development of the cress or lettuce grown in soil samples in the glasshouse.

DISCUSSION

There are many high value crops in which the current cost of metham-sodium at 125 kg/ha (£125) could be justified if it gave adequate weed control. Lower levels of weed control might be acceptable if accompanied by a reduction in soil-borne pests and diseases. The results presented show the levels of weed control achieved on three occasions and, on two of them, the effect on a following lettuce crop. The treatments were chosen to cover some of the variation that might occur in commercial usage. For instance, it is easier to achieve uniform incorporation with a rotary

Table 6

Effect of dose and method of incorporating metham-sodium in May on drilled lettuce

drilling date	Dose (kg/ha) 0	125	250	S.E. ±	LSD ∅	incorporation: rotary cultivation 5cm	10cm	irrigation 0.5cm	S.E. ±	LSD ∅
Size of seedlings on 16 June (6 WAT) (scored 0-10)										
4 DAT	10.0	5.5	2.0	0.75	4.6	5.0	5.8	6.7	0.75	NS
8 DAT	6.3	6.0	4.2	0.25	1.6	5.3	5.8	5.3	0.25	NS
Number of seedlings/m on 20 June (7 WAT)										
4 DAT	37.2	10.3	1.8	3.4	11.1	21.9	12.4	14.9	3.4	NS
8 DAT	24.3	21.0	8.9	2.1	6.8	22.3	19.3	12.7	2.1	6.8
Number of plants/m after singling on 20 June (7 WAT)										
4 DAT	5.0	2.8	1.6	0.62	1.5	3.3	3.1	3.1	0.62	NS
8 DAT	4.9	4.9	3.3	0.34	1.1	4.4	4.9	3.7	0.34	NS
Weight of heads (g) at harvest on 21 July (11 WAT)										
4 DAT	243	223	161	16.9	55	215	167	246	16.9	55
8 DAT	199	235	240	27.6	NS	195	228	252	27.6	NS

∅ LSD = Least significant difference (P=0.05)

Table 7

Effect of interval between applying and incorporating metham-sodium at 125 kg/ha in May on drilled lettuce

drilling date	untreated	not incorporated	interval - in minutes 240	16	4	1	S.E. ±	LSD (P=0.05)
Size of seedlings on 16 June (6 WAT) (scored 0-10)								
4 DAT	10	10	7.5	9	2.5	4	0.95	3.4
8 DAT	6	6	5.5	6	4	4	0.67	NS
Number of seedlings/m on 20 June (7 WAT								
4 DAT	23.4	27.0	23.1	10.9	4.2	3.9	3.08	11.2
8 DAT	14.7	18.4	27.0	15.6	7.3	5.0	13.46	NS
Number of plants/m after singling on 20 June (7 WAT)								
4 DAT	5.6	5.6	4.5	2.8	2.5	2.3	0.49	1.8
8 DAT	4.8	5.0	4.5	5.0	3.9	2.8	0.32	NS
Weight of heads (g) at harvest on 21 July (11 WAT)								
4 DAT	246	256	226	244	160	228	39.7	NS
8 DAT	252	273	289	288	290	276	34.1	NS

cultivator than with irrigation but some variation in the depth of cultivation is likely, and unless the metham-sodium sprayer is mounted on the cultivator there will be some delay in incorporation. It would be difficult to apply irrigation uniformly but this was not investigated.

The effect of metham-sodium on weed control was more impressive visually than numerically - and this is how growers assess weed control. For instance, they would be more impressed by some of the earlier results that were not statistically significant than the later ones that were. The better visual effect was due to the metham-sodium being most effective against the early germinating weeds which are also the most competitive. Those that germinated grew normally. The long term reduction in weed emergence from a single application is unlikely to be of practical significance.

Incorporation was less important than dose in determining the level of weed control. Although the best results were obtained with irrigation it is impracticable to apply small amounts of water uniformly and rapidly over large areas. It is feasible to rotary cultivate to a depth of 5-10 cm and incorporate within 16 minutes of spraying. The good control of M. recutita without incorporation could be useful in lettuce as this is one of the weeds not controlled by the current treatments.

The May experiments confirm that metham-sodium at 125 kg/ha can give adequate weed control but both seeded and transplanted lettuce suffered. Although the transplants were lighter at harvest they looked normal and would probably have hearted eventually. This would normally reduce their commercial value and interfere with production schedules, but if reproduceable it could be exploited to reduce the number of plantings needed for a continuous supply of marketable heads.

The reduction in weight of the untreated irrigated plants in May is unexpected and difficult to explain. It might be because the soil was more consolidated since these plots were not rotovated to incorporate the chemical and it was noted that planting (which was done by hand) was more difficult. If this is the reason it might also account for the smaller weight from the treated plots and perhaps the better weed control too although there was no reduction in the growth of the drilled crop.

Drilled lettuce was affected mainly by a reduction in the numbers germinating, which in turn led to a reduction in the number maturing. This could be overcome by increasing the seed rate although under less favourable conditions the survivors might not recover as well as in these experiments.

These experiments confirm the potential usefulness of metham-sodium as a non-selective pre-planting treatment. However, more information is still needed on the factors determining weed control and the disappearance of phytotoxic residues from the soil, particularly soil moisture before and after treatment.

Acknowledgements

I am grateful to Bos Chemicals Limited who supplied the Vondmetam Nematocide and Mr J Barker of Taplow who supplied the lettuce plants and my WRO colleagues for assistance with the experiments and analyses

References

FRYER, J.D. and MAKEPEACE, R.J. (Eds.) (1972) Weed Control Handbook, Vol II, 7th Ed., Blackwell Scientific Publications, Oxford.

NUYTEN, H. (1975) Vapam als onkruidbestrijder in vollegrondssla. Groenten en Fruit, 31, (17), 747.

NOTES

Proceedings 1978 British Crop Protection Conference - Weeds

A THEORETICAL APPROACH TO THE PREDICTION OF WEED POPULATION SIZES

A.M. Mortimer, P.D. Putwain and D.J. McMahon

Department of Botany, University of Liverpool, P.O. Box 147, Liverpool L69 3BX

Summary The Leslie matrix model is introduced and explained as a mathematical tool for simulating the growth of weed populations. An illustrative simulation of a Poa annua population is given. The use of the model as an unconventional approach to weed control is exemplified through considerations of weed control practices for Avena fatua.

