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Title:	Bulbs and cut flowers: development of a combined dazomet and metam-sodium treatment as an alternative to methyl bromide for soil sterilisation.
Project leader:	Dr T M O'Neill, ADAS Arthur Rickwood
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Key staff:	G Budge, A Shepherd and T Ratcliffe, ADAS Arthur Rickwood
Location of project:	Moulton, Lincs and Melbourn, Herts (field trials) ADAS Arthur Rickwood (laboratory tests)
Project co-ordinators:	Mr R Willingham, Mr P Harrison and Mr T Crossman
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The results and conclusions in this report are based on a series of experiments conducted over a three year period. The conditions under which the experiments were carried out and the results have been reported in detail and with accuracy. However, because of the biological nature of the work it must be borne in mind that different circumstances and conditions could produce different results. Therefore, care must be taken with interpretation of the results, especially if they are used as the basis for commercial product recommendations.

AUTHENTICATION

I declare that this work was done under my supervision according to the procedures described herein and that the report represents a true and accurate record of the results obtained.

Dr T M O'Neill
Principal Research Scientist
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PRACTICAL SECTION FOR GROWERS

Commercial benefits of the project

This project has identified a new contractor-applied soil sterilisation treatment for use in cut flower production as an effective alternative to methyl bromide for treatment of outdoor land to control soil-borne fungal pathogens and weed seeds. The treatment, involving the dual application of dazomet and metam sodium, is adjustable for different crops, growing systems and pest, disease and weed problems. It has a relatively short turn-around time. Commercial exploitation of this work is possible now and is likely to increase as the availability of methyl bromide for soil sterilisation declines, and as a greater range of crops and soil conditions are tested to define the situations where an economic benefit can be expected. The development of a smaller, more-readily transportable treatment machine would help to make the treatment available for smaller areas of land and for protected crops.

Background

Production of commercially important cut flower and bulb crops can be seriously affected by soil-borne diseases including *Pythium, Phytophthora, Fusarium, Verticillium, Sclerotinia,* and *Rhizoctonia*. The need for access to irrigation and other services often restricts available outdoor land to that close to the farm, resulting in intensive cropping and increased disease risk. Currently these diseases are controlled by soil sterilisation, with methyl bromide the most popular treatment because of its broad-spectrum activity and short turn-round time. However, methyl bromide is due to be phased out by 1 January 2005, with earlier substantial reductions in use. An effective alternative with wide-spectrum activity and short turn-round time is needed. Two chemical sterilants currently available, that are not cited as ozone-depleters, are dazomet (Basamid) and metam-sodium (Discovery, and various other formulations were previously available).

Product literature indicates that Basamid and Discovery are each effective against a range of weed seeds and soil-borne fungal diseases. Independent research confirms activity by one or both of these sterilant chemicals against various important diseases. These include onion white rot (*Sclerotium cepivorum*) (Davies, 1990); club root (*Plasmodiophora brassicae*) (Buczacki & White, 1979); strawberry Verticillium wilt (*Verticillium dahliae*) and crown rot (*Phytophthora cactorum*) (Harris, 1991); tomato fusarium crown and root rot (*Fusarium oxysporum* f. sp. *radicis-lycopersici*) (McGovern *et al*., 1998); and *Pythium* and *Rhisoctonia* on grapevine nursery stock (Stephens, Davoren & Wicks, 1999). Several of these studies also report associated crop yield increases.

It should be noted that beneficial effects on disease control and yield were not always recorded, and, where a trial series was carried out, results were often variable. Several of these studies also found that application method and timing significantly influenced the effectiveness of treatment; one method may work and another not. Davies (1990) found that metam-sodium gave significant reductions in onion white rot but no significant increase in marketable yield (see HDC report FV 4a). In this instance, it has been postulated that the lack of yield increase may be reduced phosphorus availability, due to reduced mycorrhizal associations following metam-sodium treatment In the USA it is reported that metam-sodium can result in stunted early season onion growth, especially in high pH soils, but this is overcome by application of additional phosphorus fertiliser (Brown, 2001).

These observations serve to illustrate that soil sterilisation with metam-sodium and/or dazomet should not be considered a panacea for all soil-borne problems. Nevertheless, with the impending loss of methyl bromide these two chemicals appear to be the most likely practical and cost-effective alternative chemical treatments in the UK.

Commercial objective

This project is designed to evaluate the effectiveness of a novel treatment system in which the two chemical sterilants Basamid and Metham Sodium 400 are applied in combination, accurately, and to different layers in the soil profile, to achieve sterilisation of weed seeds and soil-borne pathogens. Incorporation of Basamid granules in the surface layer is designed to enhance the prospects of reliable pathogen and weed control in this important zone. Use of Metham Sodium 400 to sterilise the rest of treated layer enables more economic treatment than if dazomet alone was used throughout the soil. The commercial objective of the combined chemical treatment is to overcome the shortfalls of the separate products and to ensure thorough sterilisation to the appropriate depth at an economic cost.

Summary of results

Optimising the application of dazomet and metam sodium for weed and disease control – first trial, Autumn 1999

Nylon bags containing fungal pathogens (*Fusarium, Pythium, Rhizoctonia, Sclerotinia* and *Verticillium*) were buried in October 1999 at two depths (10 - 15 and 20 - 25 cm) in a field in Lincolnshire. The soil was a fine silty loam, pH 7.9 with 2.3% organic matter. At the time of treatment soil temperature was 11ºC (15 and 25 cm depth) and soil moisture content was 16.0%. The fungi were prepared as infected pieces of root, stem, seed or as fungal resting bodies (sclerotia). Six sets of each fungus were buried in each of four large replicate plots (20 x 3 m). Plots were left untreated, or treated by Sands Agricultural Services Ltd, with Basamid spread and rotovated in the surface layer (20 g/m^2) and injected with Metham Sodium 400 at 25 cm depth at 500 l/ha (equivalent to Discovery at 392 l/ha). Immediately after treatment, the soil surface was smear-sealed using a powered roller. Seventeen days after treatment the soil surface was raked to release residual fumes. Soil samples were taken at intervals and seed germination tests conducted until the cress seed germinated normally. The buried bags of fungi were then recovered and fungal viability was assessed.

Treatment with Basamid at 20 g/m^2 and Metham Sodium 400 at 500 l/ha (equivalent to Discovery 510 at 392 l/ha) significantly reduced viability of all fungal pathogens and weed seed germination. Compared with samples buried in untreated soil, the mean % kill at this treatment rate was: *Fusarium* 75%; *Pythium* 87%; *Rhizoctonia* 97%; *Sclerotinia* 92%; *Verticillium* 85%. There was no consistent difference in % kill according to depth at which the samples were buried, or with position along the length of the plot. Weed seed germination was reduced by 66% 10 weeks after treatment. Reduction in viable weed seeds was greater at 20-25 cm than in the surface layer (0-5 cm). The intended application of Metham Sodium 400 at rates greater than 500 l/ha suffered a technical problem and from the lack of pathogen kill, abundant weed germination and early cress seed germination, it was concluded that the chemical had not been applied. Incorporation of Basamid into the top 5 cm of soil at 200 kg/ha had no effect of fungi buried at 15 cm or greater depth.

Optimising the application of dazomet and metam sodium for weed and disease control – second trial, Spring 2000

Five fungal pathogens were buried as described in Autumn 1999. Additionally, imbibed oilseed rape seed were scattered in each plot just before treatment. Treatments were applied under near-ideal conditions to large plots (50 x 3m) on 10-11 May 2000. Soil temperature was 20^0C at 15 cm depth and soil moisture content was 14% (50% of moisture holding capacity). All plots were rolled and covered with clear polythene (38 μm gauge) within 10 minutes of treatment. Basamid was incorporated in the top 5 cm at 20 g/m^2 and Metham Sodium 400 was injected at 25 cm depth at 375, 500, 750 and 1250 l/ha (equivalent to Discovery at 294, 392, 588 and 983 l/ha). Polythene sheets were removed after 7 and 14 days and the soil seal broken by raking to release residual fumes. Buried fungi were recovered 21 days after treatment, when a cress seed germination test indicated no residual phytotoxic fumes and tested for viability.

All treatments significantly reduced viability of all fungal pathogens, and gave virtually complete control of weeds. Oilseed rape plants grew in all of the untreated and none of the treated plots. The effect of Metham Sodium 400 rate on fungal pathogens varied with the target fungus. Treatment was very effective against *Pythium* and *Fusarium* (complete kill of both pathogens at 750 l/ha Metham Sodium 400 and higher concentrations), good against *Rhizoctonia* (91-95% kill) and least effective against *Phytophthora* (66-82% kill) and *Sclerotinia* (80-95% kill). Variation in treatment efficacy with depth (0-25 cm) was slight. Weed control was not improved by leaving plots covered with polythene film for two weeks after treatment, rather than one. Good weed control was maintained for at least 8 weeks. Control of deeply buried weed seed was greater when Metham Sodium 400 was used at 1250 l/ha than at 500 l/ha.

