Contract report for the Horticultural Development Council

Bulbs and cut flowers: development of a combined dazomet and metam-sodium treatment as an alternative to methyl bromide for soil sterilisation 1999 - 2000

BOF 45

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Location of project:	Moulton, Lincs (field trials) ADAS Arthur Rickwood (laboratory tests)
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The results and conclusions in this report are based on a series of experiments conducted over a one 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.

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PRACTICAL SECTION FOR GROWERS

Commercial benefits of the project

This project has identified a new soil sterilisation treatment for use in cut flower production as an alternative to methyl bromide for treatment of outdoor land to control weed seeds and soil-borne fungal pathogens. Commercial exploitation of this work is dependent on further trials on intensively cropped land, to determine the flower yield and quality benefit following soil sterilisation.

Background and objectives

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 31 December 2005, with earlier substantial reductions in use (60% by January 2001). An effective alternative with wide-spectrum activity and short turn-round time is needed. This project is designed to evaluate the effectiveness of a novel treatment in which two proven and environmentally acceptable chemical sterilants (Basamid and Metam Sodium 400) are applied in combination, accurately, and to different layers in the soil profile to achieve thorough sterilisation of weed seeds and soil-borne diseases. Incorporation of Basamid (dazomet) granules in the surface layer will enhance the prospects of reliable pathogen and weed control in this important zone; use of Metham Sodium 400 (metam-sodium) 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.

Specific targets for 1999/2000

1. To determine the effectiveness of Metham Sodium 400 (metam-sodium) and Basamid (dazomet) applied in combination at different rates in controlling selected plant pathogens (e.g. *Pythium, Phytophthora, Fusarium, Verticillium, Rhizoctonia* and *Sclerotinia*), buried at two depths in the soil.

2. To undertake cress tests to determine when it is safe to replant after soil treatment.

3. To monitor the effect of treatment on weed control.

Summary of results in 1999/2000

<u>Experiment 1 - autumn 1999</u>

Nylon bags containing of six fungal pathogens (*Fusarium, Phytophthora, 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 replicate plots (20 x 3 m). Plots were left untreated, or treated by Sands Agricultural Services Ltd with Basamid spread and rotavated in the surface layer (20 g/m^2) and injected with Metham Sodium 400 at 25 cm depth at 500 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 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%. No results were obtained for *Phytophthora.* 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.

Experiment 2 - spring 2000

Six fungal pathogens were buried as described in Experiment 1. 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^{0}C at 15 cm depth and soil moisture content was 14%. 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. Polythene sheets were removed after 7 days and the soil seal broken by raking to release residual fumes. Buried fungi were recovered and tested for viability 21 days after treatment, when a cress seed germination test indicated no residual phytotoxic fumes.

All treatments significantly reduced viability of 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). No results were obtained for *Verticillium.* 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 rather than 500 l/ha.

Conclusions from the work

1. A combined treatment of Basamid shallowly incorporated at 20 g/m^2 into a well-prepared soil in good conditions, with Metham Sodium 400 at 500 litres /ha injected to 25 cm depth, and the soil sealed with polythene, provided excellent weed control. Growing-on tests from soil collected at 5-10, 15-20 and 25-30 cm depth indicated good control of weed seeds at all depths.

2. Treatment with Basamid at 20 g/m^2 and Metham Sodium 400 at 500 l/ha resulted in large reductions in the viability of *Fusarium culmorum*, *Phytophthora cryptogea*, *Pythium* sp., *Rhizoctonia solani*, *Sclerotinia sclerotiorum* and *Verticillium dahliae.*

3. A combined treatment of Basamid at 20 g/m^2 and Metham Sodium 400 applied at a higher rate of 750 l/ha resulted in elimination of *Fusarium culmorum* and *Pythium* sp. down to 25 cm

and significant reductions (>80% kill) of *Phytophthora cryptogea, Rhizoctonia solani* and *Sclerotinia sclerotiorum,* in infested plant tissue. No results were obtained for *Verticillium dahliae.*

4. Under the conditions of these experiments, cress seed germination tests indicated the soil was suitable for planting at 13 days after treatment of warm soil in early May. Currently, the Metham Sodium 400 label stipulates that outside land should not be planted until 8 weeks after treatment. The label has no specific replanting interval for protected crops, but recommends digging over 2 and 3 weeks after application and again before planting. However Metham Sodium 400 is due to be replaced in the UK with 510 g ai/litre metham-sodium formulation (to be called Discovery), whose label conditions of use permit planting within 8 weeks of treatment, providing a cress test has shown it is safe to do so: viz, "Crops must not be planted until the safety test involving the use of cress has been carried out and germination found to be satisfactory".