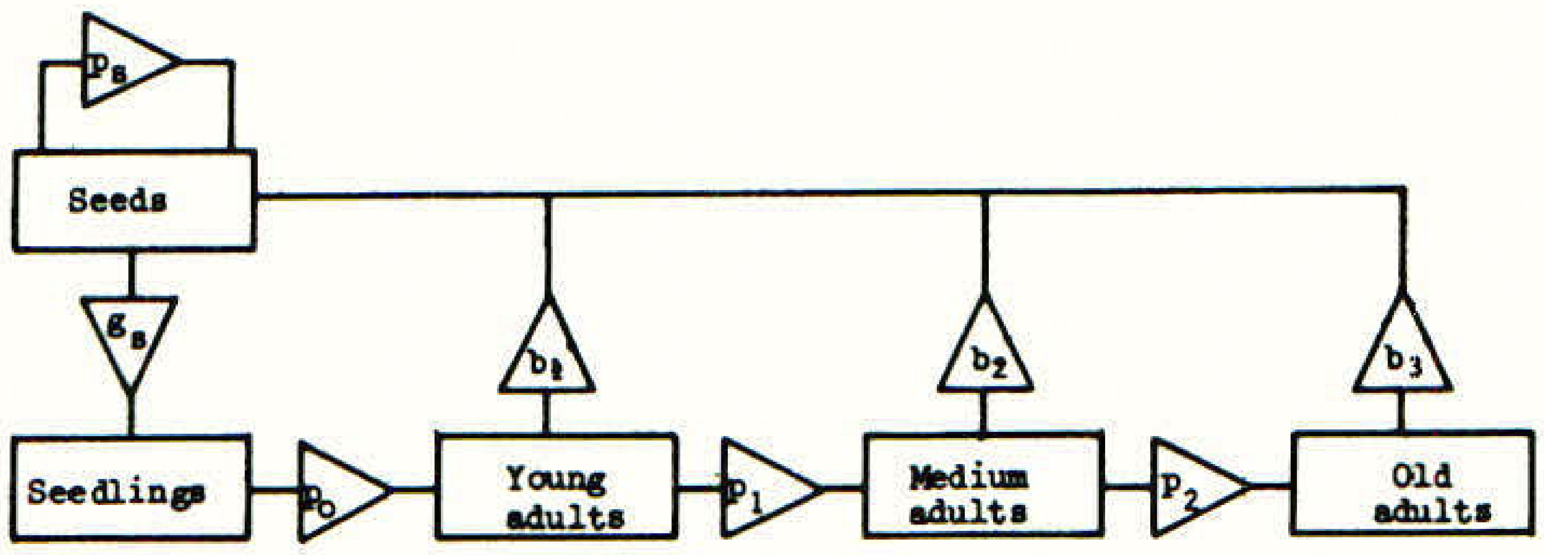
INTRODUCTION

The long term success of any weed control program depends to a large degree on an understanding of the mechanisms that regulate the size of the weed population in the crop environment. At one level this may be seen in terms of effective seed cleaning procedures which minimise the immigration of weedy species into a sown crop and at another in terms of the correct dosage and timing of application of herbicides. Deliberately these processes attempt to minimise the number of undesirable injurious competitors in a crop that may be deleterious to the ultimate crop yield. Even in the face of effective selective herbicides and rigorous management practices, particular species persist as obnoxious weeds for example Avena fatua L. and Agropyron repens. In such instances successful control may only be achieved ultimately through the comprehension of the whole life cycle of the species and its population dynamics (Fryer, 1975; Sagar & Mortimer, 1976). In this paper a simple mathematical model is introduced to describe the changes in numbers in weed populations and to predict some consequences of weed control practices.

THE MODEL

Weed populations may be subdivided into active and dormant fractions, namely photosynthesising plants and seeds. The individuals of each of these fractions are generally unequally aged, this being visually apparent in the active fraction where seedlings, juveniles, mature and old plants are conspicuous. In weed populations with the passage of time there is a continual flux of individuals from one group or age class to the next. This flux may be measured in terms of transition probabilities, (Mortimer, 1976) describing the survivorship of individuals during defined time periods. These data together with fecundity estimates of each age class, comprise life histories which may well be unique to a species. A generalised life cycle illustrating this approach is presented in Figure 1. The translation of the components of the life cycle in Figure 1 into a mathematical formulation which models the life cycle in entirety may be achieved by the use of a matrix model originally developed by Leslie (1945). This model has been used extensively by animal ecologists but rarely for plants (Sarukhan & Gadgil, 1974) even though its behaviour and properties have been fully explored (Usher, 1972; 1975). The basis of the model is a set of recurrence equations which describe the dynamics of individuals from age-class to age-class according to their respective transition probabilities. The conventional presentation of the complete model is in matrix notation which has a certain simplicity for biologists whose interests are primarily in its potential use rather than its workings. The numbers of individuals in each age-class are presented

Fig. 1. An idealised life cycle for an annual plant species (after Law, 1975).



p_s = proportion of seeds surviving from time t to t + 1.

g_s = " " " germinating " " " " "

p_o = " " seedlings surviving to become young adults from time t to t + 1.

p_1 = " " young adults " " " medium " " " " " "

p_2 = " " medium " " " " old " " " " " "

b_1 = number of seeds per plant produced by young adults from time t to t + 1.

b_2 = " " " " " " " medium " " " " " "

b_3 = " " " " " " " old " " " " " "

p_s, g_s, p_o, p_1, p_2 are all transition probability estimates in the range 0 - 1

b_1, b_2, b_3 are fecundities equal to or greater than 0.

Fig. 2. A matrix model of the life cycle outlined in Figure 1.

Transition Matrix:

$$\begin{bmatrix} p_s & 0 & b_1 & b_2 & b_3 \\ g_s & 0 & 0 & 0 & 0 \\ 0 & p_o & 0 & 0 & 0 \\ 0 & 0 & p_1 & 0 & 0 \\ 0 & 0 & 0 & p_2 & 0 \end{bmatrix} = A$$

where the elements of the matrix are as defined in Figure 1.

Column Vector of Age classes:

$$\begin{bmatrix} {}_t n_s \\ {}_t n_1 \\ {}_t n_2 \\ {}_t n_3 \\ {}_t n_4 \end{bmatrix} = {}_t N$$

where ${}_t n_s$ = no. of seeds at time t

${}_t n_1$ = " " seedlings at time t

${}_t n_2$ = " " young adults at time t

${}_t n_3$ = " " mature " " " "

${}_t n_4$ = " " old " " " "

The number of individuals at time t + 1 is computed by the equation,

$$A \cdot {}_t N = {}_{t+1} N$$

as an array of numbers, termed a column vector (Figure 2). The transition probabilities that determine the contributions of one age group to the next via survival and to the youngest age group through reproduction constitute the elements of a square matrix, the transition or projection matrix, which when post-multiplied by the vector of age-classes gives the numbers of individuals in each age-class in the next generation. The realism of this model depends critically on the construction of the transition matrix and the computation of the individual elements. Since plant populations are known to exhibit density-dependent regulation, an essential sophistication of the model is the adjustment of the relevant transition probabilities and fecundities according to the population density. A further development may be made by recognising that the transition matrix may not be the same for every transition from one time step to the next. This is essential if the time steps under consideration are shorter than the complete cycle of individuals in the population. Simulation of the dynamics of the population over as many generations as required is simply achieved by repetitive multiplication of successive column vectors by the transition matrix.

A SIMPLE ILLUSTRATION OF THE MODEL

Colonising populations of Poa annua provide an example of an annual weed species which does not reproduce vegetatively. In a study of the dynamics of a colonising population of Poa annua Law (1975) has estimated the age-specific survival of age classes from seedlings through to mature adult plants and has also estimated age-specific reproduction (seed production). Law's study of the colonisation of bare areas by Poa is analogous to invasion by annual weeds in arable cultivation, at least during the early stages of crop development before crop competition becomes significant.

The transition matrix for seedlings and adult plants depends on the number of age classes and distribution of reproduction. In populations of Poa annua there are seedlings which are defined as immature non-producing individuals, plus several reproducing age classes i.e. young, medium and old adults. The time units in the matrix (the span of each age class) are somewhat arbitrary but approximate to about 8 weeks.

For the purpose of illustrating the model, values for germination, age-specific survival and seed production in Poa annua are those chosen by Law as being reasonable approximations. We have not attempted at this stage, a detailed simulation of the population data.

As the population density of Poa annua increases with time, we would expect plant survival and seed production to be reduced. Seedling survival will be particularly sensitive to population density and thus, in the model, the transition of seedlings to young adults has been made density dependent. The relationship between seedling survival and the total density of individuals in the young, medium and old age classes is shown in Figure 3, together with age-specific seed output of adult age classes as functions of population density. The transition matrix which incorporates the survival and reproduction estimates thus takes the form shown in Figure 4.

Between successive time intervals 0.2 of the seeds remain dormant and 0.05 germinate, the proportion of individuals that survive from the seedling age class to young adults is 0.75 at very low population density but reduces to much lower values as density increases. The proportion of individuals that survive from the young adult age class onward is the fixed value of 0.75. The maximum seed production of young and old adults at very low population density is 100 seeds per plant but this becomes a negative exponential function of population density. Similarly, the maximum seed production of medium adults is 200 seeds per plant, reflecting age distributed reproduction in Poa populations where seed output peaks in the medium adult age class.

The progress of population growth was followed by the matrix multiplication

Fig. 3. Density dependent relations in Poa annua populations (from Law, 1975).