Optimising the application of dazomet and metam sodium – third trial Spring 2001

The aim of the work in the third trial was:

1. To determine the benefit to crop production of soil sterilisation using dazomet and metam sodium on land intensively cropped with cut flowers.

2. To investigate the effect of cultivation depth after soil sterilisation on weed control.

3. To compare the effect of three different methods of sealing the soil (polythene sheet, sprayable plastic and smear-sealed) after sterilisation on weed control and pathogen kill.

Pythium and *Sclerotinia* were buried at 20 cm depth in May 2001 in a field in Melbourn, Hertfordshire. Treatments were applied under good conditions to large plots (50 x 3 m) on 24 May 2001. Soil temperature was 16-19 ^{0}C at 15 cm depth and soil moisture content was 22.6% (56% of moisture holding capacity). All plots were rolled and sealed within 10 minutes of treatment. Basamid was incorporated in the top 5 cm at 20 g/m^2 and Metham Sodium 400 was injected at 25 cm depth at 750 l/ha (equivalent to Discovery at 588 l/ha). Records taken in the cab indicated application of metam sodium at the target rate was achieved. Polythene sheets were removed after 7 days and the soil seal broken by raking or rotovation (to 20 cm depth), as required, to release residual fumes. Cress seed germinated well at 11 days after treatment. Buried fungi were recovered for viability testing.

Treatment with Basamid at 20 g/m^2 and Metham Sodium 400 at 750 l/ha significantly reduced subsequent weed seed germination with good control, sufficient to allow crop establishment, until 40 days after treatment. However, not all seeds of fat hen were killed and by 7 weeks after

treatment there was a severe fat hen problem in most plots. Testing of different soil layers showed that weed control was less effective at 10-15 cm depth, the boundary layer of the two chemicals, than at other depths, and this probably accounts for the increased weed problem where rotovation, rather than raking, was used to break the soil surface seal after sterilisation. Levels of *Pythium* and *Sclerotinia* buried at 20-25 cm were significantly reduced. An unreplicated comparison of soil covers showed little difference in weed control or pathogen kill whether the soil surface was sealed by smear roller, smear roller + polythene film or smear roller + sprayable plastic.

Growth of both chrysanthemum and sunflower was enhanced in sterilised soil. This resulted in an increase in the number of marketable chrysanthemum stems, but a decrease in the number of marketable sunflower stems as the heads were too large (outside the marketing specification). Enhanced growth in sterilised plots was probably a result of reduced weed competition and possibly also the control of minor root diseases.

In order to build up a comprehensive body of evidence on the suitability of the treatment for different situations, monitoring of its efficacy and effect on subsequent crop production is required on commercial nurseries. Ideally this should cover: a) over a range of soil types, weed and pathogen problems, b) different soil conditions and c) different following crops.

Action points for growers

1. Where a need for soil sterilisation in outdoor cut flower production is identified such as when planting into land where there is a high risk of serious root disease or where there is a high weed seed population in the soil not easily controlled using herbicides in the growing crop, consider using the combined Basamid and Discovery treatment described in this report. Note however that weed control may not persist – see details below. The re-planting interval is relatively short, enabling treatment to be applied in the spring and a crop planted soon afterwards, at the normal planting time.

2. This treatment may need to be supplemented by a herbicide treatment where there is a high population of fat hen or other weed species with a long germination period, or seeds that are difficult to kill by dazomet (e.g. large, hard-coated seed). Similar late flushes of weed seed germination may also occur following soil sterilisation with methyl bromide (Russell Cooke, pers. comm).

3. The treatment is adaptable for different situations. The application rates of both Basamid (maximum 76 g/m^2) and Discovery 510 (maximum 900 l/ha) can be varied; the depth to which Basamid is incorporated and at which Discovery 510 is injected can also be varied. Decide on the treatment specification in consultation with the contractor and according to your identified needs for the crop being grown and your own production method. For example:

    - where the risk of serious root disease is considered low and the crop is being direct drilled, a suitable rate of Basamid rotovated into the surface layer can be sufficient for good weed control; or consider Basamid applied at 0-5 cm with Discovery 510 injected at 6-15 cm.

    - where *Fusarium* wilt (or other deeply-buried pathogens which pose a serious risk to the intended following crop) is widespread in the previous crop, injection of Discovery 510 to depth, together with application of Basamid in the surface layer, is likely to be a better option.

- a long-term crop (e.g. 18 months carnation) is more likely to warrant treatment at a higher rate than a short-term crop.

4. Good soil preparation and condition are critical for good results. Optimum conditions for treatment of outdoor land are usually found between 1 April and 31 October. Remove all remaining plant tissue and debris from the previous crop. Follow the guidelines detailed by Certis (for Basamid) and United Phosphorus Ltd (for Discovery 510) and the contractor. Conditions which must be assessed include:
   - soil temperature at 15 cm depth (at or above 10 C)
   - soil moisture content (around 50 % moisture holding capacity - a tightly squeezed handful of soil should remain as an intact ball in the open hand but shatter if dropped on a hard surface).
   - soil tilth (a fine, open tilth, free from clods)

5. Application of a polythene film to the soil surface after smear-sealing will assist retention of the sterilant gases and is likely to improve weed and disease control. Both Basamid and Discovery 510 begin to decompose into the active sterilising gas (MITC) on contact with moist soil. Therefore, ensure the soil is sealed and polythene is laid within a few minutes of applying the chemicals. Use of a polythene film is especially important where weed control is the prime objective.

6. Make every effort to avoid re-contamination of the treated soil (e.g. clean cultivation equipment before using it in the newly - treated land; keep the polythene on for as long as possible and either remove it just before planting or, if feasible, plant through it. If the polythene is left on over winter, consider netting it to prevent wind blow). Fungal pathogens (e.g. *Pythium, Rhizoctonia)* can spread very rapidly in recently sterilised soil.

7. Enhanced breakdown of metam-sodium has been reported where it is used frequently. Use soil sterilisation as part of an integrated disease and weed management strategy. It is suggested that soil be treated with Basamid and/or Discovery 510 no more than once every 2-3 years.

8. Note that both Basamid and Discovery 510 produce fumes which are damaging to all plants. Before you plant the new crop ensure that a cress test, on soil representative of the whole area and sampled to the appropriate depth, shows that there are no phytotoxic residues in the soil. Note that that soils with a high clay or organic matter content will retain the sterilising gas longer than lighter and more sandy soils. If residues are suspected (e.g. in a wet or very heavy soil) it is advisable to sample from deeper soil to be safe.

9. After treatment has been applied, do not cultivate close to, or below, the depth of sterilisation. If practical for your growing system, simply rake the soil surface (e.g. to 5-10 cm) to release residual fumes and plant directly without further cultivation. Rotovation can reduce weed control.

10. Seeds with hard coats will not be controlled unless the soil is moist for several days before treatment to encourage germination. Weeds which produce rhizomes (e.g. common couch) are unlikely to be controlled satisfactorily.

11. Soil sterilisation by this treatment can result in enhanced crop growth. Observations following treatment of commercial blocks of land are required to quantify this effect. Planting (e.g. density) and/or harvesting (e.g. date) may need to be adjusted to ensure that the harvested product remains within the marketing specification.

12. The approximate cost of this method of soil sterilisation to treat a 1 ha block of outdoor land, with Basamid at 20 g/m^2 and Metham Sodium 400 at 750 l/ha (equivalent to Discovery 510 at 588 /ha), for chemicals and polythene (assumes Basamid at £6/kg and Metham Sodium 400 at £1.50/l and polythene at £1,000/ha) is around £3,300 / ha. With the contractor's application cost, and own staff time to prepare land and remove polythene, the total cost is probably around £5-6,000/ha (50-60 p/m^2), which is currently comparable to, or less than, that of methyl bromide at 100 g/m^2 (contractor cost included).

Anticipated practical and financial benefits

This project has achieved its objectives and provided the outdoor cut flower and bulb crop industry with a commercially viable alternative to methyl bromide for reliable soil sterilisation. It has identified a general treatment of 200 kg/ha Basamid + 750 l/ha Metham Sodium 400 (equivalent to 588 l/ha Discovery), smear-sealed and covered with polythene, for major soil-borne pathogens and weeds. For optimum effect, rates of chemical application and depth of treatment can be varied according to the particular pest, disease and weed problems, the soil type and the nature of the following crop.