5. The machine used in these trials has the capability of treating several hectares in a day. The cost for chemicals and polythene sheet (excluding contractor cost and polythene removal and disposal cost) is estimated to be around £3,300/ha (£1,385/acre) for treatment at 200 kg/ha of Basamid and 750 l/ha of Metham Sodium 400.

6. Crop performance in soil sterilised by this new, combined chemical treatment needs to be evaluated.

7. This is a new soil sterilisation system which permits continued production of outdoor cut flowers on intensively-cropped land at an economic cost. The treatment has broad activity against weed seed and soil-borne diseases, is relatively fast, treats the soil to 25 cm depth and permits re-planting within a short time. The treatment rates can be selected according to the perceived weed and disease risk and the duration of the crop being grown.

Action points for growers

1. Where a need for soil sterilisation in outdoor cut flower production is identified (e.g. when planting into land where a serious root disease risk is present; 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 Metham Sodium 400 treatment described in the previous section.

2. There is no single recommendation for all situations. Decide on the precise 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 low rate of Basamid rotavated into the surface layer can be sufficient for good weed control. In contrast, if *Sclerotinia* for example was widespread in the previous crop and sclerotia have been incorporated into the soil, injection of Metham Sodium 400, together with application of Basamid in the surface layer, is likely to be the best option. A long-term crop (e.g. 18 months carnation) is likely to warrant treatment at a higher rate than a short-term crop.

3. Soil preparation and condition is 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 Hortichem Ltd (for Basamid) and United Phosphorus Ltd (for Metham Sodium 400) 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)

4. Application of a polythene film to the soil surface after smear-sealing will assist retention of the sterilant gases and improve weed and disease control. Both Basamid and Metham Sodium 400 begin to decompose into the active sterilising gas on contact with moist soil. Therefore, ensure the 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.

5. 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. Fungal pathogens (e.g. *Pythium, Rhizoctonia)* can spread very rapidly in recently sterilised soil.

6. 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 is treated no more than once every 2-3 years.

7. Note that both Basamid and Metham Sodium 400 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.

8. After treatment has been applied, do not cultivate close to, or below, the depth of sterilisation.

9. Analyse soil for nutrient content after sterilisation and adjust your fertiliser application accordingly.

10. Certain 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 satisfactorily controlled.

Anticipated practical and financial benefits

This project aims to provide the industry with a commercially viable alternative to methyl bromide for reliable soil sterilisation for outdoor cut flower and bulb crops. It has identified an optimum treatment of 200 kg/ha Basamid + 750 l/ha Metham Sodium 400, smear-sealed and covered with polythene, for major soil-borne pathogens and weeds.

To help ensure the new technology is implemented, the project is being supported by Sands Agricultural Services Ltd who undertook the soil sterilisation treatments, by Hortichem Ltd and United Phosphorus Ltd, who supplied chemicals for the initial trials, and latterly by Visqueen Agri, who supplied polythene film.

Outdoor prototype equipment 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. New, smaller scale equipment needs to be developed for use in glasshouses and polythene tunnels. The efficacy of the process needs to be demonstrated to growers, in terms of improved plant quality and production, and a simple cost/benefit analysis undertaken.

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).

Approximate cost of treatment for a 1 ha block of outdoor land

- Assuming cost of Basamid is £6/kg, Metham Sodium 400 is £1.50/litre and 38 μm polythene film is £1,000/ha
- Assuming Basamid is applied at 200 kg/ha and Metham Sodium 400 at 750 l/ha.
- Estimated cost of materials to treat 1 ha of land is then £1,200 + £1,125 + £1,000 = £3,325/ha (£1,385/acre)
- Contractor application and polythene disposal costs to be added
- Approximate cost to treat with Methyl Bromide at 100 g/m^2 (contractor cost included) is around £5-6,000 /ha (£2,083-2,500/acre)