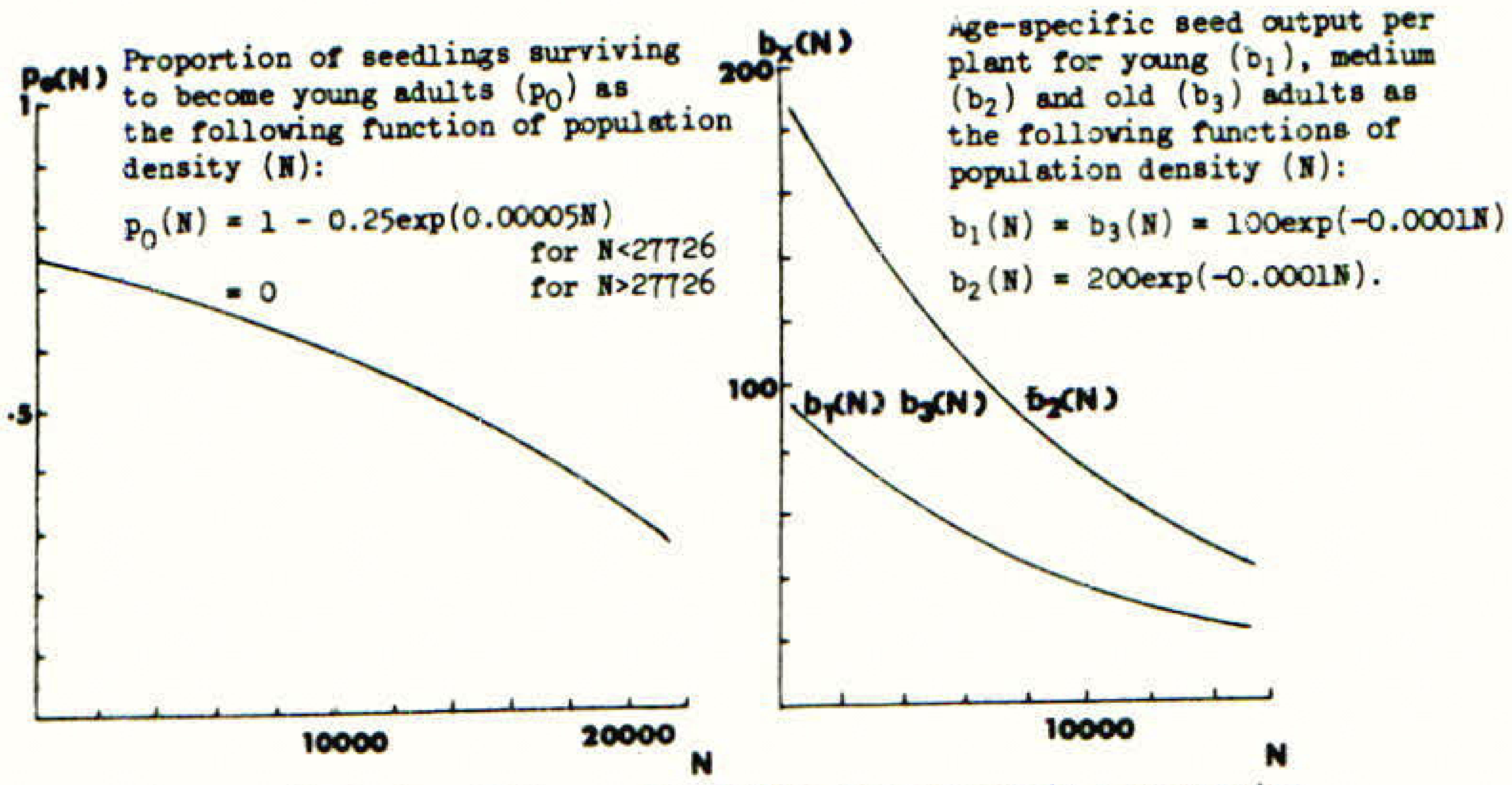


Fig. 5. Simulation of the growth of five age classes in a population of Poa annua (from Law, 1975).

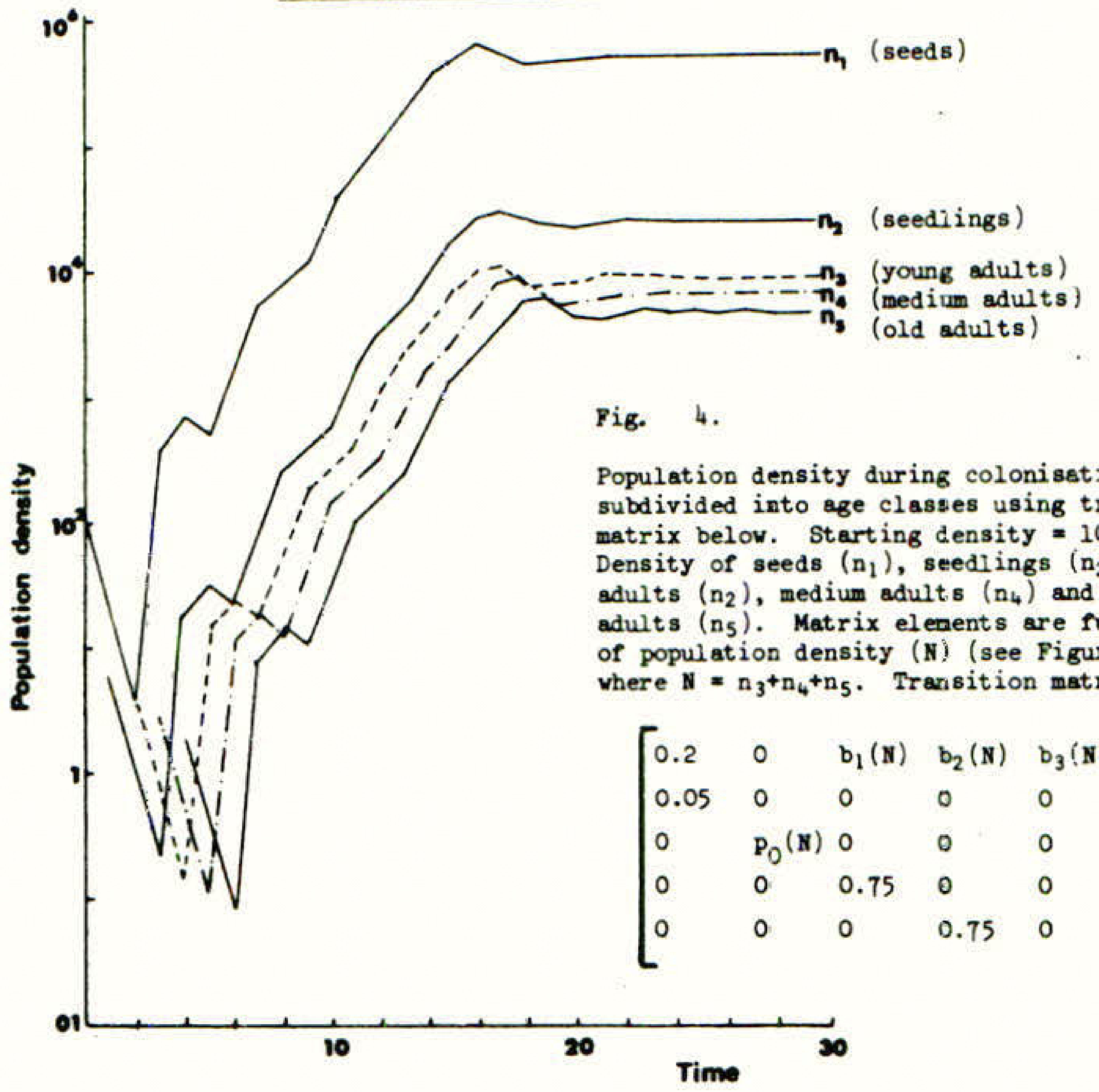


Fig. 4.

Population density during colonisation, subdivided into age classes using transition matrix below. Starting density = 100 seeds. Density of seeds (n_1), seedlings (n_2), young adults (n_2), medium adults (n_4) and old adults (n_5). Matrix elements are functions of population density (N) (see Figure 3) where $N = n_3+n_4+n_5$. Transition matrix:

$$\begin{bmatrix} 0.2 & 0 & b_1(N) & b_2(N) & b_3(N) \\ 0.05 & 0 & 0 & 0 & 0 \\ 0 & p_0(N) & 0 & 0 & 0 \\ 0 & 0 & 0.75 & 0 & 0 \\ 0 & 0 & 0 & 0.75 & 0 \end{bmatrix}$$

Fig. 6. Transition matrices and initial age distribution for *Avena fatua*. The transition probabilities are derived from various literature sources and represent generalised values.

Transition matrices:

$$A_1 = \begin{bmatrix} 0.75 & 0 & 0 & 0 \\ 0.37 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix} \qquad A_2 = \begin{bmatrix} 0.75 & 0 & 0 & 0 \\ 0.01 & 0 & 0 & 0 \\ 0 & 0.25 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}$$

$$A_3 = \begin{bmatrix} 0.75 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0.75 & 0 \end{bmatrix} \qquad A_4 = \begin{bmatrix} 0.75 & 0 & 0 & 80 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}$$

Explanation of matrices

A_1 = the transition matrix for late winter - early spring.

