THE EFFECT OF AMINOTRIAZOLE, GLYPHOSATE AND PARAQUAT APPLIED TO ALOPECURUS MYOSUROIDES SEEDS

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Summary The effect of applying aminotriazole, glyphosate and paraquat onto ungerminated *A. myosuroides* seeds was studied.

When applied to seeds on the soil surface in pots, paraquat at 0.42 kg a.i./ha and aminotriazole at 2.25 kg a.i./ha greatly reduced subsequent black-grass growth whereas glyphosate had no effect at application rates up to 5.76 kg a.i./ha. Seeds covered with 0.1 - 0.2 cm or 1.0 cm of soil in pots were not affected by paraquat applications of up to 1.68 kg a.i./ha to the soil surface. Aminotriazole at 2.25 kg a.i./ha was active against buried seeds more so with the 0.1 - 0.2 cm than the 1.0 cm soil covering.

In a field experiment, the three herbicides were applied on two dates to *A. myosuroides* seeds broadcast on a cereal stubble. Only paraquat at 0.84 kg a.i./ha significantly reduced subsequent seedling numbers and the effect was greater when the herbicide was sprayed 5 days rather than 23 days after seeds had been applied.

INTRODUCTION

In winter cereal crops *A. myosuroides* seeds are shed mainly during July and early August. If some of these seeds could be destroyed while they remain on the soil surface after harvest, the potential source of infestation would be reduced.

Previous work, mainly in glasshouse studies, has shown that paraquat can affect the subsequent germination and seedling development of several grass species when applied to ungerminated seeds (Appleby and Brenchley, 1968; Egley and Williams, 1978; Heirholzer, 1965; Klingman and Murray, 1976; Zemanek, 1973).

One possible means of destroying seeds while they lie on the soil surface is to apply a herbicide which will either directly affect the seeds while they are dormant or will influence their subsequent ability to germinate. This effect could be a useful side effect of herbicides applied for other purposes.

Three herbicides that are currently used for weed control on cereal stubble are aminotriazole, glyphosate and paraquat. It was therefore decided to study the activity of these herbicides on *A. myosuroides* seeds both in pot experiments and in the field.

METHOD AND MATERIALS

Pot experiment 1. Effects of herbicides sprayed onto ungerminated seeds on the soil surface.

Twenty five seeds were placed on the surface of a sandy loam soil in 10 cm diameter plastic pots. A single nozzle laboratory sprayer was used to apply the following rates of herbicide.

Aminotriazole	0.56, 1.13, 2.25, 4.50, 9.00 kg a.i./ha
Glyphosate	0.36, 0.72, 1.44, 2.88, 5.76 kg a.i./ha
Paraquat	0.11, 0.21, 0.42, 0.84, 1.68 kg a.i./ha

There were four replicates and three unsprayed control pots per replicate. All applications were made in 300 litres water/ha at 2.1 bar through a Spraying Systems 8001 'Teejet' nozzle at a height of 45 cm above the seeds. After spraying the pots were placed in shallow trays of water under fluorescent lights, and the soil allowed to soak. The seeds became imbibed and received the necessary light stimulation for germination. After twenty hours the pots were removed from the trays of water and placed in a warm glasshouse. The seeds were then covered with a thin layer of soil to help maintain the seeds in an imbibed condition. The pots were watered as necessary and after six weeks the fresh weight of foliage was recorded for all pots.

Pot experiment 2. Effects of herbicides on seeds covered by a soil layer

This experiment was conducted in a similar manner as pot experiment 1 except that seeds were imbibed and covered with soil before spraying. Two depths of soil cover were used; either 0.1 - 0.2 cm or 1.0 cm. Only aminotriazole and paraquat were applied but the rates of application were the same as in the first pot experiment. There were two unsprayed control plots for each soil depth on each replicate. The fresh weight of foliage was determined after four weeks.

Field experiment

An experiment was started in September 1977 to study the effects of three herbicides applied to ungerminated seeds under field conditions.

On 10 September 1977, after a previous spring barley crop had been harvested and the straw removed by baling, 4000 seeds/m^2 were applied to 2 x 1.5 m plots on uncultivated stubble. The viability of the seeds was 43%. The following herbicide treatments were applied to separate plots on 15 September and on 3 October 1977.

Aminotriazole	1.13, 2.25 kg a.i./ha
Glyphosate	0.72, 1.44 kg a.i./ha
Paraquat	0.42, 0.84 kg a.i./ha

There were four replicates and two unsprayed control plots on each replicate. Treatments were applied using an Oxford Precision Sprayer with Spraying Systems 8002 'Teejet' nozzles at 2.1 bar. Application rate was 333 l/ha. No _A. myosuroides_ seedlings emerged on any plots until after the second date of application.

Rainfall during September and October was much lower than normal. In September 10.05 mm and in October 27.05 mm of rainfall was recorded at the Weed Research Organization as against the ten year averages of 59.30 mm and 47.50 mm for these two months.

The entire area was direct drilled with winter wheat (145 kg/ha, Var. = Maris Huntsman) on 28 October 1977 using a triple disc drill. A compound fertilizer supplying 20 kg N/ha, 51 kg P_2O_5/ha and 40 kg K_2O/ha was applied at the same time. The area was lightly harrowed after drilling. *A.myosuroides* was assessed by counting all plants in a fixed 1 m^2 quadrat within each plot on 1 December 1977.

RESULTS

Where differences are stated to be significant, $p = 0.05$.

Pot experiment 1

The results are shown in Fig. 1. Glyphosate had no significant effect but both aminotriazole and paraquat significantly reduced foliage fresh weight at the three highest application rates.

Pot experiment 2

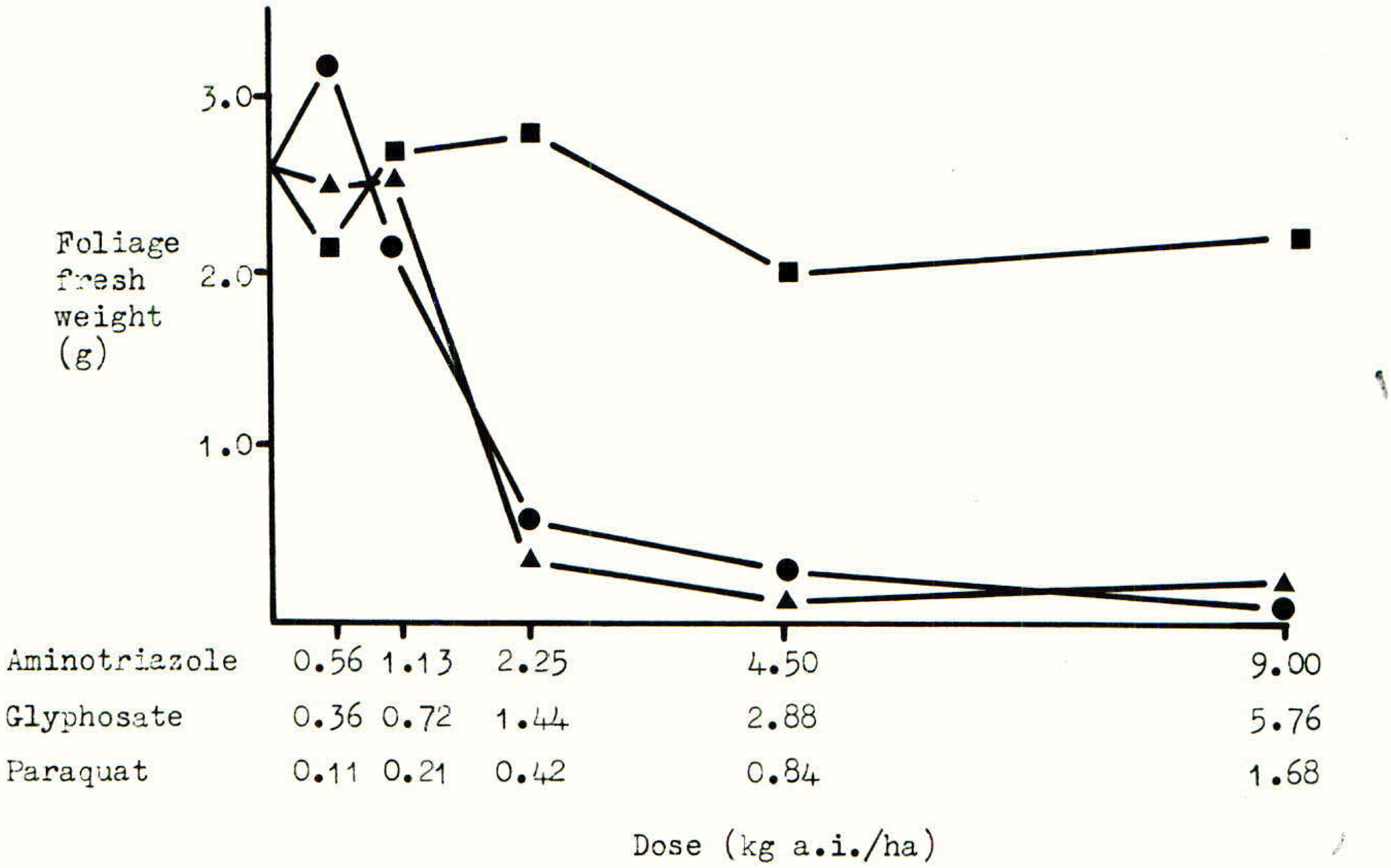
The results are shown in Fig. 2. Foliage fresh weight from unsprayed pots was not affected by depth of burial of seeds and thus both sets of control results for the two depths of burial were combined.

Paraquat had no effect on buried seeds even at the highest application rate. Aminotriazole applied to pots with seeds covered to 0.1 - 0.2 cm, gave a similar response to that found in Pot experiment 1 in which seeds were on the soil surface. Where seed was covered by 1.0 cm of soil, aminotriazole had less effect at a dose of 2.25 kg/ha. Soil cover had little effect at the higher doses of 4.50 and 9.00 kg/ha.