Note: In the near future, the metam-sodium product marketed in the UK is due to change from a 400 g a.i. formulation (Metham Sodium 400) to a 510 g a.i. formulation (Discovery). Equivalent rates of use of the two products are:

Metham Sodium 400 (litre/ha)	Discovery (litre/ha)
500	392
750	588
1,000	784
1147	900 (maximum rate)
1250 (maximum rate)	-

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. Currently these 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 phased out by 31 December 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. A novel alternative approach is to develop a method to apply jointly two proven, 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) and Metham Sodium 400 (metam-sodium) product labels. Both 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 due to replace Metham Sodium 400, 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 proposed label for Discovery is slightly less restrictive on use under protection. For both Basamid and metam-sodium, 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. If plants are to be introduced into a heated house which has been treated with Metham Sodium 400, the heat should be turned on at least 2 weeks before their introduction. Metham Sodium 400 should not be used between 1 November and 31 March, nor when the soil temperature is below 10ºC. Planting must not take place before 8 weeks after outdoor application. When Metham Sodium 400 is used to treat soil in a greenhouse, the label gives no specific prohibition interval before replanting, but recommends digging over 2 and 3 weeks after application, and again before planting.

In this work we propose to 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, with the soil sealed immediately using an hydraulically driven roller to smear the soil surface. A prototype machine has recently been developed for use in field crops and it is envisaged that a smaller version will 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.

MATERIALS AND METHODS

Site details

Field experiments were carried out at two sites on a fine silty loam soil at Moulton, Lincs, both regularly used for flower cropping and known to be weedy. The soil pH was 7.9 (trial 1), 7.3 (trial 2). Organic matter content was 2.3% (trial 1) and 1.7% (trial 2). The previous crops were Sweet William (1998) and tulips (1997) (trial 1) and asters (1999) and Dutch white cabbage (1998)(trial 2).

Experimental design and statistical analysis

For both trials a randomised block design was used with four replicates of five treatments. A 0.5 m wide gap was left between adjacent blocks (trial 1 only). Plot size in the first trial was 3 m wide and 20 m long (60 m^2). Plot size in the second trial was 3 m wide x 50 m long (150 m^2), with an additional 20 m run - in to plots. Efficacy and other tests were conducted in the central 2 m width to avoid edge effects. Results were examined by ANOVA, or by Friedman's test where initial examination of data showed that conditions for ANOVA did not hold. Significant differences between treatments are shown as *** - $P<0.001$; ** - $P<0.01$; * - $P<0.05$; or NS - not significant.

Treatments

The following treatments were applied by machine (Fig 2). Basamid was incorporated at 200 kg/ha (20 g/m^2) into the top 5 cm of soil (treatments 2-5 inclusive) and Metham Sodium 400 injected at different treatment rates at 25-30 cm depth:

<u>Experiment 1 - autumn 1999</u>

1. Untreated (control)
2. Metham Sodium 400 at 500 litres/ha + Basamid at 200 kg/ha
3. [Metham Sodium 400 at 750 litres/ha] + Basamid at 200 kg/ha
4. [Metham Sodium 400 at 1,000 litres/ha] + Basamid at 200 kg/ha
5. [Metham Sodium 400 at 1,250 litres/ha (maximum approved rate)] + Basamid at 200 kg/ha

[Note - it was subsequently found that due to a technical problem, the machine failed to apply any metham sodium to treatments 3, 4 or 5]

Treatments were applied on 12 October 1999 when the soil temperature was 11ºC at 15 and 25 cm depth. The soil moisture content was 16.0% (66% of Moisture Holding Capacity). The soil surface was sealed by a roller. No polythene cover was applied.

<u>Experiment 2 - spring 2000</u>

1. Untreated control
2. Metham Sodium 400 at 375 litres/ha + Basamid at 200 kg/ha
3. Metham Sodium 400 at 500 litres/ha + Basamid at 200 kg/ha
4. Metham Sodium 400 at 750 litres/ha + Basamid at 200 kg/ha
5. Metham Sodium 400 at 1,250 litres/ha + Basamid at 200 kg/ha

Treatments were applied on 10 - 11 May 2000, under good conditions, when the soil temperature was 20^0C at 15 cm and 16^0C at 25 cm. The soil moisture content was 14.0, 15.3 and 16.1% at 15, 25 and 35 cm depths respectively (49.8, 54.3 and 61.6% of MHC). The soil surface was sealed by a

roller and then covered within 10 minutes by roller-applied 2.75 m wide x 38 µm thick clear polythene film (Visqueen Agri). The untreated control plots were roller-sealed, covered with polythene and raked after polythene removal, exactly as for the treated plots.