A_2 = " " " " early spring - late spring.

A_3 = " " " " late spring - late summer.

A_4 = " " " " late summer - early autumn.

Initial age distribution:

$$_tN = \begin{bmatrix} 100 \\ 0 \\ 0 \\ 0 \end{bmatrix}$$

Simulation:

Population growth for one season is modelled by the equation:

$$_{t+1}N = A_1 . A_2 . A_3 . A_4 . _tN$$

procedure described previously. The results of a computer simulation using the parameters for Poa annua described in Figures 3 and 4, are shown in Figure 5.

The graph shows that numbers initially decline due to the time lag before reproduction commences, the numbers in each class increase and the proportions in each age class, which fluctuate initially, settle down and become constant. After about 16 time intervals, population growth has halted and numbers in each age class approach constant values. The size of the population has been regulated by intraspecific competition.

AN ILLUSTRATION OF THE USAGE OF THE MODEL

The dynamics of wild oat populations have attracted much attention during recent years (e.g. Selman, 1970) but there have been few attempts (e.g. Rauber & Koch, 1975) to synthesize the life historical parameters for any one population into a working model. Using the data principally of Rauber and Koch (1975) and Kurth (1967), we have simulated the growth of Avena fatua populations and explored some of the consequences of simplified weed control procedures.

The model for Avena departs from the one already discussed for Poa in one important respect. A. fatua is a semelparous annual in contrast to the iteroparity exhibited by Poa and this necessitates the need for transition matrices that change throughout the season. The set of matrices used are given in Figure 6. If population growth is simulated in the absence of any density dependent regulation, characteristic exponential growth is observed (Figure 7). When the number of seedlings surviving to the young adult age category and the fecundity of old adults are made density dependent (Figure 8), the size of the population is subject to density dependent regulation and the density after three generations remains stable with succeeding generations (Figure 7). The density at which stability is attained (the carrying capacity of the simulated 'environment') is a function of the transition probabilities and may be manipulated for example by varying the fecundity in uncrowded conditions or the probability of a seed surviving. Low population densities are the obvious result of reduced fecundities and high seed mortality (Figure 7).

This model of density dependent population growth provides the template for the assessment of various weed control practices. Effective regulation of Avena fatua is gained by control over seed output (Chancellor & Peters, 1970), harvesting before seed shed with concomittant removal of straw and trash (Wilson & Cussans, 1975) low emergence of seedlings from the soil (Thurston, 1963), and high post emergence mortality (Chancellor & Peters, 1972). The consequences of any one or combinations of these management practices on the resulting population size of A. fatua may be modelled by deliberate manipulation of the numbers of individuals in particular age classes.

Figure 9 shows the population changes resulting from control measures that reduce the numbers of seed present at the start of the growing season. The net result of a solitary reduction is merely a delay in time before the population density stabilises. Continual seed removal over a period of years merely maintains the population at a density lower than is naturally exhibited. Reduction of the numbers of seedlings for example through herbicide application has similar effects on population size (Figure 10). Upon cessation of continuous control in both cases the population grows exponentially until the carrying capacity is achieved.

Where two methods of regulation are applied, more effective control of A. fatua appears feasible (Figure 11). However, even in the instance of high levels of seed and seedling mortality, the population persists and when control is relaxed, rapid increase occurs. This persistence is a direct consequence of a bank of seeds being carried over to each successive generation.

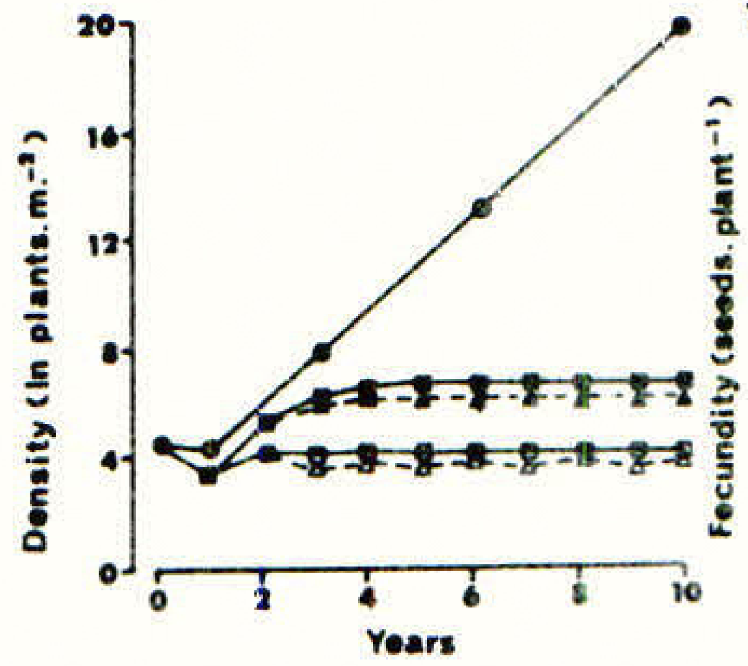


Fig. 7. The growth of Avena fatua populations with differing life history parameters.

- ●—● 0.7 chance of seed mortality, no density dependent regulation.
- ▲- - -▲ 0.7 chance of seed mortality, density dependent seedling survivorship and fecundity (F_1).
- △- - -△ 0.7 chance of seed mortality, density dependent seedling survivorship and fecundity (F_2).
- ■—■ 0.25 chance of seed mortality, density dependent seedling survivorship and fecundity (F_1).
- □—□ 0.25 chance of seed mortality, density dependent seedling survivorship and fecundity (F_2).

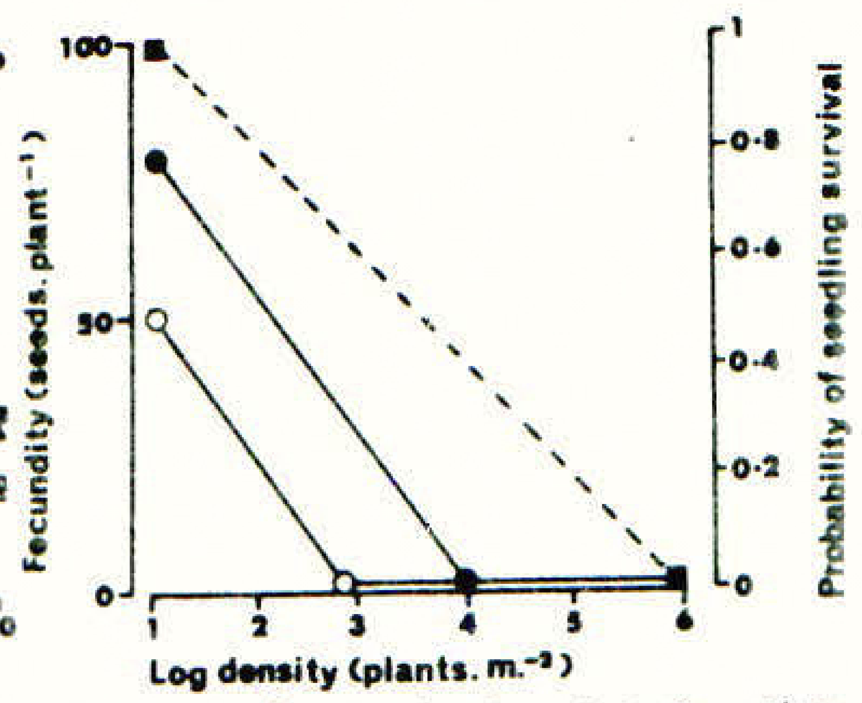


Fig. 8. Density dependent fecundity and survivorship in Avena fatua (after Rauber and Koch, 1975)

- ●—● fecundity (F_1) $F_1 = 80 - 26 \log (\text{density})$
- ○—○ fecundity (F_2) $F_2 = 50 - 26 \log (\text{density})$
- ■- - -■ seedling survivorship (S) $S = 1 - 0.2 \log (\text{density})$