Field experiment

The plant counts are shown in Fig. 3. Compared with the untreated results a reduction in seedling numbers was obtained with the following treatments : paraquat at 0.84 kg a.i./ha at both application dates, paraquat at 0.42 kg a.i./ha at the earlier date, aminotriazole at 2.25 kg a.i./ha at the later date. However this reduction in seedling numbers only reached statistical significance with the higher rate of paraquat. The effect of paraquat was greater when applied on 15 September than on 3 October.

Fig. 1. The effect of aminotriazole, glyphosate and paraquat on ungerminated A. myosuroides seeds

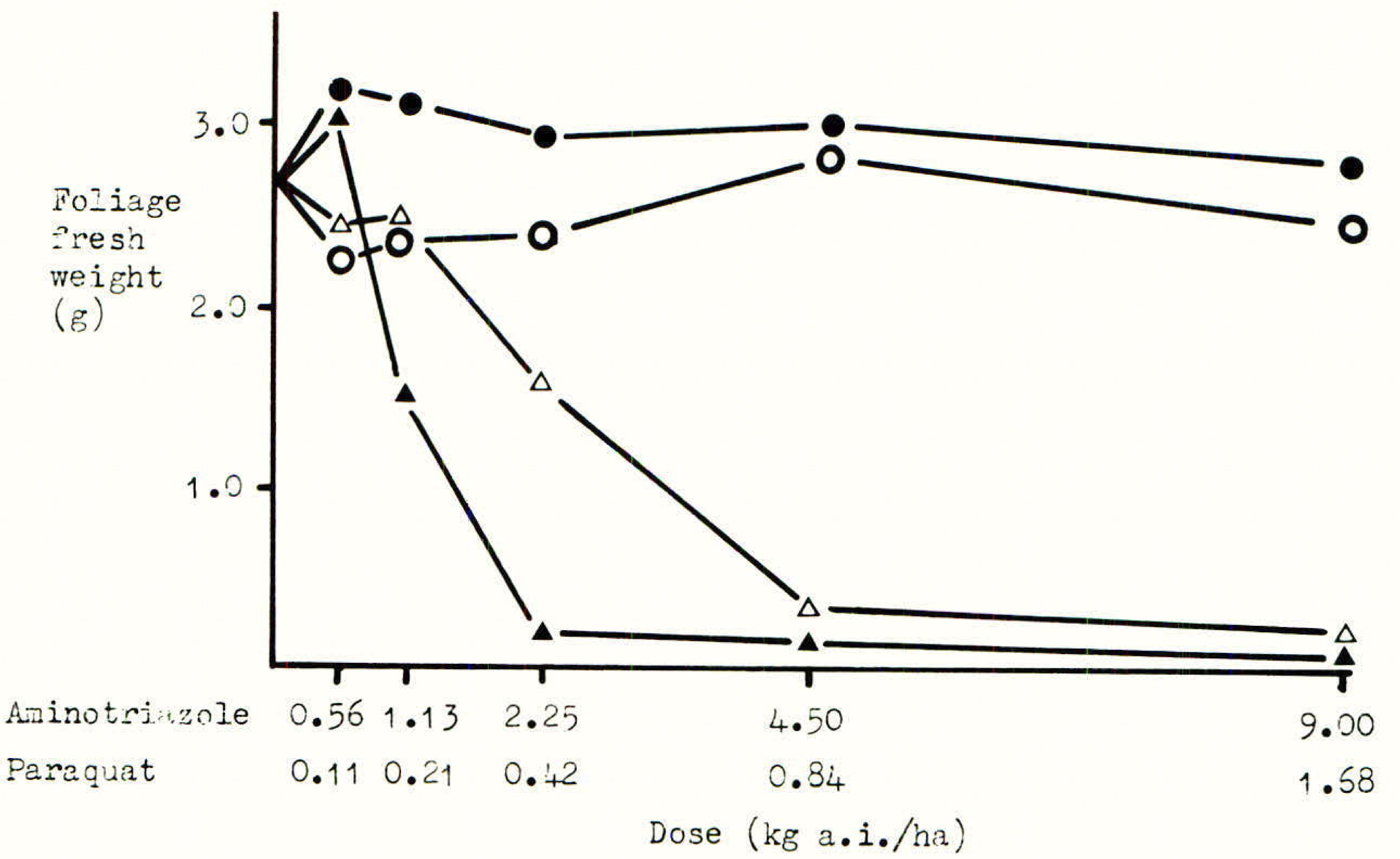


▲ = Aminotriazole ■ = Glyphosate ● = Paraquat

S.E. of difference between treated and untreated means = ± 0.44

S.E. of treated means = ± 0.38

Fig. 2. The effect of aminotriazole and paraquat on A. myosuroides seeds covered by a soil layer



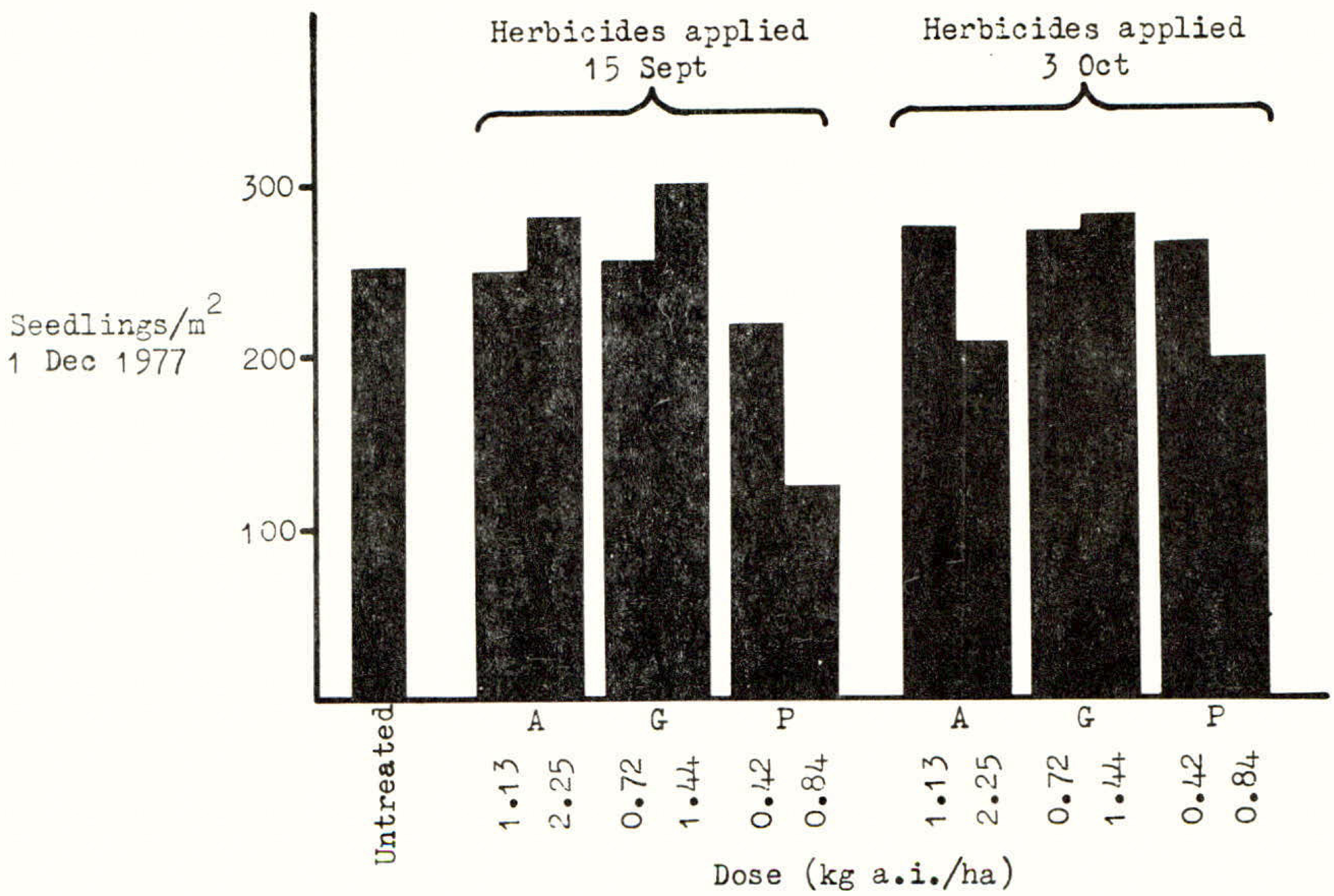
● = Paraquat + seeds 0.1-0.2 cm deep O = Paraquat + seeds 1.0 cm deep

▲ = Aminotriazole+seeds 0.1-0.2cm deep △ = Aminotriazole+seeds 1.0cm deep

S.E. of difference between treated and untreated means = ± 0.28

S.E. of treated means = ± 0.25

Fig. 3. The effect on viability of applications of aminotriazole (A), glyphosate (G), and paraquat (P) to A. myosuroides seeds on uncultivated stubble



S.E. of difference between treated and untreated means = $\pm$ 22.4

S.E. of treated means = $\pm$ 18.3

DISCUSSION

The aim of these experiments was to see if A. myosuroides seed viability could be reduced by herbicide application while the seeds are lying on the soil surface. If seeds are allowed to germinate, the seedlings can be destroyed by application of any of the herbicides used in these experiments and this is currently their normal method of use. However direct applications of herbicides to ungerminated seeds might allow the destruction of dormant seeds which are ultimately responsible for infesting subsequent crops.

The middle rates of herbicide used in the pot experiments are those commonly used on cereal stubbles. For aminotriazole and glyphosate the rate was that recommended for couch control on land to be direct drilled. The middle rate of paraquat is a typical field application for stubble cleaning.

The results of the first pot experiment suggest that where ungerminated seeds are on the soil surface, as they might be on a stubble after harvest, an application of aminotriazole or paraquat might greatly reduce the subsequent amount of A. myosuroides whereas glyphosate would have no effect. Schwerdtle (1965) also found that paraquat could reduce the germination and seedling development of this weed.

The second pot experiment showed that a shallow soil layer over the seeds protected them from the paraquat applications. This shows that if seeds become covered with even a very thin soil layer, which could occur in the field by rain splash, falling down cracks or soil fauna activity as well as by cultivations, paraquat will have no adverse effect on the seed. However, in the pot experiments aminotriazole was still active against buried seeds.