To help ensure the new technology is implemented, the project has been supported by Sands Agricultural Services Ltd who undertook the soil sterilisation treatments, by Certis and United Phosphorus Ltd, who supplied chemicals for the initial trials, and by Visqueen Agri (now known as BPI Agri), who supplied polythene film.

Outdoor machinery is now available for the combined application of liquid and granular soil sterilants in 3m wide bands. This is offered as a contractor-applied treatment by Sands Agricultural Services Ltd, Holbeach, Lincs (Tel: 01406 422606). New, smaller scale machinery needs to be developed if the method is to be used in glasshouses and polythene tunnels. The efficacy of the process needs to be further demonstrated to growers, in terms of improved plant quality and production, by monitoring treatment and the resulting crop performance on nurseries/farms in a wide range of situations (i.e. different soil types, soil conditions, weed spectrum/burden, pathogen spectrum/burden).

There are opportunities for wider commercial exploitation to field vegetable problems (e.g. *Septoria* in celery, *Sclerotinia* in lettuce) and to protected salad problems (e.g. weed control, *Sclerotinia* and *Rhizoctonia* in lettuce).

SCIENCE SECTION

INTRODUCTION

The marketability of cut flower and bulb crops grown intensively can be significantly reduced by soil-borne diseases e.g. *Pythium* and *Phytophthora* in a wide range of crops (aster, chrysanthemum, column stocks, lisianthus, tulip), *Fusarium* in aster, lisianthus and lily, *Phoma* in chrysanthemum, *Rhizoctonia* in iris and tulip (grey bulb rot), and in column stocks and *Sclerotinia* in a wide range of hosts (e.g. chrysanthemum, column stocks, sunflower) (see: *HDC News* **54**, 6-7). Some of these pathogens (e.g. *Sclerotinia, Rhizoctonia, Pythium*) are believed to be most damaging when in the surface layer, others (e.g. *Fusarium*) are known to be able to cause root infection from depth.

Control of weeds is also an important reason for soil sterilisation and previous HDC projects (BOF 40, CP 6, FV 229 and HNS 31) have investigated this in detail in various crops. The work reported here monitors effect of treatment on weed control.

Soil-dwelling ectoparasitic nematodes are not commonly found on the major cut flower crops, although occasional problems can occur (e.g. *Pratylenchus* on alstroemeria). Telone (1, 3 dichloropropene) is usually the preferred treatment where there is a specific soil-borne nematode problem, because of cost considerations. This project has therefore concentrated on soil-borne diseases and weeds, and not considered efficacy of treatment on nematodes. From previous studies, some control of nematodes would be expected from both dazomet and metam-sodium.

Currently important root diseases are controlled by soil sterilisation, with methyl bromide fumigation by far the most popular method due to its very effective broad spectrum of activity and the very short waiting period (around 7 days) between treatment and replanting. However, as a result of its ozone depleting activity, use of methyl bromide is due to be phased out by 1 January 2005. The cut flower industry needs a suitable alternative treatment which is demonstrably effective against major root pathogens, is commercially acceptable with a short turn-around time and is economic to use. Protected soil-grown edible crops, particularly lettuce and celery, will also require suitable alternatives to methyl bromide. One recognised alternative is steam treatment, but this has several drawbacks, notably a high cost (boiler and fuel), relatively slow and labour-demanding work, and very few nurseries now have a steam boiler. An alternative approach is to use the non-ozone depleting chemical sterilants (dazomet and metam-sodium) in order to achieve cost-effective, yet thorough sterilisation.

Recommendations regarding crop safety are listed on the Basamid (dazomet), Metham Sodium 400 (metam-sodium) and Discovery (metam-sodium) product labels. The chemicals are used on soil before planting. The maximum recommended dose for Basamid is 760 kg/ha (76 g/m^2); for Metham Sodium 400 it is 1,250 litres/ha. The maximum recommended dose for Discovery, a 510 g ai formulation of metam-sodium which replaced Metham Sodium 400 in 2001, is 900 litres/ha. This equates to 1147 litres/ha of Metham Sodium 400. When Basamid is used outdoors, a 1 metre safety zone between treated area and adjacent crop is recommended. A soil temperature above 7ºC is recommended. Basamid should not be used in glasshouses or tunnels where living plants are present. Metham Sodium 400 should not be used in glasshouses containing living plants, or adjacent to glasshouses in which there are growing plants, or which will be used for propagation of plants within 10 weeks of application. The label for Discovery is slightly less restrictive on use, permitting re-planting once a cress seed test has shown the treated soil is free of phytotoxic chemicals. It is critical that a cress germination test is done to check that all traces of the breakdown gas methyl isothiocyanate (MITC) have disappeared before sowing or planting is attempted.

In this work we use an improved version of a soil sterilant application machine, developed in 1997 by Sands Agricultural Services Ltd, to apply and incorporate Basamid granules into the surface layer of soil and to inject Metham Sodium 400 solution at depth. The soil is sealed immediately using a hydraulically driven roller to smear the soil surface.

Machines are available for use in field crops and it is envisaged that a smaller version could be designed and developed for use in greenhouses by contractors. Contractor-applied soil sterilisation can offer to the grower an assurance of effective treatment, based on research results and accumulated experience. Moreover, safety will be optimised and operator exposure minimised if treatment is applied by trained and experienced staff.

A trial undertaken in Lincs in spring 2000 demonstrated good weed control for at least 8 weeks and large reductions in the viability of buried fungal pathogens. The effect on growth and yield of a following crop was not tested. The objective of the work described here was to test the soil sterilisation system on a different soil type and to determine the effect of treatment on growth of a following crop. Specific objectives were:

1. To determine the benefit to crop production of soil sterilisation using dazomet and metam sodium on land intensively cropped with cut flowers.

2. To investigate the effect of cultivation depth after soil sterilisation on weed control.

3. To compare the effect of three different methods of sealing the soil (polythene sheet, sprayable plastic and smear-sealed) after sterilisation on weed control and pathogen kill.

MATERIALS AND METHODS

Site details

A field experiment was carried out on a sandy clay loam soil at Melbourn, Royston, Herts, on a site regularly used for flower cropping. The previous crops were: sunflowers (2000), sunflowers (1999), spray carnations (1998), asters (1997) and strawberries (1996).

Experimental design and statistical analysis

A randomised split plot design was used, with sterilisation as the main-plot treatment and cultivation as the sub-plot treatment. All main plots had a 50 m run-in to allow calibration of application machinery. The sub-plot area was 3 m x 3 m (9 m^2). Each sub-plot was cropped with both chrysanthemum (4.5 m^2) and sunflower (4.5 m^2).

Efficacy tests against buried fungal pathogens and weed assessments were made in the central 2 m width to avoid edge effects. Results were examined by ANOVA, following data transformation where necessary. Significant differences between treatments are shown as *** $P < 0.001$; ** $P < 0.01$; * $P < 0.05$, NS - not significant.

An additional, unreplicated comparison of soil covers on sterilised soil was made. Plot size was 9 m^2, with a 50 m run-in.

Treatments

The following treatments were applied, with Basamid incorporated at 200 kg/ha (20 g/m^2) into the top 5 cm of soil and Metham Sodium 400 injected at 750 l/ha (75 ml/m^2) at 25-30 cm depth:

1. Unsterilised, lightly cultivated (raked)
2. Unsterilised, rotovated to 20 cm
3. Sterilised, lightly cultivated (raked)
4. Sterilised, rotovated to 20 cm

Treatments were applied on 24 May 2001, under good conditions, when the soil temperature was 16-19 ^{0}C at 15 cm depth. Treatment was delayed approximately one week from the intended application date because of heavy showers at the site. The soil moisture content at the time of treatment was 22.6% (56% of moisture holding capacity). All plots were covered with 2.75 m wide x 30 μm thick clear polythene film (BPI Agri) within 10 minutes of soil treatments. The application rate of Metham Sodium 400 to each plot was recorded (Appendix 1).

The unreplicated comparison of soil covers on sterilised soil consisted of:
1. Smear seal by roller
2. Smear seal and covered with 30 um polythene
3. Smear seal and covered with sprayable plastic (a form of polyvinyl acetate, prepared at 500 ml/litre and applied at 150 l/ha; this material is bio-degradable and is used in other countries to reduce erosion of soil by wind-blow).

The soil was rotovated to 20 cm one week after treatment to release residual fumes.