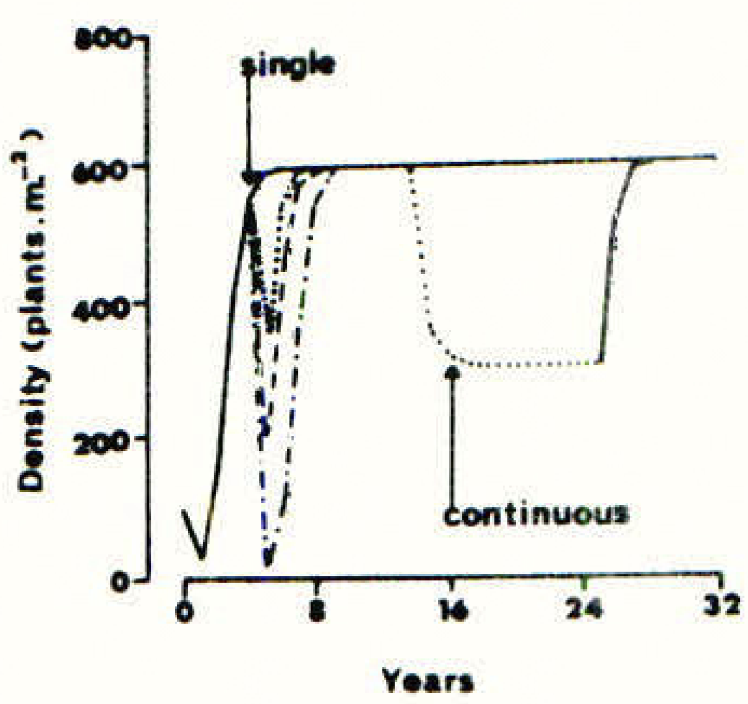


Fig. 9. The consequences of seed removal to the growth of a population of Avena fatua.

- ——— unregulated
- .... 50% seed removal
- - - - - 75% seed removal
- -.-.-.- 90% seed removal

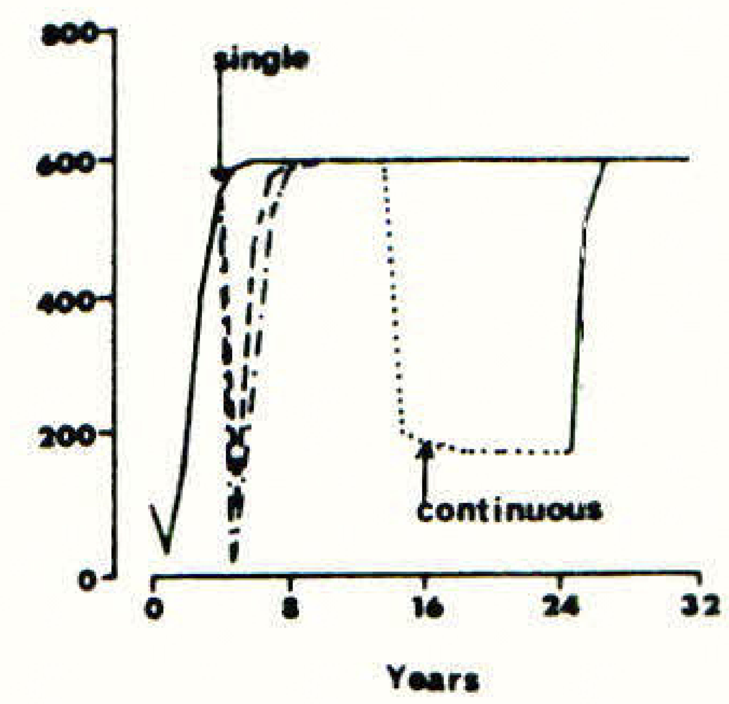


Fig. 10. The consequences of seedling reductions to the growth of a population of Avena fatua.

- ——— unregulated
- - - - - 90% seedling removal
- -.-.-.- 99% seedling removal

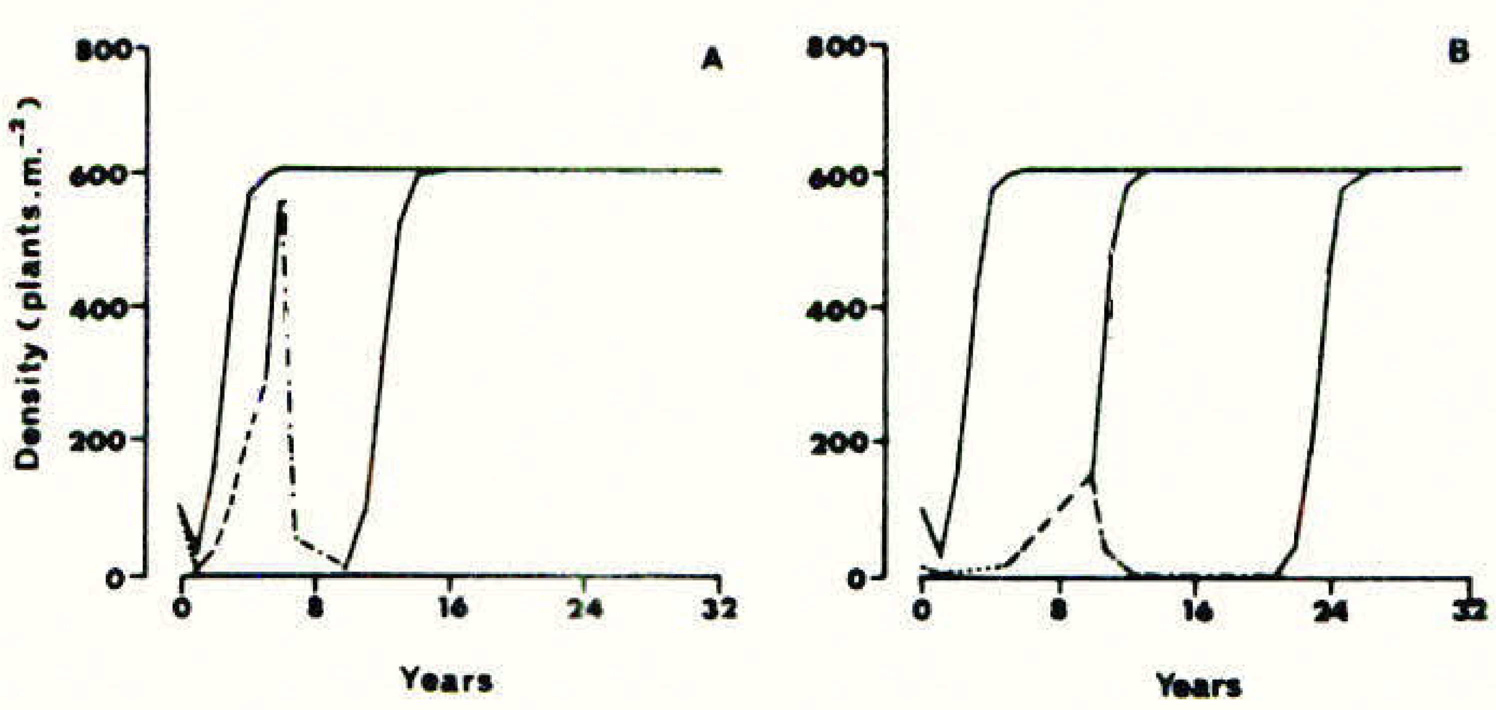


Fig. 11. The effects of two simplified control programs on the growth of Avena populations.

A. With realisation of potential infestation, 90% seed removal for 1 year (......), no control for 1 year, 50% seedling kill for 3 years (- - -), no control for 1 year, 90% seed removal and 50% seedling kill for 5 years, (-·-·-), no control (———)

B. With realisation of potential infestation, 90% seed removal for 5 years (......), 75% seedling kill for 5 years (- - -), 90% seed removal and 75% seedling kill for 10 years (-·-·-), no control (———)

DISCUSSION

It is not our intention in this paper to suggest novel methods of weed control nor do we presume to have presented highly realistic models of *Avena* and *Poa* populations. The models presented lack sophistication in many important aspects. The influence of seed dormancy patterns in a weed species and of crop competition may very well materially influence the levels of weed infestation. The effectiveness of herbicide based control measures often involves the realisation that there is a critical stage of growth in the life cycle of a weed during which herbicide application should occur. Implicit in this realisation is the idea of age specific mortality under herbicide application - as illustrated by simazine on *Senecio vulgaris* (Holliday, Putwain & Dafni, 1976). A matrix model that does not incorporate this feature is necessarily deficient. Enhancements such as these are all perfectly feasible following the approaches of Sarukhan and Gadgil (1974) and Law (1975). The remaining major limitation to this approach to the evaluation of weed control measures is still a paucity of pertinent data upon which to base a model.