The field experiment was designed to assess the effect of the herbicides under more practical conditions of usage. Only paraquat at the higher rate significantly reduced the numbers of seedlings appearing in the crop. This effect was greater when the herbicide was applied to seeds that had been on the soil surface for 5 days than when they had been down for 23 days. This difference may be due to the gradual natural burial of seeds after they reached the soil surface. Despite its activity against A. myosuroides in the pot experiments, aminotriazole did not significantly reduce seedling numbers in the field. This may have been due to the dry soil conditions existing during September and October as total rainfall was only 34% of the ten year average. Thus lack of moisture may have reduced the soil activity of the herbicide.

Some of the seedling populations were slightly lower on untreated than on treated plots. This was probably due to competition from volunteer cereals which may have limited the numbers of A. myosuroides seedlings that could develop. However on treated plots the herbicides applied destroyed many of the volunteer cereals and there was consequently less competition.

The numbers of seedlings recorded in December on untreated plots were derived from only 15% of the viable seeds applied. This suggests that many seeds either remained dormant in the soil or that they germinated but the seedlings rapidly died. Possibly the environment of undisturbed stubble was a relatively poor one for black-grass establishment. However, this comparatively low level of survival is not necessarily unrealistic. On one experiment where A. myosuroides seeds were shed naturally, the seedlings recorded in April represented only 1.3% of the viable seeds shed in the previous crop on plots where no herbicide was used against the weed (Moss, 1978).

The results from the field experiment are presented in the belief that any effect of the herbicide on seeds is most likely to be reflected in a reduction in seedling numbers, even though this may represent only a small proportion of the total viable seeds in the soil.

In winter cereal crops, A. myosuroides seeds are shed mainly in July but the seeds on the soil could not easily be treated with these herbicides until after harvest. The time interval between the weed seed shedding and harvest of the crop is likely to be several weeks with winter wheat but less than this with winter barley. The field experiment indicates that with paraquat, the longer the seeds were left on the soil, the less was the effect of the herbicide at reducing viability.

Under practical farming conditions, it seems unlikely that the viability of ungerminated A. myosuroides seeds can be reliably reduced by application of currently recommended rates of these herbicides although such a beneficial side effect may occur.

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PARTIAL SOIL STERILISATION AND SOIL AND LEAF MOISTURE CONTENT MEASUREMENT BY MICROWAVE RADIATION

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Summary Microwave radiation when adsorbed by a load is converted to heat, leading to a rise in temperature at a rate determined by the thermal and electrical charactertistics of that load. Three examples have been chosen to demonstrate how this property can be exploited to partially sterilise soil and to measure the moisture contents of soils and leaf tissue. Laboratory scale experiments are described which use a microwave oven operating at 2450MHz at a power level of 1kW. It is shown that fungal growth can be inhibited in soils, whilst leaving their bacterial activity unchanged, and that measurements of soil and leaf moisture contents by microwaves are comparable to the values obtained from the use of standard 50Hz power ovens.

Résumé Le rayonnement micro-ondes adsorbé par un corps est transformé en chaleur, ce qui entraîne une hausse de température progressive en fonction des caractéristiques thermales et électriques de ce corps. Trois exemples ont été choisis qui démontrent comment cette propriété peut être exploitée pour stériliser partiellement le sol et pour mesurer le taux d'humidité du sol et des feuilles. On décrit des expériences a l'échelle de laboratoire ou l'on utilise un four micro-ondes à une fréquence de 2450MHz et une puissance électrique de 1kW. Il est démontré que l'on peut réduire au minimum la croissance fongique dans les sols, tout en laissant inchangée leur activité bactérielle, et que la mensuration du taux d'humidité du sol et des feuilles par micro-ondes donne des valeurs comparables à celles obtenues dans des fours conventionnels de 50Hz.

INTRODUCTION

Microwave radiation is an energy source that is little used in agriculture and horticulture although a variety of applications have been suggested (Person 1972, Champ et al 1972, Menges and Wayland 1974, Jervis et al 1974, Nelson 1977). The advantages include the rapid penetration of the load by the radiation and the conversion of the latter to heat with no residues. Power can be dissipated evenly throughout the load and the centre can rise in temperature at the same rate (sometimes faster) as the outside instead of being the last place to get hot as is the case when normal thermal conduction processes are used. The quantity of energy absorbed depends upon several factors - amongst them the dielectric constant and the dielectric loss factor of the material, the frequency of the radiation and the strength and homogeneity of the electric field inside the load. The rate of rise of temperature depends upon the power dissipation, mass and specific heat (White 1970), and due account can be made of any heat loss by conduction via other surfaces and radiation if the temperatures are high enough.

The properties of microwave radiation could be used to partially (or completely) sterilise soil and also to obtain soil and leaf moisture measurements. These processes would utilise the rise in temperature during irradiation to either kill unwanted fungal spores and bacteria or to drive off the water present in soil or plant tissue. Partial sterilisation of soil is limited in agriculture but more widely used in horticulture, and present methods use steam or chemical which can be cumbersome in practice and expensive.

The dielectric properties controlling energy absorption vary between soil and plant tissue types and depend upon the moisture content (Cihlar and Ulaby 1974; Hoekstra and Delaney 1974; Nelson 1973; Stuchly et al 1978).

During an investigation of American high power mobile microwave weed killing machines (Wayland et al 1975) the authors had noted the interaction between 2450MHz radiation and soils and the resulting temperature rises and moisture losses. In addition, during the literature review related references were found (Vela el al 1976; Heald et al 1974; O'Bannon and Good 1971). The authors then decided to make more specific investigations into the possibilities of partial soil sterilisation (Garrett 1944) and the determination of soil and leaf tissue moisture contents. The preliminary results of this work are now presented in this paper.

METHOD AND MATERIALS

All experiments were carried out using a stainless steel microwave oven measuring 46cm x 30cm x 34.5cm (length x height x width) which was supplied with microwave energy by a magnetron operating at 2450MHz ± 30MHz. A mode stirrer was used to ensure an even distribution of the electric and magnetic fields throughout the cavity and the load. A Pyrex glass shelf was placed in the middle of the oven, and the centre marked, so that the petri dishes containing the samples would always be placed in the same position. For the partial sterilisation experiments, a quantity of garden soil (classified as an organic loam) was sieved to break up large particles and remove stones. Samples of this soil were placed into nine 6cm petri dishes (approximately 25g in each) and the lids were placed on. One sample was put aside for a control and the remaining eight samples were exposed to 1kW of microwave power (corresponding to $11 J cm^{-3} s^{-1}$ dissipated in a 40ml water load in a 6cm petri dish in the same oven position as the soil samples) for varying periods of time. After its particular exposure each sample was removed from the oven still with the lid on the petri dish, and sealed in a plastic bag for transport to the Department of Botany for analysis.

The viable microbial population of each soil sample was assayed by the soil plate technique (Warcup 1950). A sample of soil (approx. 15mg, oven-dry wt.) was taken from each treatment and transferred aseptically to a sterile petri dish. A drop of sterile distilled water was added and the soil dispersed in this. Ten ml of molten malt extract agar medium at 45° was then added to the dish and swirled gently to disperse the soil particles evenly throughout the medium. Ten replicate dishes were prepared from each treatment. The dishes were incubated at 25° for 48h and then examined for microbial growth. The number of bacterial and fungal colonies in a single low-power field of view of a binocular microscope was recorded. This figure is not therefore an absolute measure of population density.

Four different soil types were used for the moisture content measurements; sand, an organic loam garden soil, Levington compost and John Innes compost. Samples of each were placed in 9cm diameter petri dishes without lids which were weighed before irradiation and then re-weighed at intervals throughout their treatment. The exposures were at a power level of 1kW and continued until two successive weight recordings were the same. As a comparison, similar soil samples of known weights were placed in a normal (50Hz power) oven at a temperature of 80°C for 24h and then re-weighed to establish the amount of water that had evaporated.

Leaf moisture content measurements were made with 1kW of microwave power in a similar manner to soil moisture measurements, with samples of Hollyhocks (*Althea rosea*) and *Avena fatua* leaves being used. All moisture content measurements were made on a dry weight basis.

RESULTS

Table 1 shows the number of bacterial and fungal colonies counted as a result of different exposures to the microwave radiation. Fungal colonies can only be counted for the control sample - even the short period of 30s irradiation is sufficient to remove them, whilst at this level bacterial populations are the same as their control value. Increasing the exposure period to 60s and more shows decreasing amounts of bacterial activity.

Table 1.

The number of bacterial and fungal colonies per field of view from samples of an organic loam soil exposed for varying periods to 1kW of 2450MHz radiation.

Exposure Period (s)	No. of colonies per field of view: Bacterial colonies	Fungal colonies
0	70.2 ± 6.8	23.8 ± 5.4
30	71.4 ± 3.4	0
60	47.6 ± 15.0	0
90	19.4 ± 5.3	0
120	13.6 ± 7.5	0
180	8.8 ± 9.6	0
240	6.2 ± 2.7	0
300	4.2 ± 1.6	0
360	1.6 ± 2.3	0
	95% confidence limits	95% confidence limits

Figures 1, 2, 3 and 4, show the changes of weight of samples of sand, organic loam soil, Levington compost and John Innes compost respectively. It can be seen that most of the weight change occurs at the beginning of the treatment. On each graph are marked the moisture contents as measured after the first 12 mins. of the exposure and the value at the very end, and it can be seen that the maximum difference is 1.1% (Levington compost) with the differences for the other three soil types less than 0.5%. The measurements made in the 50Hz power oven test are given in Table 2 and the values of the moisture contents obtained by the microwave method are also given for comparison. In each case there is good agreement, with the values determined in the microwave oven being slightly higher.

Table 2.

The moisture contents of four soil types as determined by microwave (1kW, 2450MHz) oven and conventional (50Hz power) oven techniques.