Diary of events (2001)

15 May	soil sampled for analysis
21 May	samples buried
24 May	soil treated
31 May	polythene removed; soil raked or rotovated, as required
31 May	soil sampled for first cress test
4 June	soil sampled for second cress test
12 June	fungal samples recovered for viability testing
13 June	soil sampled from 3 depths for weed assessment & chemical analysis
13 June	chrysanthemum planted; sunflower drilled
3 July	first weed assessment
23 July	fleece (rabbit protection) removed from over the crops
27 July	second assessment completed
27-30 July	all plots weeded by hand (to remove fat hen)
16 August	soil sampled from 5 depths for weed assessment
3 September	sunflowers harvested
11 September	count of weed from 5 depths
21 September	chrysanthemum harvested
22 October	weed counts on trays of soil from 5 depth

Dispersal of residual gas (re-planting interval)

A laboratory cress test was carried out at one and two weeks after soil sterilisation, on soil sampled from 0-30 cm from 5 cores from the central area of each plot. Germination of cress seed suspended in closed jam jar above treated soil was compared with seed suspended over untreated soil after 5 days.

Determination of treatment efficacy on buried plant pathogens (*Pythium* and *Sclerotinia*)

In order to obtain reliable results, it was desirable that there was a known, quantified and uniform inoculum of target pathogens in the replicated areas. This cannot be guaranteed when a naturally infested site is used. It was also important that the target pathogens were in a state that naturally occurs in the soil i.e. most probably within the roots or stems of affected crop debris. Both these criteria were fulfilled by burying equal portions of infested plant tissue, or naturally produced sclerotia, in each plot. The pathogens were in a highly resistant state within plant tissue and therefore presented a severe challenge for the sterilisation treatment. Any differences between plots in background levels of pathogens will be irrelevant as efficacy tests were conducted on the deliberately buried and recovered samples. The following were prepared:

1. Radish seed affected by a *Pythium* species (an oospore-forming species, originally isolated from lisianthus root)
2. Sclerotia of *Sclerotinia sclerotiorum* grown on celery sticks (originally isolated from sweet pea)

Burial and recovery of plant pathogens

Standard numbers of pathogen inoculum were prepared, mixed with washed silver sand, and enclosed in 180 µm mesh nylon gauze. Sets of the 2 pathogens were assembled in a large-mesh bag. A magnet was buried with each bag of pathogen samples to aid recovery.

Five labelled sets of inoculum were buried at 20-25 cm depth (bottom of the bag at 25 cm), approximately 2 m apart and at measured distances from plot markers in each plot. Samples were

recovered by use of magnet detectors and forking the areas around where they were buried, after the cress tests have indicated all plots were free of residual phytotoxic gases (i.e. maximum time has elapsed for sterilant gases to act on target pathogens). Depth of each sample bag was measured at recovery.

Testing for pathogen viability

Buried crop debris was sieved from the silver sand, surface sterilised and pathogens assessed for viability by plating onto selective agars. The number of pieces of tissue (of 10) in each sample from which the target pathogen was recovered was determined.

Soil temperature

Soil temperature at 15 cm depth was recorded both within and just outside a polythene covered plot from 24-31 May 2001, using temperature probes attached to a Delta - T data logger. Soil thermometers were also used as a check.

Soil moisture

Samples of soil were taken from known depths at the trial sites, placed in metal trays and weighed. They were re-weighed after drying overnight in an oven at 110 ^{0}C. Weight of soils at field capacity was also determined. Values calculated were: % soil moisture (field wt - dry weight/field weight) and % moisture holding capacity (MHC) (field wt - dry weight/field capacity wt - dry wt).

Weed control

The percentage cover by weeds was assessed in 6 x 0.25 m^2 quadrats in each plot, at 40 and 63 days after treatment. The predominant weed species were identified. At the first assessment, the absolute numbers of each weed species were also recorded. To reduce the risk of wind-blown seeds contaminating treated plots, weeds on field headlands in close proximity to the trial area were strimmed prior to establishing the trials

Additionally, at 3 weeks after treatment, pits were dug in the unplanted area of all plots of treatments 1 and 3 (unsterilised and sterilised raked treatments) and soil carefully collected from three layers: 0-5, 10-15 and 20 - 25 cm. Moistened samples were laid in seed trays lined with paper towel, placed on Mypex matting in a polythene tunnel and the number of weeds assessed after 40 days. This was repeated at 12 weeks after treatment with soil samples taken from 5 layers (0-5, 6-10, 11-15, 16-20, 21-25) in all plots from treatments 1 and 3.

Cropping

Block-raised chrysanthemum, cv. Beppe Yellow, was planted on 13 June. Sunflower, cv SunRich Orange, was drilled on the same day. Irrigation was used to ensure crop establishment. The crops were covered with fleece until 23 July to prevent rabbit damage. All plots were hand-weeded on 27 and 30 July. Sunflower seeds were drilled at 14 seeds/m in four rows 30 cm apart. Chrysanthemum blocks were planted at 20/m^2.

Crop assessments

When the majority of plants were at marketable stage, all stems were cut (c. 50 sunflower and 50 chrysanthemum plants per plot) and assessed as follows:

- stem weight
- stem length
- number of marketable stems

Additionally, 10 plants from each of treated/raked and untreated/raked plots were dug up and the roots were examined for rotting and tested in the laboratory for fungal pathogens.

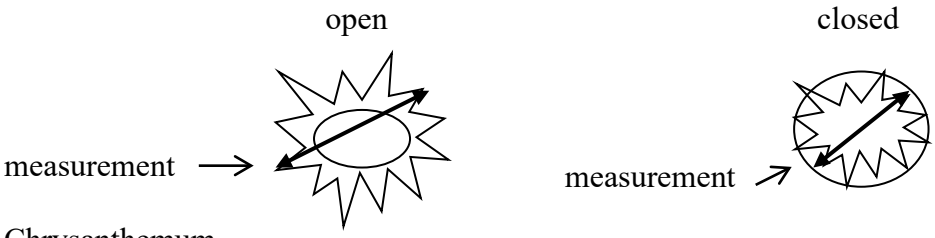
Assessments for marketability were made in conjunction with the host grower. Flowers which were just past or just before the optimum marketing stage were assessed for marketability as if they were at the optimum stage. The following categories were used:

Sunflowers:

Sunflowers were graded in to 4 size grades, all stems were trimmed to 50 cm from the bend in the stem at the flower head, all leaves were stripped off except two at the top of the stem. The major cause of rejection was too large a head, generally found on thicker stems.

Size grades - for flower heads

Small closed 4.5-7.5 cm	Large closed 7.5-12 cm
Small open 8.0-12 cm	Large open 12-17.5 cm



Chrysanthemum

Marketability was assessed on stem length, with a minimum requirement of 55 cm, and the balance of the flowers on the stem. Thin spindly stems with small leaves and flowers were rejected; weakly growing stems were rejected; stems which had gone floral then vegetative then floral again were rejected; stems with few and small blooms on single stems were also rejected.

RESULTS

Dispersal of residual gas

There was good germination of cress seed over most of the soil samples taken on 31 May, 7 days after treatment, and full germination over the samples taken on 4 June. Cultivation treatment after removal of the polythene appeared to have little effect on the rate at which residual fumes were released.

Table 1. Release of residual fumes after soil sterilisation

Treatment	Cress germination after treatment:	
	31 May (7 days)	4 June (11 days)
Main experiment		
1. Untreated, raked	++++	++++
2. Untreated, rotovated	++++	++++
3. Sterilised, raked	++++	++++
4. Sterilised, rotovated	+++	++++
Comparison of soil covers		
1. Smear seal	+	+++
2. Polythene film	++	+++
3. Sprayed plastic	++	+++

+ the number of replicate jars of 4 (main experiment) or 3 (soil cover comparison) with good cress seed germination.

Weed control

At 40 days after treatment, the ground area covered by weeds (Table 2) and the absolute number of weeds per unit area (Table 3) were both low and significantly reduced compared with untreated soil. Although cultivation treatment to release residual fumes had no statistically significant effect on weed control, there was a consistently greater number of weeds, and greater ground cover, where sterilised soil was rotovated to 20 cm rather than raked. It is probable that only the treated and raked area would have been deemed to be acceptable weed control at this stage. The most common weeds present were small nettle, shepherd's purse, field speedwell and fat hen. Of these predominant weed species, soil sterilisation with raking to release residual fumes resulted at 40 days in more than 94% control of field speedwell, small nettle and shepherd's purse but only 76% control of fat hen (Table 4). Where the soil was rotovated after sterilisation, the degree of control of fat hen fell to 36%. Ground area covered by weeds was generally slightly less in the sunflower plots than in the chrysanthemum plots, probably because of the greater shading effect (Appendix 3). In the unreplicated comparison of soil covers after sterilisation, weed control appeared unaffected by the type of soil cover (Table 5).

The number of viable weed seeds found at different depths in untreated soil ranged from 32/seed tray at the soil surface (0-5 cm) to 87/seed tray at 20-25 cm depth (Table 6). Soil sterilisation without subsequent rotovation reduced numbers at all depths, with highly effective weed control (98% of total weed numbers) at 20-25 cm depth, and the poorest weed control (57%) at 11-15 cm depth. Control in the surface layer (0-5 cm) was moderate (84%).