The use of the Leslie matrix model, however, does present an unconventional approach to weed control procedures in a number of ways.

Firstly it allows the integrated synthesis of all demographic stages of the life cycle of a weed species in a cogent form. In consequence it focusses attention on the relationship and relative significance of particular transition probabilities and gives a mathematical vehicle by which they can be used.

Secondly it provides a means by which the effects of potential regulators on weed population sizes may be assessed. The magnitude of transition probabilities and fecundities may be manipulated through a variety of management regimes and the consequences evaluated through simulation.

The approach is unconventional in a third way in so far as it may suggest integrated forms of weed control that may be novel. Given relevant data on a number of different control procedures, a simulation may provide an informative and cost effective analysis of an integrated combination of control measures.

Acknowledgement

We are grateful to Dr. R. Law for permission to quote the data for *Poa annua*.

References

CHANCELLOR, R.J. & PETERS, N.C.B. (1970). Seed production by *Avena fatua* populations in various crops. *Proc. 10th Brit. Weed Control. Conf.* 7-11.

CHANCELLOR, R.J. & PETERS, N.C.B. (1972). Germination periodicity, plant survival and seed production in populations of *Avena fatua* L. growing in spring barley. *Proc. 11th Brit. Weed Control Conf.* 218-225.

FRYER, J.D. (1975). Opening address - European weed research society symposium, status and control of grassweeds in Europe, 1975. *Symposium on Status, Biology and Control of Grassweeds in Europe.* 2, 1-6.

HOLLIDAY, R., PUTWAIN, P.D. & DAFNI, A. (1976). The evolution of herbicide resistance in weeds and its implications for the farmer. *Proc. 13th Brit. Weed Control Conf.* 937-947.

KURTH, H. (1967). The germinative behaviour of weeds. *SYS Reptr.* 3, 6-11.

LAW, R. (1975). Colonisation and the evolution of life histories in *Poa annua*. Ph.D. University of Liverpool, 211pp.

LESLIE, P.H. (1945). On the use of matrices in certain population mathematics. *Biometrika* 33, 183-213.

MORTIMER, A.M. (1976). Aspects of the seed population dynamics of Dactylis glomerata L., Holcus lanatus L., Plantago lanceolata L. and Poa annua L. Proc. 13th Brit. Weed Control Conf. 687-694.

RAUBER, R. & KOCH, W. (1975). Zur Population Dynamik des Flughafers (Avena fatua L.) unter dem Aspekt der langfristigen Befallsprognose. Symposium on Status, Biology and Control of Grassweeds in Europe. 1, 114-125.

SAGAR, G.R. & MORTIMER, A.M. (1976). An approach to the study of the population dynamics of plants with special reference to weeds. Appl. Biol. 1, 1-43.

SARUKHAN, J.K. & GADGIL, M. (1974). Studies on plant demography: Ranunculus repens L., R. bulbosus L. and R. acris L. III. A mathematical model incorporating multiple modes of reproduction. J. Ecol., 62, 921-937.

SELMAN, M. (1970). The population dynamics of Avena fatua (Wild Oats) in continuous spring barley. Proc. 10th Br. Weed Control Conf. 1176-1188.

THURSTON, J. (1963). Biology and control of wild oats. Report Rothamsted Experimental Station, 1962, 236-253.

USHER, M.B. (1972). Developments in the Leslie Matrix model. Mathematical models in Ecology (Ed. by J.N.R. Jeffers), pp.29-60. Symp. Br. Ecol. Soc. 12th, Blackwell, Oxford.

USHER, M.B. (1975). Biological management and conservation. Chapman and Hall (London) pp.394.

WILSON, B.J. & CUSSANS, J.W. (1975. A study of the population dynamics of Avena fatua L. as influenced by straw burning, seed shedding and cultivation. Weed Res. 15, 249-258.

THE CONTROL OF RUMEX OBTUSIFOLIUS IN GRASSLAND BY SELECTIVE APPLICATION OF HERBICIDES

A.K. Oswald
ARC Weed Research Organization, Begbroke Hill, Yarnton, Oxford, OX5 1PF

Summary The results of one greenhouse experiment and three carried out in the field show that effective control of Rumex obtusifolius was achieved when high concentrations of glyphosate were mixed in alginate solution and smeared onto foliage. Plants treated in July or September 1977 with a mixture of 10% glyphosate in 3% alginate solution had not regrown by June 1978. In three of the experiments there was no significant effect on grass yield after treatment. These results point to a new method of selective application exploiting the difference in height between crop and weeds. It is envisaged that selective or non-selective herbicides could be applied only to the weeds during a period when they are growing taller than the crop, without affecting grass production.

INTRODUCTION

Selective herbicides can be used for suppression of Rumex spp. in grassland. However, re-infestation usually occurs due to regeneration from surviving roots in the year after treatment (Frame and Harkess, 1972; Oswald and Elliott, 1970; Oswald and Haggar, 1976). If it were possible to apply a chemical, only to the exposed Rumex leaves, effective long-term control might be achieved without damaging the surrounding grass. This is not possible with conventional spray methods because the chemical runs off the Rumex foliage onto the grass which is also sprayed. Thus, the chemical needs to be mixed in a medium that will not run off treated weed foliage but will remain long enough to allow for translocation to the roots.

Alginates appear to provide a suitable medium. They are naturally occurring polysaccharides which are extracted from seaweed. The sodium salt is water soluble and a 3% w/v solution forms a solution similar in viscosity to thick treacle which reacts rapidly with calcium ions to form an insoluble gel of calcium alginate.

Work at the Weed Research Organization has showed that an alginate solution of diquat applied under water will readily adhere to weeds in the water so allowing the slow release of the herbicide (Barrett, 1978). It was therefore decided to see whether control of Rumex spp. could be achieved by applying glyphosate in an alginate solution exclusively to the weed. Four experiments are described in which different amounts of alginate solution of glyphosate were applied onto Rumex foliage. The effects of the treatments on visible green material and harvested dry weights of Rumex and grass are discussed.

METHOD AND MATERIALS

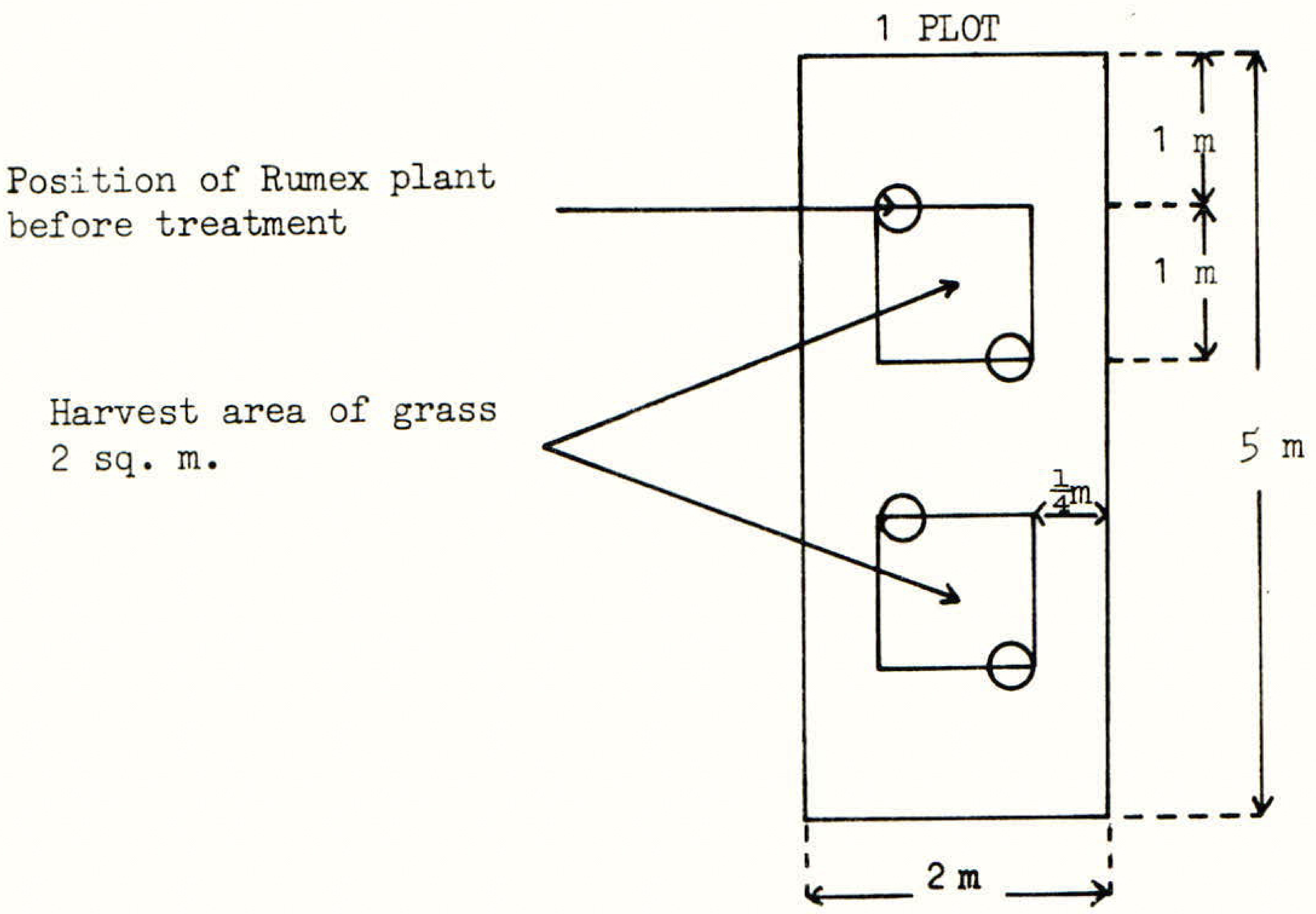
Details of the experiment sites are shown in table 1. Individual Rumex plants growing in pots in the greenhouse were treated in experiment 1. In the field experiments 2, 3 and 4, 4 plants were chosen on each plot using the layout shown in Fig. 1.