Soil Type	Moisture Contents: Microwave Oven 12m	Microwave Oven 52m	Conventional Oven 24hrs.
Sand	5.1%	5.3%*	5.1%
Organic Loam	26.8%	27.2%	26.8%
Levington Compost	61.0%	62.1%	61.5%
John Innes Compost	35.7%	36.0%	34.5%

* 30m

Figure 5 shows the changes in weight of the samples of Althea rosea and Avena fatua leaves respectively with Table 3 showing the microwave oven values compared with those from the 50Hz power oven. Similarly to the soil measurements, most of the change occurs at the beginning of the irradiation period and the values from the two methods are in close agreement.

Table 3.

The moisture contents of two leaf types as determined by microwave (1kW, 2450MHz) oven and conventional (50Hz power) oven techniques.

Leaf Type	Moisture Contents: Microwave Oven 5m	Microwave Oven 14m	Conventional Oven 24hrs.
Althea rosea	75.1%	77.8%	78.6%
Avena fatua	82.0%	83.9%	84.6%

DISCUSSION

The results from the first of the experiments show that in the sample of organic loam soil used, partial sterilisation was achieved after 30s exposure to 1kW of 2450MHz radiation in the experimental oven. The samples used were small ones - in the order of 25g - but the oven could have accommodated much larger samples, as only a small amount of the available energy was used. The moisture content of the soil at the time of the experiment was 22.0% (dry weight basis), and the variations in this would alter the treatment time necessary. These initial results are very encouraging, however, and further work is being done with different soil types and different moisture contents, to determine the temperatures reached during the irradiation periods and the energy requirements for partial sterilisation.

The moisture contents of both soils and plant leaves as measured by microwave methods are comparable with those values obtained by conventional methods. The advantage of the microwave radiation lies in its speed. It is possible to make measurements after minutes although this time will vary with the microwave oven used, the soil or plant type, its moisture content and the amount of material. It is certainly much shorter, however, than the time period of hours required by using conventional ovens at temperatures of 80-110^{o}C.

Microwave ovens for domestic purposes are quite suitable for these applications and are available from £200, and the running costs of one for a few minutes will be less than that of a conventional oven for a few hours. Although a large model of one of the latter may be able to contain more samples, the rapidity with which the results are available should compensate for smaller oven sizes. Large microwave units could be built if necessary, perhaps with conveyor belts providing soil for continuous whole or partial sterilisation processes. Portable units could be used when fields of crops are discovered to have tiny pockets of infection i.e. in strawberries.

These experiments have shown the ability of microwave radiation to partially sterilise soil, and to provide measurements of soil and leaf moisture content quickly, and demonstrate the versatility of this type of energy source.

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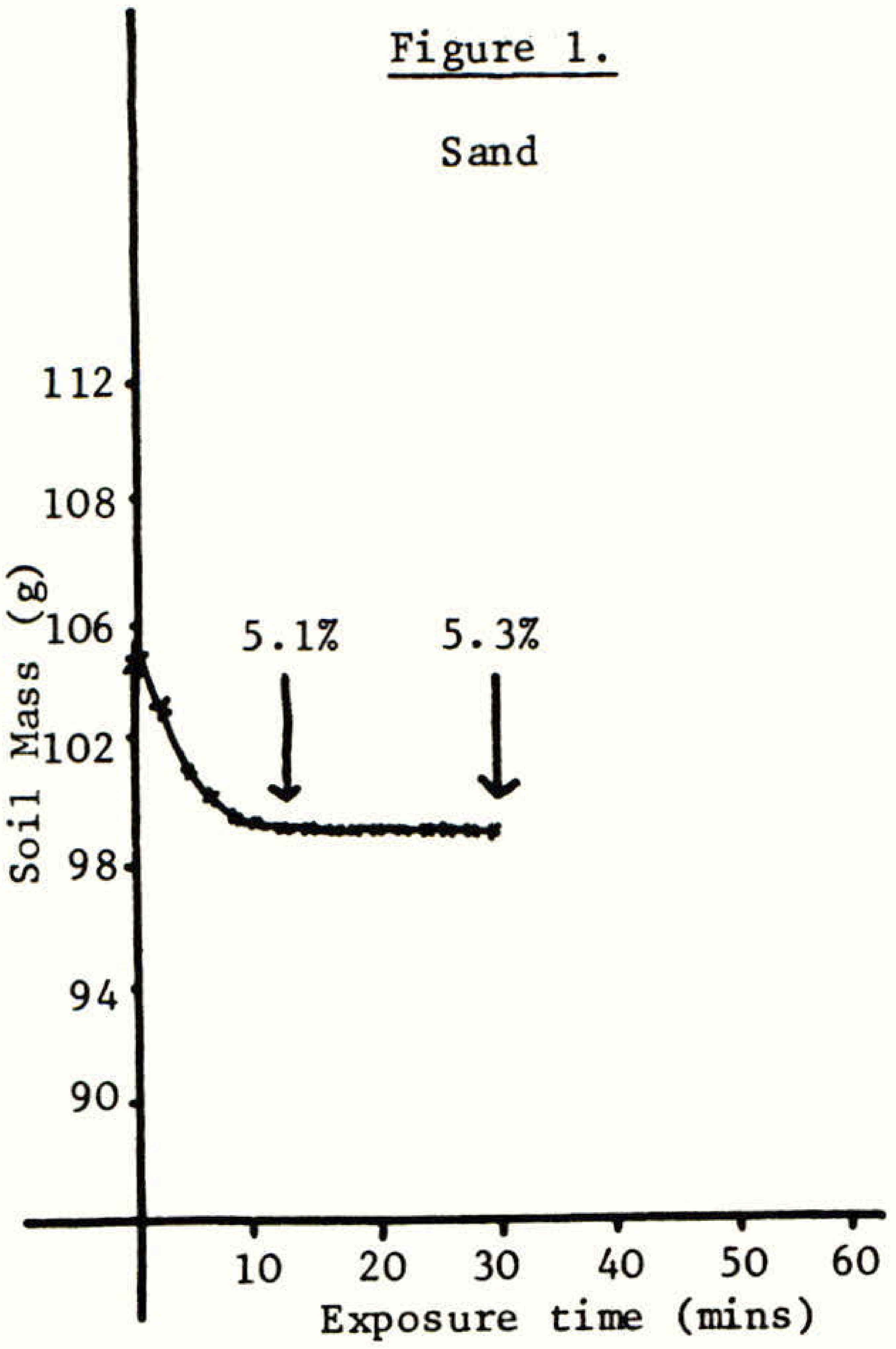
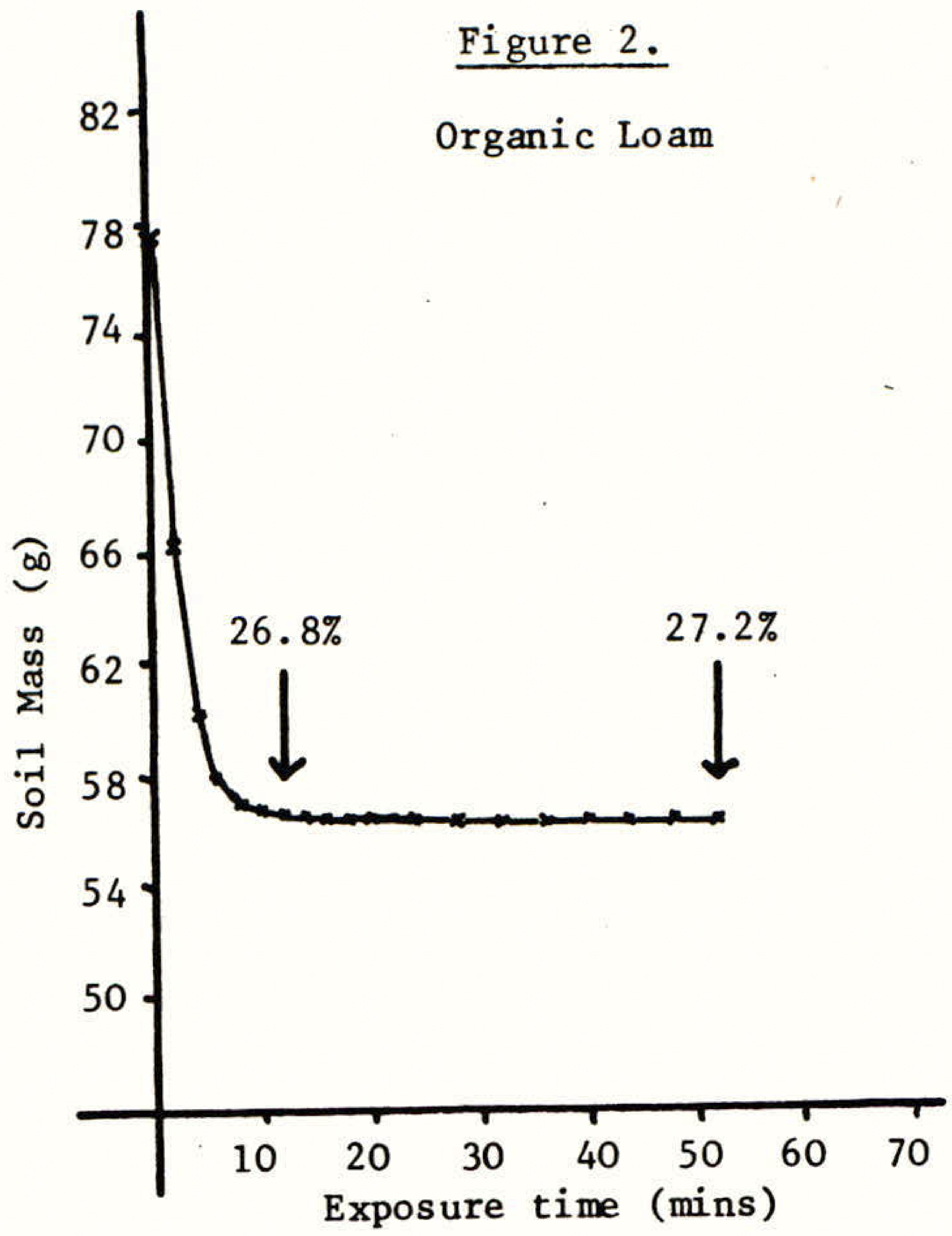
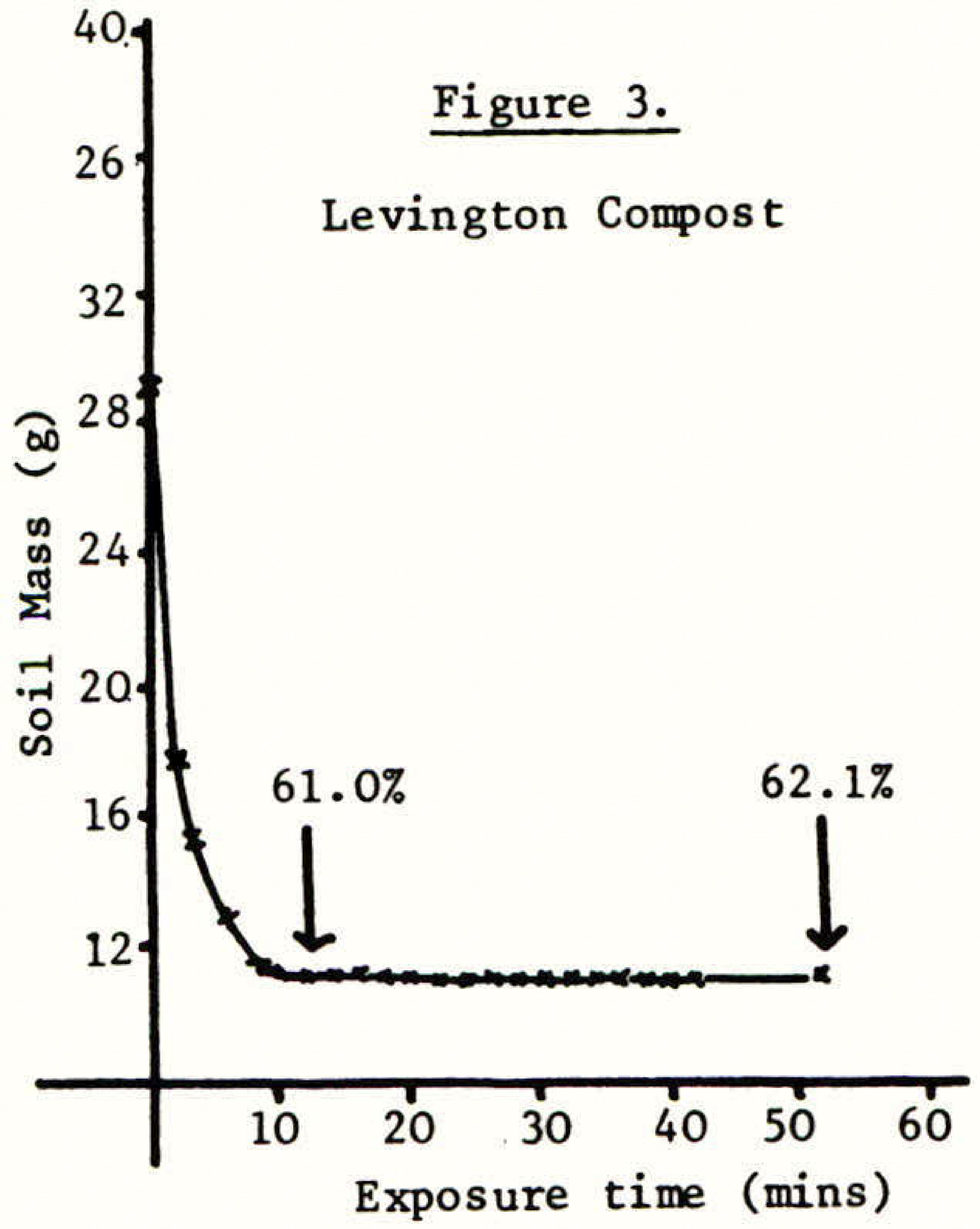
The decrease in weight of four soil samples when exposed to 1kW of 2450MHz radiation for increasing periods of time.