A similar experiment was carried out at 84 days after treatment, comparing total weed numbers and % control at five layers in the soil profile, each 5 cm thick, in areas of soil undisturbed since

sterilisation (Table 7). Weed burden was greatest at 11-20 cm depth, with c. 110 viable weeds/seed tray in untreated soil and just 28 in the surface layer (0-5 cm). Soil sterilisation reduced weed numbers at all depths being most effective at 20-25 cm (80% control) and, as in the previous experiment, least effective at 11-15 cm (46% control). Control in the surface layer (0-5 cm) was again moderate (64%). It is interesting to note in the run-in strips, where no Basamid was applied, that Metham Sodium 400 gave no control of the weeds in the upper soil layer (0-15 cm).

Table 2. Effect of soil sterilisation on weed control (% ground cover) - Melbourn, 2001

Treatment	% ground cover after:	
	40 days	63 days
Sterilisation		
Untreated	60.7 (51.4)	97.8 (82.7)
Treated	11.9 (15.8)	70.9 (59.8)
Significance (3 df)	**	*
SED	5.82	4.50
Cultivation		
Raked	30.2 (28.9)	77.2 (65.9)
Rotovated	42.4 (38.3)	91.6 (76.6)
Significance (3 df)	NS	*
SED	-	3.11
Sterilisation x Cultivation		
Untreated, raked	57.5 (49.3)	98.1 (83.2)
Untreated, rotovated	63.9 (53.5)	97.5 (82.2)
Treated, raked	2.9 (8.5)	56.2 (48.7)
Treated, rotovated	20.9 (23.0)	85.6 (70.9)
Significance (6 df)	NS	**
SED	7.20	5.47

( ) - arcsine transformed values
*, ** - significant difference between treatments at P< 0.05 and 0.01 respectively; NS - no significant differences.

Table 3. Effect of soil sterilisation on weed control (weed numbers) - Melbourn, 2001

Treatment	Mean no weeds/0.25 m^2 after 40 days
Sterilisation	
Untreated	73.5
Treated	15.8
Significance (3 df)	**
SED	8.41
Cultivation	
Raked	39.7
Rotovated	49.7
Significance (3 df)	NS
SED	5.05
Sterilisation x cultivation	
Untreated, raked	72.0
Untreated, rotovated	75.0
Treated, raked	7.3
Treated, rotovated	24.3
Significance (6 df)	NS
SED	9.81

** significant difference between treatments at $P < 0.01$.

Table 4. Weed species occurring after soil sterilisation - after 40 days

Common name	Latin name	Mean number seedlings*					
		Untreated - raked	Treated - raked	% control	Untreated - rotovated	Treated - rotovated	% control
Small nettle	*Urtica urens*	29.38	0.92	97	35	7.42	79
Shepherd's Purse	*Capsella bursa-pastoris*	12.29	0.58	95	11.38	3.54	69
Mayweed	*Matricaria.* spp.	0.25	0.25	-	0.67	0.29	-
Chickweed	*Stellaria media*	1.58	0.04	-	0.63	1.92	-
Groundsel	*Senecio vulgaris*	1.04	0.29	-	0.92	0.33	-
Pale Persicaria	*Polygonum lapathifolium*	0.13	0.04	-	0.00	0.08	-
Fumitory	*Fumaria officinalis*	0.08	0.00	-	0.08	0.00	-
Annual meadow grass	*Poa annua*	0.13	0.00	-	0.04	0.00	-
Docks	*Rumex* spp.	0.08	0.00	-	0.04	0.08	-
Fat-hen	*Chenopodium album*	10.63	2.58	76	10.54	6.71	36
Common field-speedwell	*Veronica persica*	14.04	0.83	94	11.92	2.54	78
Field Penny-cress	*Thlapsi arvense*	1.88	1.63	-	2.63	0.88	-
Black nightshade	*Solanum nigrum*	0.21	0.08	-	0.42	0.33	-
Annual sowthisle	*Sonchus* spp.	0.17	0.00	-	0.46	0.25	-
Crane's bill	*Geranium* spp.	0.08	0.04	-	0.00	0.00	-
Creeping thistle	*Cirsium arvense*	0.04	0.00	-	0.21	0.00	-
Total		72.01	7.28	90	74.94	24.37	68

* Mean of 24 x 0.25 m^2 quadrats per treatment and cultivation combination. % control figures are shown for weeds occurring at more than 10/m^2 in untreated soil.

Table 5. Effect of soil cover after sterilisation on weed control

Treatment	Mean % cover by weeds[a] after:	
	40 days	63 days
1. Unsterilised, smear seal + polythene film	57.5	98
2. Sterilised, smear seal + polythene film	3.3	98
3. Sterilised, smear seal	2.3	88
4. Sterilised, smear seal + sprayable plastic	3.0	93

[a] Whole plot assessment. Soil was lightly rotovated after 7 days.

Table 6. Viable weed number in different soil layers after soil sterilisation (sampled 13 June, 20 days after treatment)

Soil layer (cm)	Treatment		% weed control
	Treated raked	Untreated raked	
0 – 5	5.0	32.0	84
11 – 15	27.0	63.3	57
21 – 25	2.0	87.0	98

Means of 4 replicate seed trays (1 per plot)

Table 7. Effect of soil sterilisation on viability of weeds at different soil depths - (sampled 16 August, 84 days after treatment)

Soil depth (cm)	Mean no seedlings/tray[a] Untreated raked	Treated raked	% weed control	Mean no seedlings/tray Untreated run-in	Treated run-in	% weed[b] control
0-5	28	10	64	18	24	0
6-10	59	25	57	24	145	0
11-15	109	59	46	30	57	0
16-20	112	51	55	84	6	93
21-25	83	17	80	94	9	90

[a] Mean of 4 trays at each depth; soil sampled 16 August, trays assessed 22 October.
[b] Basamid not applied in the run-in strips

Control of *Pythium* and *Sclerotinia*

A viability test on unburied *Pythium*-infested seed and *Sclerotinia* sclerotia demonstrated high initial levels of viability. When the bags were recovered most were found at 20-25 cm though a few were at depths down to 36 cm. Soil sterilisation treatments resulted in large reductions in the viability of both fungi, though neither was eliminated (Tables 8 and 9). Treatment appeared to be more effective against the *Sclerotinia* sclerotia (97% kill) than the *Pythium* infested radish seed (56% kill) and slightly more effective where the soil was raked rather than rotovated at 7 days after application to release residual fumes. The sprayable plastic and smear seal cover in this experiment appeared to result in similar levels of pathogen kill to the polythene film cover (Table 9).

Fungal root rots

For both sunflower and chrysanthemum, there was no noticeable difference between plants grown in untreated and treated plots in the extent of root growth. Slight root rot, particularly of the root tips, was observed on most plants. A range of root rotting fungi were isolated (Table 10). On chrysanthemum, *Phytophthora* was only recovered from plants in untreated soil and *Pythium* only from plants in treated soil. There was a relatively high incidence of brown root rot (*Cylindrocarpon*) on plants from both soils. On sunflower, *Phytophthora, Pythium* and *Cylindrocarpon* were isolated from plants in both untreated and treated soil.

Table 8. Efficacy of soil sterilisation on *Pythium* and *Sclerotinia*

Treatment	% fungal viability on recovery from soil[a]		
	Pythium	*Sclerotinia*	
Sterilisation			
Untreated	94.0	90.8	(17.5)
Treated	44.0	2.4	(1.4)
Significance (3 df)	**		**
SED	0.76		(1.46)
Cultivation			
Raked	68.0	45.4	(9.3)
Rotovated	70.0	47.8	(9.6)
Significance (3 df)	NS		NS
SED	0.42		(0.21)
Sterilisation x cultivation			
Untreated, raked	91.2	88.6	(17.3)
Untreated, rotovated	95.8	93.1	(17.8)
Treated, raked	44.1	2.3	(1.4)
Treated, rotovated	43.5	2.5	(1.4)
Significance (6 df)	NS		NS
SED	0.86		(1.47)

[a] Arcsine transformed values are shown in parenthesis. Mean of 5 replicate pouches/plot
** - significant difference between treatments at $P < 0.01$

Table 9. Effect on soil covers on efficacy of soil sterilisation treatment

Soil surface cover	% fungal viability on recovery[a]	
	Pythium	*Sclerotinia*
Smear seal	-	4
Polythene film	-	0
Sprayable plastic	-	0

[a] Mean of 5 replicate pouches per treatment.