Table 1

Details of experiment sites, management and assessments

	Experiment number 1	2	3	4
Location	WRO greenhouse	Gt. Rollright, Oxon	Gt. Rollright, Oxon	WRO grassland
Sward type	-	Rye-grass/Timothy/ White clover	Rye-grass/Timothy/ White clover	Rye-grass/White clover
Sward age	-	7 years	6 years	1 year
Pre-treatment management	Rumex plants established in greenhouse, transferred outside after treatment	1 or 2 hay/silage cuts before July, then grazed, dairy cattle	Grazed, dairy cattle	Grazed, beef cattle
Mean sward height (cm)	-	12.5	12.5	7.5
Mean Rumex " "	15	48	17	22
Mean Diameter	25	46	39	56
Plot size (m)	19.5 cm diam. pots	5 by 2	5 by 2	5 by 2
Treatment date	25 May 1977	29 July 1977	23 September 1977	23 September 1977
Assessments				
Visual scores	Every 10 days from treatment to 12 September 1977	Every month from treatment until 22 November 1977	10 days, then every month after treatment until 22 November 1977	Every 10 days after treatment until 22 November 1977
Yield cuts	20 October 1977	31 May 1978	5 June 1978	8 June 1978

Fig. 1. The positions of the Rumex plants treated and harvested on experiments 2, 3 and 4 and the areas of grass also harvested



Treated and control plants were labelled. All experiments were in a randomised block design with 5 replicates in experiment 1 and 4 replicates in experiment 2, 3 and 4.

Treatments

Experiment 1:
1. Untreated control
2. All leaves smeared, 15 ml per plant
3. One leaf " 2.5 " " "
4. Random droplets on all leaves, 15 ml per plant
5. " " " one leaf 20 mm diam., 2.5 ml per plant

Experiment 2, 3 and 4:
1. Untreated control
2. One leaf smeared, 2.5 ml per plant
3. Random smear over plant

The 3% w/v alginate solutions were prepared by wetting the required quantity of dry alginate powder using acetone as an organic solvent. The glyphosate solutions were then added rapidly so that the particles of alginate were dispersed before going into solution. A 0.15% solution of calcium citrate was added, causing the viscosity of the mixture to increase and form calcium alginate. The mixtures were made up 24 h before each application. A 2% w/v concentration of glyphosate was used in experiment 1 to provide a sub-lethal dose so that treatment differences could be recorded. The concentration used in experiments 2, 3 and 4 was 10%.

A plastic syringe was used to apply all treatments in experiment 1 and treatment 2 in experiments 2, 3 and 4. The required amounts were placed on the upper leaf surfaces and smeared with a gloved finger.

A sponge-coated plastic paint roller was impregnated with the glyphosate/alginate solution to apply the random smear treatments on experiments 2, 3 and 4. The roller was brought into contact with Rumex foliage in a single-pass rolling movement at a height which cleared the grass.

Assessments

Visual scores: Treated *Rumex* plants were scored periodically for the amount of green material present compared with untreated plants. Scoring was from 0 (no green material visible) to 9 (no visible effect). Two people scored independently and a mean of both scores was recorded.

Dry-matter yields: Harvests were carried out using hand shears. All 4 *Rumex* plants were cut at ground level from each plot on experiments 2, 3 and 4 and two areas of grass each measuring 1 m^2 were also cut as shown in Fig. 1. Cut material was weighed fresh and then placed in an oven at 100°C for at least 6 h. The dried material was then weighed.

RESULTS

Experiment 1

Effects on green material were first recorded 15 days after application of all treatments. Maximum effects (Fig. 2) were reached 60 to 85 days after smeared treatments and 40 to 50 days after the application of droplets. Recovery thereafter was gradual with all treatments, although full recovery was not achieved, even after 150 days. Smear treatments were more effective than droplet treatments in terms of green material reductions and eventual recovery. All treatments caused a significant reduction in dry-matter yield (table 2). Yields of material treated with a smear of the mixture were significantly lower than material treated with a droplet (table 2).

Experiment 1 indicated that since treating all leaves, rather than a single leaf, caused a more severe reduction it was decided to see if there was any significant difference in effect due to the amount of solution used and the area of *Rumex* foliage covered. Hence experiments 2, 3 and 4 were set up in natural situations in the field.

Experiments 2, 3 and 4

Visible effects of the treatments were recorded 10 days after treatments, with maximum effects being reached after 40 to 60 days (Fig. 3). Complete destruction of aerial parts was recorded following all treatments except the one-leaf smear in experiment 2. Recovery was not recorded by the end of the assessment on any of the experiments.

Reductions in dry weight of *Rumex* were achieved by all treatments in experiments 2, 3 and 4. (table 3). Removal of the *Rumex* plants from the sward did not have any significant effect on grass yield even though some bare space was created (table 3).

DISCUSSION

An effective control of *R. obtusifolius* can be achieved for at least one year by treating a single leaf with 2.5 ml of a chemical/alginate solution, exploiting the height difference between the weed and surrounding grasses. The technique has several potential uses for controlling tall growing weed plants that commonly occur, in pastures recently vacated by grazing animals. Even with relatively short weeds in closely grazed swards, the grass might be eaten to a height of a few centimetres, exposing the weed to treatment. At this time effective weed control could be carried out selectively with economical use of chemical.

Investigations into this technique are at an early stage. Although aerial parts of Rumex plants were largely eradicated, the fate of the rootstocks was not investigated in the work reported here. It is essential that the long term effects of this technique are recorded in future studies. A wider range of herbicides and doses needs evaluating and optimum concentrations of chemical and alginate need working out. The minimum amount of chemical/alginate solution and the proportion of foliage requiring treatment to give plant kill are other important factors.

Machines have been developed for use in selective herbicide application to control weeds in sugar beet crops in Belgium and France. (Vigoureux, 1976). What is now required is an effective means of applying treatments on weeds growing in grassland if the technique is to be used by grassland farmers.

Although this work was carried out on R. obtusifolius, the technique could be developed for application to other grassland weeds. Thistles, nettles, ragwort, rushes and tussock grass are all species which grow taller than grass in pastures and often cause problems of control.

Acknowledgements

I thank F.W. Kirkham and P.G. Smith who helped in the field and laboratory and assisted with the analysis of the results. I am also grateful to Sir Charles Dorman for his kind co-operation in providing land for two of the experiments.

References

BARRETT, P.R.F. (1978) Some studies on the use of alginates for the placement and controlled release of diquat on submerged aquatic plants. Pesticides Science 9 (in press)

FRAME, J. & HARKESS, R.D. (1972) Herbicides for control of docks (Rumex spp.) in grassland. Proceedings 11th British Weed Control Conference, 1972, 323-330.