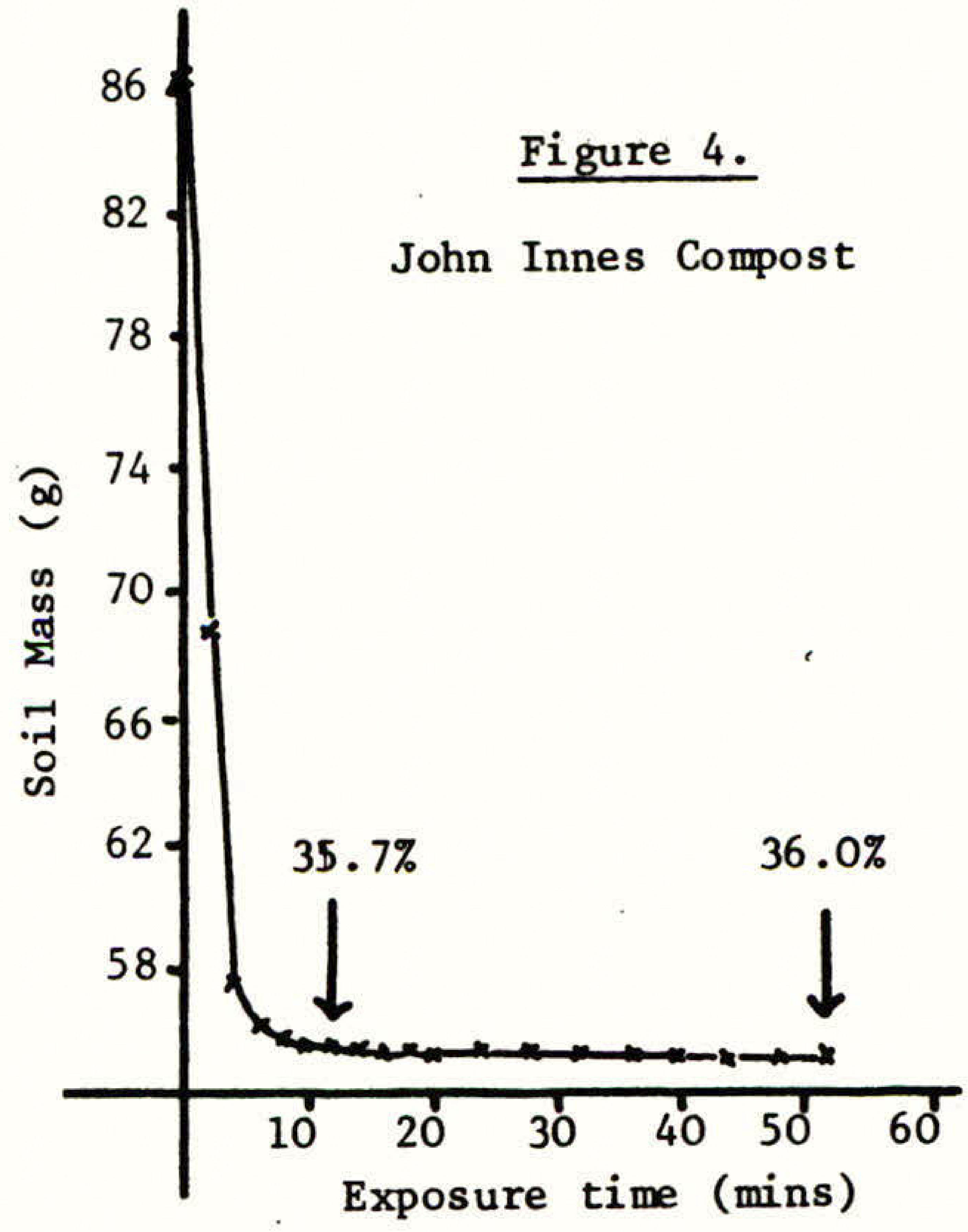
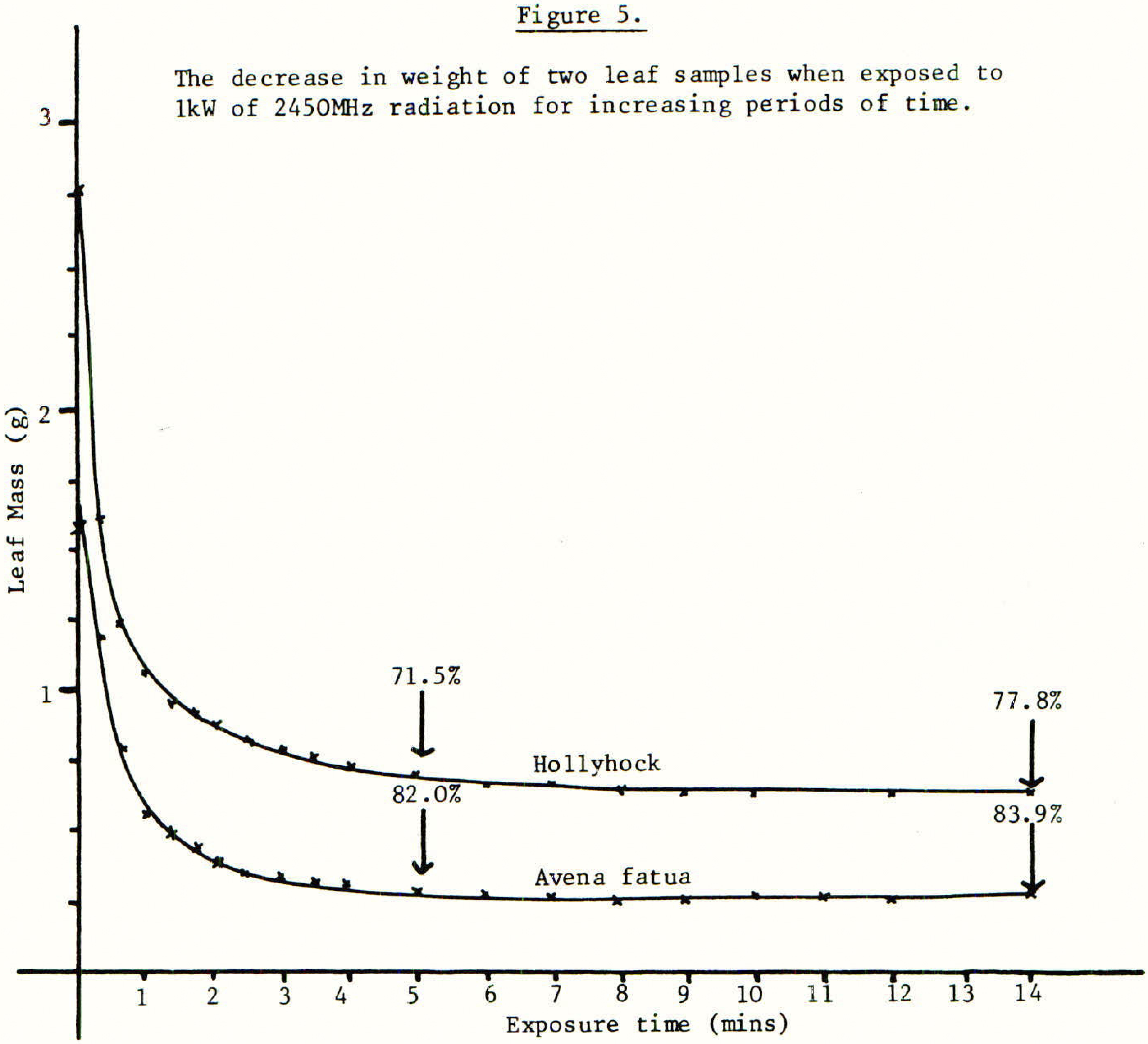


Figure 5.