Table 10. Occurrence of root pathogens at harvest

Fungal pathogen	% samples positive			
	Chrysanthemum[a]		Sunflower[b]	
	Untreated	Treated	Untreated	Treated
Pythium	0	10	80	30
Phytophthora	10	0	60	80
Phoma	1	1	0	0
Cylindrocarpon	19	17	20	40

[a] 200 root samples plated out; 20 root pieces floated.
[b] 50 root pieces floated

Effect on crop growth

Sunflower

Soil sterilisation resulted in a significant increase in growth, with the mean harvest weight of stems from treated/raked plots almost double that of stems from untreated/raked plots (Table 11). Stems were visibly much thicker, and the heads larger. The mean total plot weight was increased from 9.2 to 11.2 kg by soil sterilisation. Mean stem length was not significantly affected. Although not statistically significant, the total number of stems per plot at harvest was slightly less in sterilised soil compared with unsterilised soil. Possibly this reflected greater competition for space between the larger plants, and a greater level of seedling death. Unfortunately, the increase in flower head diameter associated with soil sterilisation resulted in almost 50% of stems being out of specification for sale, compared with only 23% in unsterilised soil.

Table 11. Effect of soil sterilisation on growth and marketable yield of sunflower - Melbourn, 2001

Treatment	Mean stem length (cm)	Mean total plot wt (kg)	Mean stem wt (g)	Mean total no stems/plot	Mean % marketable	
Sterilisation						
Untreated	152.1	9.21	123	76.1	76.8	(41.0)
Treated	151.0	11.16	195	59.2	50.6	(23.6)
Significance (3 df)	NS	NS	**	NS	-	*
SED	2.61	0.959	11.6	8.45	-	4.57
Cultivation						
Raked	153.2	11.15	184	64.4	61.2	(30.3)
Rotovated	149.9	9.23	134	71.0	66.1	(34.3)
Significance (3 df)	NS	*	*	NS	-	NS
SED	4.40	0.531	13.5	4.31	-	7.05
Sterilisation x cultivation						
Untreated, raked	157.5	9.50	123	75.7	74.5	(44.5)
Untreated, rotovated	146.7	8.93	123	76.5	79.0	(37.6)
Treated, raked	148.9	12.80	245	53.0	47.9	(16.0)
Treated, rotovated	153.2	9.53	145	65.5	53.3	(31.1)
Significance (6 df)	NS	*	*	NS	-	NS
SED	5.11	1.096	17.8	9.49	-	8.40

( ) - angular transformed data
*, ** - significant differences between treatments at $P < 0.05$ and 0.01 respectively; NS - no significant differences.

Chrysanthemum

The mean total number of stems, from plants grown on sterilised soil (85.7) was significantly greater than from plants on unsterilised soil (53.5) (Table 12). The reduced number of stems in untreated soil was probably largely due to plant death or reduced growth from weed competition. The proportion of marketable stems was around 90% in all plots. Neither sterilisation nor cultivation affected mean stem weight or mean total plot weight, though rotovation appeared to increase stem length slightly. The crop grown on sterilised soil appeared visually to be more vigorous.

Table 12. Effect of soil sterilisation on growth and marketable yield of chrysanthemum - Melbourn, 2001

Treatment	Mean stem length (cm)	Total plot wt (kg)	Mean stem wt (g)	Mean total no stems/plot	Mean % marketable
Sterilisation					
Untreated	64.8 (8.08)	6.34	118	53.5	90.2 (72.4)
Treated	63.1 (7.97)	10.02	119	85.7	91.2 (73.4)
Significance (3 df)	NS	NS (0.07)	NS	*	NS
SED	0.11	1.390	10.2	7.62	1.76
Cultivation					
Raked	62.3 (7.92)	8.46	112	76.5	90.8 (73.1)
Rotovated	65.6 (8.12)	7.90	124	62.7	90.6 (72.6)
Significance (3 df)	*	NS	NS	NS	NS
SED	0.07	0.458	11.8	6.63	1.89
Sterilisation x cultivation					
Untreated, raked	64.6 (8.06)	6.27	115	54.0	91.1 (73.2)
Untreated, rotovated	65.1 (8.09)	6.41	120	53.0	89.3 (71.5)
Treated, raked	60.1 (7.78)	10.65	109	99.0	90.5 (73.0)
Treated, rotovated	66.1 (8.16)	9.39	128	72.5	92.0 (73.7)
Significance (6 df)	NS	NS	NS	NS	NS
SED	0.0134	1.464	13.1	10.10	2.59

( ) - transformed values shown in parenthesis

Soil analyses

The soil was a light sandy loam, pH 7.8 with organic matter content of 3.34%. Chemical analyses before and after soil sterilisation are shown in Table 13. Sterilisation appeared to increase slightly the levels of extractable potassium, manganese and sodium. Although nitrate release is considered to occur after soil sterilisation, associated with the breakdown of micro-organisms killed by the treatment, no increase was detected at a single sampling. In retrospect, it would have been preferable to sample frequently (e.g. weekly) for around 12 weeks after treatment.

Table 13. Effect of soil sterilisation on selected nutrient levels

		After sterilisation	
Analysis	Initial	Untreated	Treated
pH	7.8	7.9	7.9
Conductivity (µs/cm)	-	2100	2145
Nitrate - N (mg/l)	-	19.5	18.0
Extractable P (mg/l)	38	42.5	44.5
Extractable K (mg/l)	198	201	227
Extractable Mg (mg/l)	58	59.5	57.5
Extractable Mn (mg/l)	-	0.6	1.3
Extractable Na (mg/l)	-	5.5	7.5

Soil temperature

Peak daily soil temperatures at 15 cm depth were generally highest with the polythene cover and lowest in the smear-sealed plots, a difference of approximately 0.7^0C (Appendix 2). The soil treated with sprayable plastic showed peak daily temperatures similar to the bare soil. Peak daily temperature increased from 19.2^0C at covering (24 May) to 22^0C after one week, and then declined over the next week to 16^0C after the cover was removed and the soil cultivated.

Discussion

Weed control

Compared with the very effective weed control observed with the same treatment (750 l/ha Metham Sodium 400 + 200 kg/ha Basamid) applied to soil at Moulton, Lincs in May 2000 (weed cover on treated, raked ground was 0.8% at 6 weeks after treatment), the results obtained here were slightly disappointing (weed cover on treated, raked ground was 2.9% at 6 weeks after treatment but 56% by 9 weeks after treatment). Although no weed assessments were made at more than 6 weeks after soil sterilisation in spring 2000, the host farmer and others reported that treated areas were noticeable for their lack of weeds throughout the summer. This was very visibly not the case at Melbourn. The prime reason was rapid growth of fat hen during July at Melbourn.

The total weed populations in untreated soil at the two sites, as determined by seedling counts in replicate 0.25 m^2 quadrats 6 weeks after soil preparation, were broadly similar with 51 and 72 at Moulton and Melbourn respectively. However, while the main species at Moulton were mayweed (51%) and shepherd's purse (21%) with only 0.38 fat hen seedlings/quadrat (< 1% of seedlings), at Melbourn the main weeds were small nettle (58%) and fat hen (21%); there were 10.63 fat hen seedlings/quadrat (i.e. 28 times more than at Moulton). Fat hen was the weed species which was most resistant to the sterilisation treatment, with only 76% control in raked soil and 36% control in rotovated soil. Control of all other weeds present at significant levels, at either site, was ≥ 94%. Information on the absolute kill of dormant weed seeds of different species in soil by dazomet and metham sodium would be useful. If combined with soil weed seed determinations before treatment, it would allow a better prediction of the likely effectiveness of soil sterilisation on weed control. Product literature indicates that absolute kill of fat hen seed by Basamid should be very good, precluding subsequent germination from treated soil.

Key features of the predominant weeds found at the two sites are summarised below:

Weed	Main germination period	Seed type
Small nettle	Feb - Sep/Oct	Soft
Shepherd's purse	Jan - Dec	Soft
Mayweed	Jan - Dec	Soft
Field speedwell	Jan - Dec	Hard
Fat hen	Feb - Nov	Hard

Fat hen has noticeably hard seed and a long germination period (Williams & Morrison, 1987). It is possible that these factors mean that a large proportion of fat hen seed are not primed ready for germination even if the soil is warm and moist, and consequently are more difficult to kill by soil chemical treatment. It is known that seeds in their resting state are more difficult to kill with dazomet than germinating weeds. Other hard-coated weed seeds (e.g. nut sedge) have been reported difficult to kill with Basamid or metam sodium (Locasio *et al*., 1997). However, field speedwell also has hard seed and yet control of this weed in our trial was good. Also, there is specific evidence that Basamid is effective against dry and dormant seed of fat hen when used at 30 g/m^2 to 20 cm (Anon).