OSWALD, A.K. & ELLIOTT, J.G. (1970) The toxicity of three herbicides to the docks (Rumex spp.) and grasses growing in a mainly rye-grass pasture. Proceedings 10th British Weed Control Conference, 1970, 481-487.

OSWALD, A.K. & HAGGAR, R.J. (1976) The effect of asulam on two Lolium perenne swards containing Rumex obtusifolius. Weed Research, 16, 7-10.

VIGOUREUX, A. (1976) Developpements dans le probleme des betteraves mauvaises herbes. La Sucrerie Belge 95 219-227.

Fig. 2. Experiment 1. The visible effects on Rumex obtusifolius grown in pots.

Scored 0 (no green material) to 9 (no visible effect)

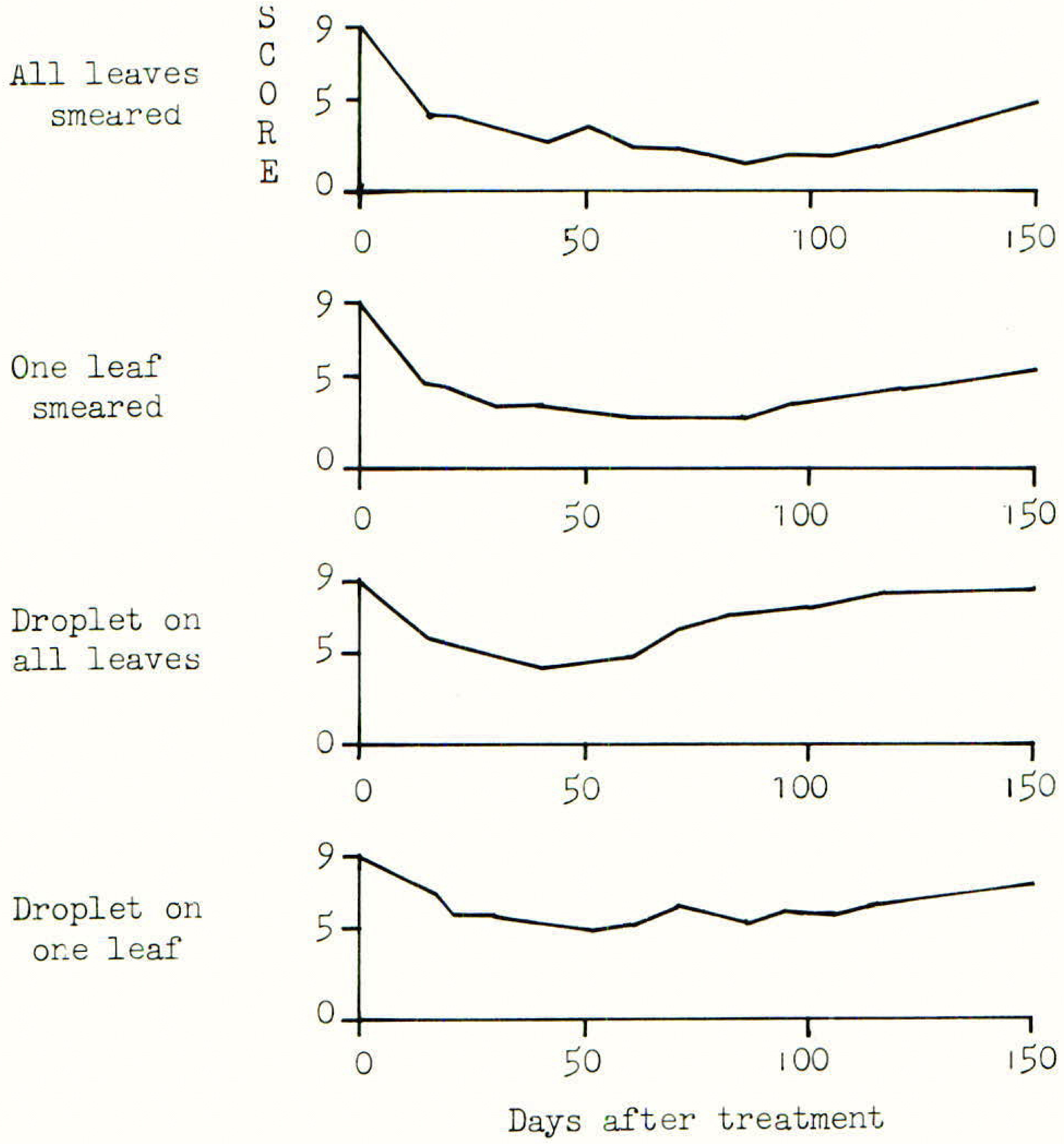


Fig. 3. Experiments 2, 3 and 4. The visible effects on Rumex obtusifolius growing in grass swards

Scored 0 (no green material) to 9 (no visible effect)

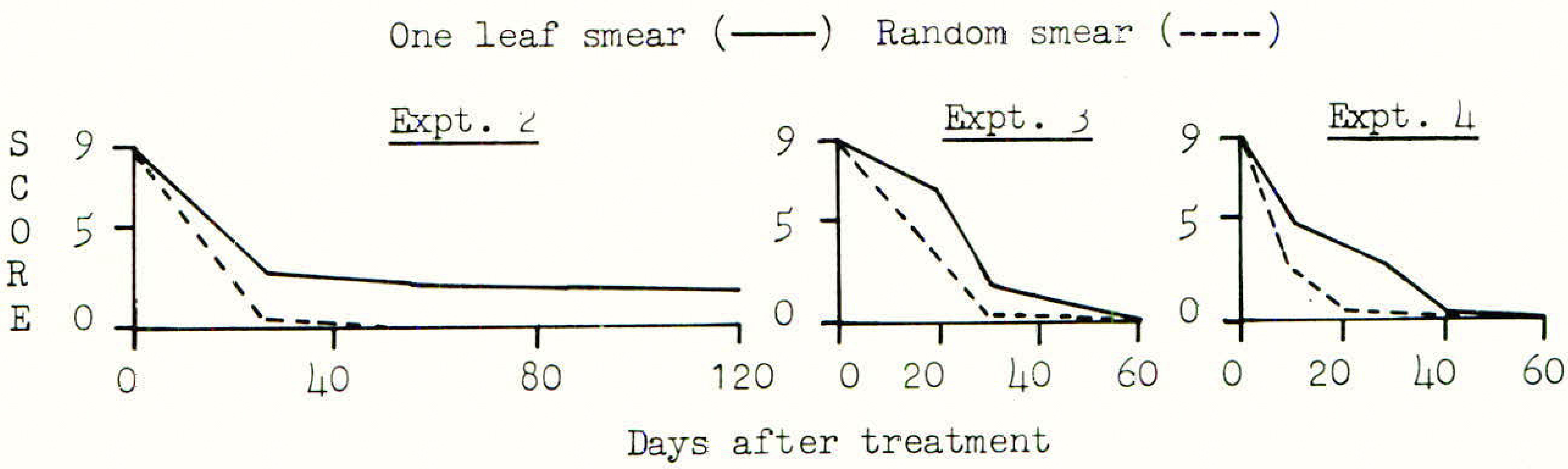


Table 2

Experiment 1. Mean effects of a 2% concentration of glyphosate applied in a 3% alginate solution on Rumex obtusifolius grown in pots

Treatment	Dry weight per pot (g)
1. Untreated Control	19.05
2. All leaves smeared, 15 ml/plant	4.15
3. One leaf " 2.5 ml/plant	6.87
4. Droplet on all leaves, 15 ml "	12.96
5. " " one leaf, 2.5 " "	11.67
LSD (p = 0.05)	4.41

Table 3

Experiments, 2, 3 and 4. Mean effects of a 10% concentration of glyphosate applied in a 3% alginate solution on Rumex obtusifolius growing in three grass swards

	Rumex dry wt (g) per plot				Grass dry wt (g) per sq. m			
	Experiment				Experiment			
	2	3	4	Mean	2	3	4	Mean
Untreated Control	122	79	312	171	469	514	363	449
One leaf smeared	Trace	0	0	Trace	532	486	405	474
Random smear	Trace	0	0	Trace	501	496	388	462
LSD (P=0.05)					NS	NS	NS	NS