The decrease in weight of two leaf samples when exposed to 1kW of 2450MHz radiation for increasing periods of time.



BIOLOGICAL CONTROL OF PERENNIAL BINDWEEDS WITH ARGUS TORTOISE BEETLE

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Summary Larvae of the Argus Tortoise Beetle (Chelymorpha cassidea) consumed leaves of hedge bindweed (Convolvulus sepium) in about 3 ha in an abandoned field and about 1 ha in volunteer field rye (Secale cereale). Only a few plants around the perimeter of a dense infestation escaped depredation from larvae, to be consumed later by the adults. Pupation was evident on plants such as goldenrod (Solidago canadensis). Adult beetles which emerged in about 7 days consumed leaves of bindweed which infested an adjoining field of maize. The 24 rows of maize were completely cleaned of bindweed within 10 days.

Larvae and adults were successfully transferred to hedge and field bindweed (C. arvensis) infesting ornamental crops and vegetables. The fact that the Argus Tortoise Beetle feeds only on plants of Convolvulaceae makes it a potential candidate for the control of bindweeds (Convolvulus spp.) and morningglory (Ipomoea spp.) in areas and crops where insecticides are not used during periods of larval and adult feeding.

Résumé La larve de Chelymorpha cassidea a mangé tous les feuilles de liseron (Convolvulus sepium) sur environ 3 ha et 1 ha en seigle (Secale cereale). Seulement quelques plantes restaient au tours de périmètre d' infestation être mangé par les adultes plus tard. La larve a choisi les plantes comme Solidago canadensis pour la pupation. Après sept jours, les adultes ont émergé des pupes et ont cherché les liserons comme nourriture. Les adultes ont trouvé les liserons dans un champ de maize. Apres dix jours, le liseron était bien controllé en 24 lines de maize.

La larve et les adultes de Chelymorpha étaient porté avec succès a liserons (aussi liserons des champs, C. arvensis) parmi les plantes ornamentales et les legumes. Depius Chelymorpha cassidea mange seulement les plantes de la famille Convolvulaceae, il y a la chance de controller ses mauvaises herbes où les insecticides ne sont pas utilisé pendant le grandissement des insects.

INTRODUCTION

The bindweeds (Convolvulus spp.), particularly Convolvulus arvensis is one of the most prevalent and difficult to control perennial weeds in North America and Northern Europe. These weeds are difficult to control in cereals, fruits and ornamental crops, and are almost impossible to control in potatoes (Solanum tuberosum). Road sides and waste places serve as common sources of re-infestation of cropland. The Argus Tortoise Beetle (Chelymorpha cassidea), a native of U. S. and occurring in Canada, was first reported by Fabricius in 1775. According to early reports, this insect feeds on bindweeds, morningglory (Ipomoea spp.) and in 1919 was reported as a pest on sweet potato (Ipomoea batatas). The species is distributed over a wide area of the United States from Washington to Texas, Florida, the Northeastern states and the eastern tier of the Midwestern states. Although the insect has been observed on many plants including maize, cabbage, strawberries, raspberries and goldenrods. Members of the family Convolvulaceae are considered to be the sole source of food for the Argus Tortoise Beetle (Chittenden, 1924).

This insect is prey for at least 14 species of birds, particularly the starling and kingbird. Insect parasites include an egg parasite Emersonella niveipes, a minute chalcidoid, a parasitic fly on larvae (Masicera exilis) and a larvae-eating bug (Apateicus bracteatus) (Chittenden, 1924).

METHOD AND MATERIALS

An ecological study of Argus Tortoise Beetle was conducted from May to August 1977 and 1978 in hedge bindweed and associated plants on an abandoned field and in crops on Long Island, New York. Observations included insect predation of hedge bindweed infesting rye and maize, as well as a beetle migration into sweet potatoes.

The insect was reared in the laboratory from emergence of the egg through larval and pupal stages to mature adults on fresh leaves of hedge and field bindweed. Certain other species were selected also as a potential source of food. Larvae and beetles were transferred to maize, zucchini, rye, pine, grape, yew and Euonymus at 6 locations infested with hedge or field bindweed to assess adaptability and establishment of new colonies.

RESULTS

Field studies

In May of 1977, mature beetles, eggs and larvae were observed on some hedge bindweed plants comprising an area of about 3 ha. Beetles were noted on several species including mustards (Brassica spp.), goldenrod (Solidago spp.), and ladysthumb (Polygonum persicaria), but eggs were laid only on the undersides of the hedge bindweed leaves. From early May to mid-July, larvae developed from 1 mm to 1 cm long, during which time an area of bindweed approximately 7 x 7 m^2 was completely decimated. Annual grasses and forbs subsequently competed intensively in this area of denudation, and regrowth of the hedge bindweed did not occur throughout the remainder of the 1977 season. Tortoise beetles were observed feeding on hedge bindweed in the surrounding area until late August, at which time adults disappeared. Several ha of bindweed flowered, matured and set seed.

In late May of 1978, adult Tortoise beetles were observed to be copulating and laying eggs on hedge bindweed plants in an area of approximately 2.5 ha. Within a week larvae were hatching and consuming the tender, new leaves. Egg laying occurred until late June, but by mid-June some plants were virtually stripped of their leaves, and larvae had developed to approximately 1 cm in length. In an adjacent field of rye, beetles searched out bindweed to lay their eggs, and developing larvae effectively denuded the leaves. By the end of June, adult beetles were rare in the area, and the main infestation of bindweed was completely defoliated by the golden-hued larvae. Larvae selected such plants as goldenrod, milkweed (Asclepias), bindweed stems, leaves of rye or plot stakes for pupation. Pale yellow pupae were evident June 27, and were common by July 1. On this date, bindweed plants intact with leaves could be found only around the perimeters of the main infestation.

By July 9 most pupae had metamorphosed to pale yellow adult beetles. These adults migrated to remaining bindweeds and began to feed on the leaves. By July 12, not a single bindweed shoot could be found in the entire infested area, and beetles migrated into patches of sweet potatoes. Because of the overwhelming population, an application of foliar insecticide although effective, failed to protect the plants.

Approximately 50 ml of beetles died of poisoning at the base of each plant. Although winged, beetles migrated only on foot. The invading beetles also discovered hedge bindweed in an adjoining field of maize about 20 cm tall. Although cultivated between the rows, and tilled 6 times prior to planting, the bindweed had reached 12 to 15 cm within rows and were entwined about the maize plants. Within 10 days, hordes of adult beetles had consumed the bindweed across 24 rows. By July 23, most of the population had wandered away, with only a few beetles remaining in the tall maize, and a few others were attacking emerging bindweed shoots in late maize plantings. On the abandoned field at this date, dead beetles were prevalent everywhere, but live ones were extremely difficult to find. There was no indication of any egg-laying by the adults, and at the end of July, live specimens of either Tortoise beetles or bindweed were rare indeed.

A few beetles which appeared dormant were found beneath the debris among bindweed rhizomes on July 30. Proliferation of shoots at nodes on rhizomes examined at 20 locations suggested that beetles had repeatedly consumed emerging shoots.

Tortoise beetle larvae ranging in length from 4 to 15 mm were transferred to a field bindweed infestation and to hedge bindweed at three locations, one in maize and zucchini, one in field rye, and one in an abandoned field. Of these, the transfer to the abandoned field failed to survive because of use nearby of foliar insecticides in potatoes. The larvae demolished the hedge bindweed in maize and zucchini. In the rye, larvae pupated and produced adults.

Mature first generation beetles were transferred to hedge bindweed in pines, grapes, maize, zucchini, rye, Euonymus and yew, and in abandoned fields at 3 locations on July 9. Beetles survived at the new locations except one adjacent to a potato field in which foliar insecticides were used. Although some copulation was observed, there was no sign of egg-laying by first generation beetles at any of the locations. The beetles were often found on grasses and several other species including milkweed, goldenrod, lambsquarters (*Chenopodium album*), mustard and ladysthumb, but there was no sign of feeding on the foliage of any of the plants. The masses of dead beetles in the area confirm observations that the insect cannot survive on plants other than members of the family Convolvulaceae.

Laboratory studies

Hedge bindweed leaves with egg clusters attached, and hatched larvae were brought into the laboratory and reared in petri-plates. The larvae developed on fresh bindweed leaves which were collected every 2 days. Although the eggs failed to hatch, minute larvae which just emerged from eggs developed normally, pupated and emerged as adults. The adults continued to feed on hedge or field bindweed leaves which were collected. Larvae and beetles were offered leaves of Irish potato and field dodder (*Cuscuta spp.*) (one of the Convolvulaceae), but refused to eat and therefore died.