Soil moisture content is of particular importance for soil sterilisation. With dazomet, insufficient soil moisture results in too low a gas (MITC) concentration and unsatisfactory control. The % moisture at Moulton (14%) and Melbourn (23%) at time of treatment was similar. The % moisture holding capacity was 56% at Melbourn and 50% at Moulton. Certis literature on Basamid recommend that soil is at least at 40% of its maximum water-holding capacity to ensure the desired rapid breakdown of dazomet, and 60-70% MHC is optimum (Anon). Soil moisture was satisfactory

therefore.

Soil temperature was well above the 10^0 C minimum requirement for rapid breakdown of dazomet at time of treatment, and also, below the recommended maximum of 22-25^0 C, when the gases escape too rapidly. Incorrect temperature is therefore not the reason for poor weed control.

In an earlier weed control experiment using soil sterilants on this farm (Briggs, 1977), Basamid was hand-applied to soil in mid-February at 5 and 10 g/m^2 and incorporated to 2.5 cm depth (equivalent to 10 and 20 g/m^2 for 10 cm incorporation) 6 weeks prior to drilling larkspur. Both treatments resulted in significant reduction in weed cover through to 30 June. Weed cover in the untreated areas on 30 June was 81%, compared with 15 and 10% in the 5 and 10 g/m^2 Basamid treatments (weed numbers not specified).

In another weed control experiment using soil sterilants carried out near Ashford, Kent (Brough, 1993), Basamid was applied to a sandy soil by hand at 10 g/m^2 and raked into the top 5 cm of soil, and at 38 g/m^2 and forked into the top 15-20 cm of soil. Treatment was applied on 5 November and plots covered with polythene until mid-March. The degree of weed control on 15 June (12 weeks after polythene removal) was 81% and 74% respectively, reducing to 19 and 55% by 16 August. The main weeds not controlled well by these treatments were perennial weeds (creeping buttercup and dock), willowherb and groundsel.

Basamid is reported to be 100% effective when used against fat hen (59 weeds/m^2) at 50 g.m^2 incorporated to 20 cm (Anon). Control was 95% when Basamid used against a population of 69 fat hen weeds/m^2 at a rate of 30 g/m^2 (incorporation depth not given). In the trial reported here, Basamid was used at 20 g/m^2 incorporated to approximately 5 cm, equivalent to 80 g/m^2 if incorporated to 20 cm i.e. at more than the quoted rate for 100% control of fat hen. However, if incorporation in our trial was inadvertently done to a depth significantly greater than 5 cm, the control of weed seed was likely to be reduced.

Efficacy of soil sterilisation against weeds at different depths in the soil

In spring 2000, in the trial at Moulton, sterilisation with 500 l/ha Metham Sodium 400 + 200 kg/ha Basamid resulted in weed reductions of 100, 87 and 97% at 0-5, 10-15 and 20-25 cm depths respectively. In spring 2001, in the trial at Melbourn, sterilisation with 750 l/ha Metham Sodium 400 + 200 kg/ha Basamid resulted in weed kill of 84, 57 and 98% at these depths respectively. The predominance of fat hen and the slightly higher total weed seedling population, probably accounted for the poorer results at Melbourn. In both trials the least effective weed control was at 11-15 cm, and this was confirmed by a further test on undisturbed soil at the Melbourn site (Table 7).

Provided soil is not rotovated after sterilisation, this should not present a problem with weed control in the planted crop as most weed germination occurs in the top 5 cm and especially in the top 2 cm (Grundy *et al*., 1996). The reason for the 11-15 cm soil layer having less effective weed seed kill is that it lies below the layer to which Basamid is incorporated (0-5 cm) and above the band where Metham Sodium is injected (20-25 cm), and consequently is dependent on good diffusion of metham sodium in the soil moisture and upward movement of MITC gas for sterilisation to be achieved (there would be little or movement of MITC gas downwards from the Basamid treated layer).

Control of *Pythium* and *Sclerotinia*

Where weed control is the prime objective, and the soil is not cultivated after treatment other than to break the surface seal, it seems likely that more effect weed control may be obtained if the metam-

sodium is injected less deeply (e.g. at 10-15 cm).

Soil sterilisation resulted in 56% kill of *Pythium* (as measured by re-growth of the fungus from radish seed recovered 19 days after treatment) and 97% kill of *Sclerotinia* sclerotia. This compares with 100% and 86% for the same fungal pathogens using the 750 l/ha rate of Metham Sodium 400 in spring 2000. The results of the two trials are therefore largely comparable for *Sclerotinia*. The reason for the relatively poor control of *Pythium* this time is unknown. In the trial reported here, the fungi were buried at 20-25 cm, so it is the Metham Sodium 400, rather than Basamid that will have been the active sterilising treatment. Although disappointing that complete kill of the two fungi was not achieved, it is probable that such a large reduction in fungal inoculum would have resulted in reduced risk of a serious disease problem from these fungi occurring. Previous trials with Basamid against *Pythium* indicate a concentration of more than 200 ppm dazomet (equivalent to > 60 g/m^2 Basamid incorporated to 20 cm) can be required for effective control of *Pythium ultimum* (Anon).

The comparison of root rot fungi occurring on crop plant roots was made on a relatively small sample. Nevertheless, there was evidence of a reduction in *Phytophthora* root rot on chrysanthemum associated with soil sterilisation. However, there was also an increase in *Pythium* associated with soil sterilisation. The treatment appeared to be relatively ineffective against *Cylindrocarpon*, the cause of brown root rot, with isolation from around 20% of discoloured roots from both treated and untreated areas. No *Verticillium*, or other fungal pathogens, were isolated from the stem base of plants showing leaf yellowing.

Re-planting interval

Cress tests on treated soil indicated it was safe to plant at 11 days after treatment, 4 days after removal of polythene. Soil was not fully clear of phytotoxic fumes at 7 days. In spring 2000, there was poor germination at 7 days (none over soil taken from 30 cm depth) but good germination after 13 days. When applied to warm soil in the spring, it therefore appears that it is reasonable to expect to be able to plant at 14 days after soil sterilisation using the treatment described here. In all cases though, a cress test should be done to verify the soil is free of phytotoxic fumes.

Comparison of soil covers

The three methods of covering treated soil (smear seal only; smear seal + 30 µm polythene film; smear seal + sprayable plastic) appeared to be equally effective in retaining the sterilant gases. There was a similar degree of weed control at 40 days after treatment in all 3 areas (< 4% weed cover, compared with 58% in untreated plots), while fungal pathogen kill was slightly better with the polythene and sprayable plastic covers. These results contrast with those of a trial in Lincs in autumn 1999, where smear seal resulted in a relatively poor control of weed seedlings. In spring 2000, all plots were covered with polythene. Until and unless there is evidence to the contrary, it would appear wise to cover the soil surface after sterilisation in order to ensure retention of the gases, in the critical first few days after application. Further work is needed to determine if the sprayable plastic is as effective as polythene film in retaining the gases. If so, this would considerably enhance the practicality and speed the process of sterilising soil with the chemicals as described here. This treatment may be particularly useful in the spring where a crop is to be planted soon after soil sterilisation.

Crop growth

Effects of soil sterilisation treatment on crop growth need to be interpreted with caution because of

(i) the small plot size and (ii) the poor control of fat hen, and hence the competition exerted by this weed. Because of these confounding factors, a formal cost-benefit analysis was therefore not undertaken. All plots were hand-weeded of fat hen, and other large weeds on 27-30 July, c. 45 days after planting chrysanthemum and drilling the sunflower. The sunflower outgrew the developing weeds, but in the chrysanthemum beds there was strong competition until the plots were hand-weeded.

With the sunflower, soil sterilisation markedly increased crop growth (21% increase in total plot weight), albeit that this resulted in a reduction in the number of marketable stems because of the increased head size. Possibly this could be overcome by planting at an increased density after soil sterilisation.

With the chrysanthemum, soil sterilisation increased total number of stems per plot by c. 60%, with no loss of marketability. It is probable that this resulted largely from the reduced weed competition (ground cover at 40 days reduced from 61% to 12%), and in part from control of minor root diseases (e.g. *Phytophthora*), and nitrogen mineralisation (although no detectable effect was measured). Sterilisation appeared to increase slightly the extractable soil levels of potassium, manganese and sodium, but it seems unlikely this would have influenced growth as levels in unsterilised soil were satisfactory.

Conclusions

1. A combined treatment of Basamid shallowly incorporated at 20 g/m^2 and Metham Sodium 400 at 750 l/ha (equivalent to Discovery at 588 l/ha) injected at 25 cm depth, into a well prepared sandy clay loam soil, on 24 May 2001, under near ideal conditions, and the soil sealed with polythene, and subsequently lightly raked to release residual fumes, provided good weed control for 40 days, sufficient to allow crop establishment.

2. Control of fat hen later in crop growth was poor. A flush of fat hen seed germinated c. 6-9 weeks after soil sterilisation resulting in a severe weed problem. Even in the sterilised raked plots, 53% of ground area was covered by weeds at 9 weeks after sterilisation, necessitating hand-weeding.

3. There was evidence of reduced weed seed kill in the soil at around 11-15 cm depth, the boundary layer between the two applied chemicals. This probably accounted for the reduced weed control where the soil was rotovated at 7 days after treatment, to release residual fumes, rather than raked. The % ground area covered by weeds was increased from 3% (raking) to 21% (rotovating).

4. Further information is needed on the absolute level of kill of common weed seeds by dazomet and metam-sodium to assess the rate of Basamid to be used. Greater knowledge of which seeds are difficult to kill by this combined treatment, together with a pre-sterilisation assessment of weed species in the soil, will allow a judgement to be made on the likely effectiveness of the combined treatment for effective weed control.

5. The combined treatment of Basamid at 20 g/m^2 and Metham Sodium 400 at 750 l/ha gave significant reductions but not complete control of *Pythium* and *Sclerotinia* buried at 20-25 cm. The degree of control of Sclerotinia was similar to that achieved in the trial in spring 2000, while control of Pythium appeared less. It is probable that large reductions in soil inoculum of soil-borne fungal pathogens will result in a reduced risk of a serious root disease problem.

6. Under the conditions of this experiment, cress seed germination tests indicated the soil was suitable for planting at 11 days after treatment of warm soil in late May. Similar results were obtained in a trial in spring 2000. The conditions of use for Discovery (a new formulation of metam-sodium which has replaced Metham Sodium 400) permit planting of crops once a cress germination test has been carried out and the germination found to be satisfactory.

7. Growth of chrysanthemum (from block raised plants) and sunflower (direct drilled) was enhanced by the soil sterilisation treatment. This probably arose in part from reduced weed competition and in part from control of minor root pathogens. Treatment under the conditions of our trial resulted in an increase in the number of marketable chrysanthemum stems, and in the weight of sunflowers. The latter, unfortunately, resulted in a reduced number of marketable sunflowers because heads were too large.

8. A more comprehensive body of case-studies monitoring the efficacy of soil sterilisation by Basamid and Discovery on commercial nurseries, assessing weed control, root diseases and crop growth, is required to confirm and extend the results of the trials conducted in this project.

9. Further work is needed to determine the efficacy of a bio-degradable polyvinyl acetate spray in comparison with a smear-seal and polythene film, for sealing-in the sterilant gas (MITC).

TECHNOLOGY TRANSFER

1. Presentation to growers by Tim O'Neill and Giles Budge at the HDC Cut Flowers Walk, HRI Kirton, 21 September 2000.

2. Cut flowers and bulbs - development of an alternative to methyl bromide for soil sterilisation (article for above meeting).

3. Good as methyl bromide? *HDC News* **68**, 20-21.

4. Project review meetings, Spalding, 5 October 2000 and 21 March 2002.

5. Know your enemy - the key to good disease control. presentation by Tim O'Neill at HDC/HRI Cut Flower Conference, HRI Wellesbourne, 27 November 2001.

6. DEFRA-funded seminars for growers, by Tim O'Neill and Dan Drakes, on: Alternatives to methyl bromide for soil sterilisation:

   Preston' Lancs, 18 February 2002
   Askham Bryham College, Yorkshire, 19 February 2002
   Spalding, Lincs, 25 February 2002
   Chichester, West Sussex, 27 February 2002

7. Annual report, December 2000.

8. Interim progress report, August 2001 (to consortium members).

9. HDC News. New and views.

10. Grower walk (planned), Spalding, 18 July 2002.

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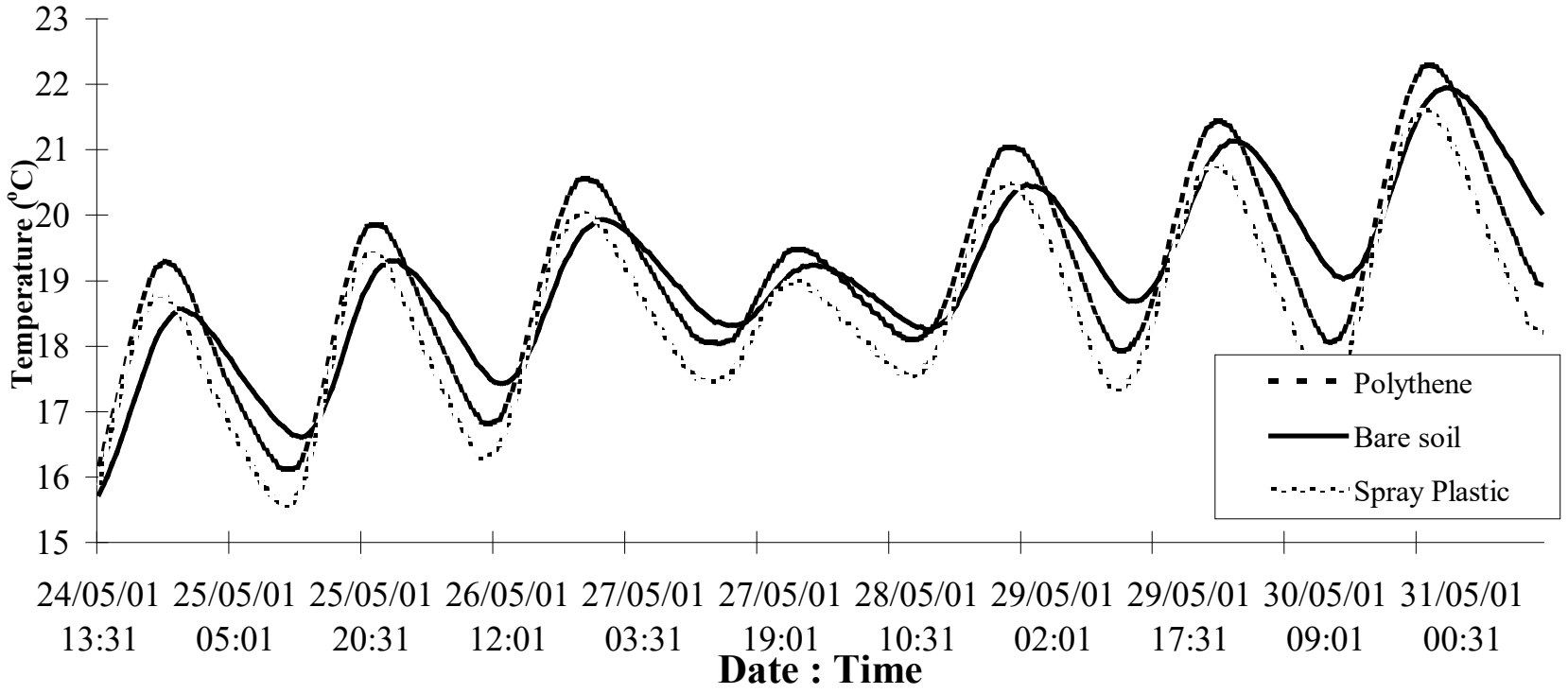
Appendix 1 Record of Metham Sodium 400 Application

Application Date: 24/05/01

	PLOT	Untreated strips				Treated strips				Bare	Poly	Spray
	BLOCK	1	2	3	4	1	2	3	4	-	-	-
	RATE	0	0	0	0	750	750	750	750	750	750	750
D	10	0	0	0	0	1343	809	785	947	910	890	830
I	20	0	0	0	0	705	722	740	743	752	755	777
S	30	0	0	0	0	754	772	757	763	751	760	738
T	40	0	0	0	0	757	750	747	748	749	742	727
A	50	**0**	**0**	**0**	**0**	**751**	**735**	**746**	**746**	**761**	**732**	**757**
N	60	**0**	**0**	**0**	**0**	**758**	**747**	**752**	**751**	**750**	**739**	**754**
C												
E												
Total MeNa applied (l)		0	0	0	0	14	13	13	13	13	13	13
Time taken to cover (mins)		4	2	2	2	2	2	2	2	-	2	2

Notes
Bold areas indicate burial areas

Soil temperature at 15 cm depth
(soil sterilisation treatments applied on 24 May)



Appendix 3. Effect of soil sterilisation on weed control - comparison of crops

Treatment	% weed cover[a]	
	Chrysanthemum	Sunflower
After 40 days (3 July)		
1. Untreated, raked	62.5	52.5
2. Unsterilised, rotovated	60.8	67.0
3. Sterilised, raked	5.0	0.8
4. Sterilised, rotovated	25.5	16.3
After 64 days (28 July)		
1. Untreated, raked	100	96.7
2. Unsterilised, rotovated	100	95.0
3. Sterilised, raked	78.3	40.0
4. Sterilised, rotovated	100	91.7