Second generation beetles which had fed on bindweed leaves were given choices of three substrates in petri plates: 1) thinly-sliced tuber of sweet potato 2) mashed raw sweet potato and 3) boiled, mashed sweet potato. They preferred the sliced tuber, but ate little. Since beetles did not feed on bindweed leaves which were added after 24 hours, and later died, it is likely that the feeding cycle was completed.

DISCUSSION

The larvae and adult of the Argus Tortoise Beetle has thoroughly decimated approximately 3 ha of hedge bindweed. Regrowth did not occur after severe insect depredation in 1977. Regrowth occurred on only about 1% of the infestation by mid-September, 1978. It is likely that infestations of hedge and field bindweed can be eradicated with 3 consecutive years of depredation. It remains to be seen, however, whether the beetle population will be maintained in 1979 since the insect population exceeded food supply in 1978. The presence of least some beetles in soil litter suggests that sufficient adults may overwinter to repopulate the area in 1979. Earlier observations have indicated that the insect produces one generation, or one and a partial second generation before hibernating in soil during August (Metcalf and Flint, 1951).

It is interesting to note that tillage operations which sever rhizomes in small pieces induce regrowth almost immediately, while regrowth is not induced after the bindweed plant is denuded by insects. Similarly, regrowth occurred after applications of the herbicide glyphosate on emerged bindweed at the same location in June 1977 (Selleck and Kline, 1978).

Although insects, particularly adults, have been reported on the foliage of several species, feeding has occurred only on plants of the family Convolvulaceae. The fact that this native insect has not developed secondary food preferences suggests the utility of this species for control of weeds in the morningglory family. The fact that larvae, and particularly beetles can be transferred to new locations provides the opportunity for establishment of populations for the control of hedge and field bindweed and possibly morningglory (*Ipomoea* spp.) in ornamental and field crops, vegetables and waste areas. The use of insecticides in crops during the active period of larvae and beetles would negate the use of this insect for biological control. Beetles can be reared in the laboratory on bindweed and possibly on sweet potato to serve as a supply for establishment of populations at locations where weeds are present.

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HERBICIDE DEVELOPMENT FOR TRANSPLANTED AND DIRECT SEEDED TOMATOES

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Summary Research during the past 5 years has shown that metribuzin can be used effectively for broad spectrum weed control in transplanted tomatoes if applied post-emergence at a dosage appropriate to the soil type, following a period of sunny weather, and if directed to the bottom one-third of the tomato plant. Season long weed control was obtained when metribuzin was applied sequentially to a dinitroaniline herbicide applied pre-planting soil incorporated. Herbicides which have shown promise in direct-seeded (plug-mix) tomatoes are low rates of trifluralin, ethalfluralin or napropamide tank-mixed with diphenamid and applied as soil incorporated pre-seeding treatments. Activated charcoal applied in a mixture with fine vermiculite over the plug successfully protected emerging tomato seedlings from injury from metribuzin applied pre-emergence, permitting satisfactory weed control for this direct-seeding technique.

Résumé La recherche au cours des 5 dernières années a démontré que la métribuzine peut être utilisée efficacement pour le contrôle d'un large spectre de mauvaises herbes chez les tomates transplantées si appliquée après l'émergence à un taux approprié au type de sol, après une période d'ensoleillement et si elle est dirigée sur le tiers inférieur du plant de tomate. Le contrôle pour toute une saison est obtenu lorsque la métrabuzine est appliquée séquentiellement à un sol où un herbicide de type dinitroaniline a été incorporé avant la plantation. Les herbicides les plus prometteurs pour les tomates en semis direct (plug-mix) sont de bas taux de trifluraline, éthalfluraline ou napropamide, mélangés en réservoir avec la difénamide et incorporés au sol comme traitement pré-semailles. Il est possible de protéger les plantules de tomates contre la métribuzine appliquée avant leur émergence en ajoutant du charbon activé mélangé à du vermiculite fin par dessus le semis.

INTRODUCTION

Tomatoes (Lycopersicon esculentum Mill.), grown both for the early fresh market and for the processing industry are an important crop in southern Ontario with about 10,000 ha grown annually. Their cash value exceeds all other vegetables grown in the province. Weed control practices consist of inter-row tillage and the use of recommended herbicides.

Research on the development of herbicides for weed control efficacy and crop tolerance was started about 20 years ago (Saidak, 1962). These early investigations showed that pentamide (solan), chloramben G, or sulfallate provided effective control of many weed species with adequate crop safety. The next major development was the introduction of diphenamid and the dinitroaniline herbicides, notably trifluralin. These herbicides controlled many grass-type weeds not previously controlled and sequential treatments of trifluralin or diphenamid followed by one of the above herbicides largely replaced hand weeding operations.

Invariably some weeds have escaped even such herbicide programs. The degree of competition afforded by a few surviving weeds, which grow rapidly and attain considerable size, may be serious and they also interfere with mechanical harvesting operations. Studies have indicated that even 95% weed removal is insufficient to prevent excessive yield reductions (Friesen, 1978). These studies also showed that the critical period of weed competition is between 24 and 36 days after transplanting and complete weed control is essential during this period. These results prescribe very high standards of efficacy for any herbicide to be developed and used in a tomato crop.

Perhaps the most significant breakthrough in recent years has been the introduction of metribuzin as a selective herbicide. Initially this herbicide appeared to be the panacea that tomato growers were looking for; broad spectrum weed control for most of the growing season. It was soon noted, however, that metribuzin caused crop injury in certain situations and many growers were reluctant to adopt its use.

Satisfactory weed control programs are also a prerequisite to the field seeding of tomatoes. Diphenamid, the only currently recommended herbicide for this technique, generally fails to provide satisfactory broad-leafed weed control. Metribuzin is highly effective for both broad-leafed and grass weed control but pre-emergence application of this herbicide results in phytotoxicity to emerging tomato seedlings (Fortino and Splittstoesser, 1974; Henne and Guest, 1974). Activated charcoal adsorbs most herbicides and when applied over direct-seeded tomatoes will protect them from pre-emergence herbicide treatment (William and Romanowski, 1972; Henne and Guest, 1974). Liptay and Marriage (1978) protected plug-mix seeded tomatoes from metribuzin injury by specific placement of an activated charcoal-vermiculite mixture.

The experiments described in this paper deal primarily with dosages and methods of applying metribuzin, tank mixed or sequential treatments with other herbicides, effect of weather conditions, the use of protectants, etc., and encompass the past 5 years of research on tomatoes at the Harrow Research Station.

METHOD AND MATERIALS

Transplanted tomatoes

Experiments were conducted on Fox sandy loam soil (70% sand, 16% silt, 14% clay, 1.1% o.m., pH 6.7) and Brookston clay loam soil (41% clay, 29% silt, 30% sand, 4.1% o.m., pH 5.9). Tomato varieties were Springset, an early fresh market type, or C-28, a processing type. Tomato plants were started in a commercial greenhouse in late March and transplanted to the field between May 14 and May 20 depending on the year. Plots consisted of single rows 8 m long and spaced 2 m apart. Plants were spaced 60 cm within the row giving 13 plants/plot. The crop received 670 kg/ha of N-P-K fertilizer (10-20-20) at time of planting and 75 kg/ha of ammonium nitrate as a side dressing about 30 days later. Endosulfan and captafol were used as required for insect and disease control. Weed species on sandy loam consisted mainly of

Chenopodium album L., Ambrosia artemisiifolia L., Cenchrus longispinus (Hack) Fern, Digitaria sanguinalis L. Scop., and Amaranthus retroflexus L. The clay loam also contained Abutilon theophrasti Medic., Setaria glauca L., and Echinochloa crusgalli L. Beauv. Depending on the year, the weed density averaged 150-220 weed seedlings/m^2 on the sandy loam and 25 - 80 m^2 on the clay loam. Mature fruit was hand harvested from the centre 11 plants in each row at 7 - 10 day intervals beginning about mid-July and continuing through August on the early variety and from mid August to late September on the processing variety. Herbicides were applied with a boom-type plot sprayer delivering 740 /ha total solution at a pressure of 2.4 bars. Weeds were in the cotyledon to 4-leaf stage (0-8 cm high) at time of post-emergence treatments. Pre-planting treatments were soil incorporated with a dual double-discing at right angles followed by a harrow or cultipacker. All treatments were replicated four times in randomized block experiments.

Direct-seeded tomatoes

Plug-mix for tomato seeding was prepared by mixing the following: 12 l. sifted peatmoss, 2 l. vermiculite, 2 l. perlite, 60 g lime, 16 g of 10-52-17 soluble fertilizer, and water to moisten the mixture to approximately 70%. Tomato seeds cv. H-1706 were pregerminated at 25^{o}C for 48 h and combined uniformly into the above using the equivalent of 4 g of dry seed. Using a Holland plug-mix planter, a "plug" of approximately 75 ml of the seeded mix was placed in the soil from the soil surface to a depth of 4 cm and soil was pressed around the plug. For herbicide evaluation experiments without charcoal, herbicides were applied and incorporated prior to seedling as described for transplanted tomatoes. Plot size was 1.5 m by 8 m containing a single row of plugs spaced at 30 cm intervals and four replicates were used per experiment.

Charcoal-vermiculite (Gro-Safe, I.C.I.:Zonolite No. 4, 1:4 w/w) was prepared by tumble mixing until all charcoal had adhered to the vermiculite. This mixture was applied over the plug-mix seeded tomatoes by the following methods: 15 ml applied by hand or mechanical applicator in a 10-cm square (5 mg/cm^2 actual activated charcoal) over the plugs following planting or 15 ml applied from a dispenser to the top of the plug in the pocket of the plug-mix planter just prior to planting. Following charcoal treatment, metribuzin was applied pre-emergence at 0.60 kg/ha alone or in combination with napropamide or diphenamid.

RESULTS AND DISCUSSION

Transplanted Tomatoes

Results over a period of 3 years have shown that metribuzin at 0.28 to 0.56 kg/ha applied post-emergence is adequate for satisfactory weed control, but that at least 0.56 kg/ha is required if applied pre-planting soil incorporated (Table 1). The post-emergence treatment is preferred on sandy soil with low o.m. Varietal differences are known to exist and have been reviewed by Stephenson et.al. (1976) but have not been studied at Harrow. The optimum time for post-emergence applications is somewhere between 14 and 24 days after transplanting (Table 2) and the wettable powder and flowable formulations have been essentially equal in performance.

Table 1

Methods of metribuzin application to transplanted tomatoes
Harrow, Ont. 1974-76

Metribuzin Kg/ha	Broad-leafed weed control*	Grass-type weed control*	Tomato yields (3 yr. av.) kg/plot
Sandy loam			
hand weeded	10.0	10.0	39.6
.28 post	8.4	9.1	37.7
.56 post	9.6	9.6	40.4
.28 + .28 post	9.1	8.7	35.9
.56 ppi	9.2	8.6	32.3
			N.S.
Clay loam			
hand weeded	10	10	23.3
.56 post	9.5	8.2	23.8
.28 + .28 post	9.3	8.7	24.8
.56 ppi	9.5	8.7	25.6
.56 ppi + .56 post	9.7	9.5	21.6
			N.S.

* 0-10 scale; 0 = no weed control; 10 = complete kill

Table 2

Effect of dates of spraying metribuzin
on transplanted tomatoes, 1978

Metribuzin (days after transplanting)	Tomato yields First pick kg/plot	Total picks kg/plot
10	5.86	15.88
12	5.75	16.84
14	6.15	20.96
16	5.87	20.52
18	4.97	17.60
20	5.19	18.74
22	6.56	20.00
24	6.90	19.05
26	5.73	17.48
28	4.92	14.93
30	4.61	15.46
check	6.89	19.70
	N.S.	N.S.

Research results on the effect of sunlight on metribuzin injury have been published (Friesen and Hamill, 1978). Early pick yields were reduced when spraying followed 72 hrs of cloudy and/or cool cloudy weather, but total yields were generally not affected. These findings agree with work done by Phatak and Stephenson (1973) who found, using artificial shading techniques, that metribuzin toxicity increased as sunlight intensity decreased prior to spraying. Weed control was also improved if spraying followed at least 2 - 3 days of sunny weather (Table 3).

Table 3

The effect of sunlight on weed control with metribuzin

Treatment	Sunny (72 hr)	Cloudy (72 hr)
	Broad-leafed weeds	(3 yr. av.)
check	10.0	10.0
metribuzin (0.28)	8.4	7.1*
metribuzin (0.56)	9.6	9.4
	Grass-type weeds	(3 yr. av.)
check	10.0	10.0
metribuzin (0.28)	9.1	7.4**
metribuzin (0.56)	9.6	9.4

*Significantly lower than other treatments (P=.05), based on 0-10 scale (0=no control, 10=complete kill)

The application of a dinitroaniline herbicide as a pre-planting incorporated treatment has had no noticeable effect on crop response to metribuzin applied post-emergence (Table 4). In 1975, such prior treatments actually prevented injury to tomato plants from metribuzin following a period of cloudy weather. Further work is necessary to evaluate this phenonema.

Table 4

Effect of dinitroanilines on sequential metribuzin treatments, Harrow, 1974-1978

Pre-planting treatment* (kg/ha)	No. of Experiments	Tomato Yields kg/plot
Handweeded	10	33.9
Trifluralin (0.84)	10	32.9
Butralin (1.68)	8	33.5
Dinitramine (0.37)	10	30.9
Profluralin (1.12)	6	30.8
Fluchloralin (1.12)	7	30.9
Ethalfluralin (1.00)	1	33.4
		N.S.

*Metribuzin applied post-emergence at 0.28 kg/ha

The most effective weed control combined with high crop yields over the 5-yr. period have resulted from a dinitroaniline herbicide applied pre-planting soil incorporated, followed by metribuzin at 0.28 to 0.56 kg/ha post-emergence. If the possibility of injury to the crop exists, then metribuzin should be applied as a directed spray to the bottom 1/3 of the tomato plants to ensure added crop safety. The lower rate should be used on sandy loils and the higher rate on clay soils.

Two other herbicides require mention at this time; bentazon (Basagran) and chloramben methyl ester (Vegiben). Bentazon has shown sufficient selectivity for the control of certain perennial weeds in a tomato crop, while chloramben methyl esterappears to have somewhat more selectivity in a tomato crop than the salt formulations. These herbicides, however, are presently not registered for use in tomato crops in Canada.

Direct-seeded Tomatoes

In the search for selective herbicides for direct-seeded tomatoes, results over the past 2 years on 2 soil types indicate that napropamide, ethalfluralin or trifluralin tank mixed with diphenamid, applied pre-seeding soil incorporated, offer considerable promise (Table 5). Pebulate was effective on the clay soil but not on the sandy soil. Low rates of metribuzin applied post-emergence were inconsistent both as to selectivity and weed control.

Table 5

Herbicide evaluation in direct seeded (plug-mix) tomatoes, 1977-78

Herbicide(s)	Rate Kg/ha(ai)	Time of application	Fox sandy loam Tomato yields* t/ha	Fox sandy loam Weed wt. t/ha	Brookston clay loam Tomato yields* t/ha	Brookston clay loam Weed wt. t/ha
chloramben (methyl ester)	2	pre	0.9 g	17.7	14.0 bcd	3.0
napropamide	2	ppi	15.3 ab	1.7	13.2 cde	2.0
napropamide + diphenamid	1+6	ppi(T/M)	16.6 a	1.6	17.8 abc	1.8
napropamide & metribuzin	1&0.125	ppi/post	10.6 bcd	1.4	18.3 abc	1.8
ethalfluralin	1	ppi	2.9 efg	9.4	10.8 def	3.2
ethalfluralin + diphenamid'	1+6	ppi(T/M)	12.1 abc	2.5	15.8 bcd	1.0
trifluralin	0.5	ppi	2.8 efg	15.2	10.0 def	2.8
trifluralin + diphenamid	.5+6	ppi(T/M)	13.0 abc	4.7	19.7 ab	0.8
pebulate	5	ppi	1.3 g	27.2	17.6 abc	1.8
pebulate & metribuzin	5&0.125	ppi/post	5.6 d-g	6.1	19.7 ab	1.2
butam(propanamide)	3	ppi	10.7 bcd	5.4	12.5 c-f	2.4
butam(")	3	pre	7.9 c-f	7.3	9.8 def	3.8
weed free check	-	-	14.4 ab	0	23.4 a	0
unweeded check	-	-	1.6 fg	27.7	5.9 f	6.6

*Yields followed by the same letter are not significantly different according to Duncan's Multiple Range Test (P=.05)

T/M = tank mixed

Metribuzin applied without a protective layer of charcoal over the plug was very phytotoxic to emerging seedlings and reduced stands by over 50%. A similar reduction occurred in one exception to the protection by charcoal when the charcoal-vermiculite applied to the plug after planting was dispersed by a high wind. With charcoal protection, application of metribuzin in seven experiments over 3 yr. caused no reduction in the number of plugs with plants (97.6 ± 5.1% of control) or the number of plants per plug (96.4 ± 7.6% of control). These results included the two soil types, all methods of charcoal application, combinations with napropamide and diphenamid, and experiments in which plugs treated with charcoal as they were planted were covered with soil to leave only a 3 to 4 cm^2 opening, to simulate deep planting or soil covering by press wheels. At 0.6 kg/ha of metribuzin, fresh weight per plant in protected plugs was 83.3 ± 5.5% of the control weight. Although this reduced plant weight was not significant, it may reflect uptake of low doses of unadsorbed metribuzin by emerging and developing seedlings especially since at 0.4 kg/ha of metribuzin, plant weight averaged 93.9% of the control. Increase in the rate of metribuzin to 0.9 kg/ha in two experiments caused no significant decrease in the number of plugs (90.1%) or the plants per plug (81.9%) compared to the control but at 1.2 kg/ha, metribuzin significantly reduced the number of plugs with plants; 74.4% of the untreated control.

Charcoal was also found to provide protection of gel-seeded tomatoes from pre-emergence application of metribuzin but not as effectively as with plug-mix-seeded tomatoes.

Table 6

Protection of gel-seeded tomatoes from pre-emergence application of metribuzin using activated charcoal

Experiment and treatment	Rate kg/ha	Charcoal location[a]	Gel sites /plot	Plants/ gel site	Plant wt[b]/ gel site	Weight[b]/ plant
Greenhouse						
Control				5.3		23.1
Metribuzin	0.6	above gel		3.6*		12.0*
Metribuzin	0.6	in gel		2.4*		7.1*
Metribuzin	0.6	above and in		3.8		15.5
Field						
Control		above and in	15.3	2.2	401	234
Metribuzin	0.6	above and in	8.3	1.2	188	164
Metribuzin + diphenamid	0.4 6.7	above and in	9.3	1.5	355	244

[a]Charcoal (0.25 g) above the gel was applied in an aqueous gel suspension to cover a 50 cm^2 area: charcoal-vermiculite mixture (0.5 g) in the gel was mixed in prior to seeding.

[b]Dry weight (mg) for greenhouse: fresh weight (g) for field.

*Significantly different from the control: LSD 5%; 1.5 (plants) and 11.0 (weight).

Although injury and plant loss occurred in all treatments, the best protection, as evidenced by growth rate, number of gel sites with plants, plants per gel site, and plant weight, was obtained where charcoal was placed both in and above the gel (Table 6). Metribuzin at both concentrations in the field decreased the gel sites per plot and plants per gel site but only metribuzin at 0.6 kg/ha reduced the fresh weight of plants per gel site (P=0.01) and the fresh weight per plant (P=0.05).

Weed control provided by 0.6 kg/ha of metribuzin applied pre-emergence over the charcoal-protected plugs averaged 76% and 80% for annual broad-leafed weeds and 58% and 86% for annual grass weeds on sandy loam and clay loam soil, respectively. Where napropamide at 4.0 kg/ha or diphenamid at 6.7 kg/ha was added to the metribuzin in combination, corresponding weed control was 82% and 88% for broad-leafed weeds and 82% and 94% for grass weeds indicating the improved control which these herbicides confer, especially for grasses on sandy loam soil.

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