The application rate of Metham Sodium 400 was recorded at 5 positions (at 10 m intervals) along the length of each plot, and the total quantity applied to each plot was also recorded (Appendix 1).

Diary of events

Experiment 1 - autumn 1999

07 September	soil sampled for general analysis
12 October	samples buried, soil treated
15 October	soil sampled for % moisture
19 October	soil sampled for first cress test
26 October	soil sampled for second cress test
29 October	soil raked, cap broken
02 November	samples recovered for viability testing
03 December	soil sampled from 3 depths for weed assessment
17 December	first on-site weed assessment
10 February	second on-site weed assessment

Experiment 2 - spring 2000

11 April	soil sampled for analysis
10-11 May	samples buried, soil treated (T1-2 on 10 May; T3-5 on 11 May)
18 May	polythene removed over fungal areas; soil raked
19 May	soil sampled for first cress test
23 May	soil sampled for second cress test
25 May	polythene removed, over non - fungal areas; soil raked
31 May	fungal samples recovered for viability testing
21 June	first weed assessment
28 June	weed assessment completed
9 July	soil sampled from 3 depths for weed assessment

Dispersal of residual gas (re-planting interval)

Experiment 1

The soil was raked to break the surface seal two weeks after treatment. 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 centre of each plot. Germination of cress seed suspended in closed jam jar above treated soil was compared with seed suspended over untreated soil after 3 and 7 days.

Experiment 2

The polythene cover was removed from half the length of each plot (fungal depot areas) after 7 days and from the remaining halves after 14 days. The soil was immediately raked after uncovering, to break the surface seal. Soil samples were collected from 0 - 15 and 16 - 30 cm depth for cress tests (5 cores from each plot) at 9 and 13 days after treatment.

Determination of treatment efficacy on buried plant pathogens

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 is also important that the target pathogens are 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 naturally infested plant tissue, or naturally produced sclerotia, in each plot. The pathogens are in a highly resistant state when within root/stem pieces and therefore present a severe challenge for the sterilisation treatment. Any differences between plots in background levels of pathogens will be irrelevant as efficacy tests will be conducted on the deliberately buried and recovered samples.

Sources of plant pathogens

The following were prepared

1. Radish seed affected by a *Pythium* species (originally isolated from lisianthus root)
2. Sclerotia of *Sclerotinia sclerotiorum* grown on celery sticks (originally isolated from sweet pea)
3. Stem bases of carnations affected by *Rhizoctonia solani* (isolated from column stocks)
4. Stems of carnations affected by *Fusarium culmorum* (isolated from pinks)
5. Roots of aster (exp. 1) or wheat seed (exp. 2) (affected by *Phytophthora cryptogea* (isolated from aster)
6. Roots (exp. 1) or stem bases (exp. 2) of chrysanthemum affected by *Verticillium dahliae* (isolated from chrysanthemum)

Pieces of root or stem (c. 1 cm in length) were prepared after the fungus had colonised the host material, or produced sclerotia.

Burial and recovery of plant pathogens

Standard numbers of colonised root or stem pieces of pathogen inoculum were prepared, mixed with washed silver sand, and enclosed in 180 μm mesh nylon gauze. Sets of 6 pathogens were assembled in a large-mesh bag. A magnet was buried with each bag of pathogen samples to aid recovery. Three labelled sets of inoculum were buried at 10-15 and at 20-25 cm depth approximately 2 m apart and at measured distances from plot markers in each plot (i.e. 6 sets per plot). Depth of burial within a plot was randomised. 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). Rotavation to incorporate Basamid prior to rolling and sealing was adjusted to 4-6 cm, so that the buried samples were not brought to the surface. Depth of sample bags was measured at recovery.

Testing for pathogen viability

Buried crop debris were sieved from the silver sand, surface sterilised and 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 in May 2000, 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 approximately 8 and 15 weeks after raking (experiment 1) or in 10 x 0.25 m^2 quadrats at 5 weeks after uncovering and raking (experiment 2). The predominant weeds species were identified. To reduce the risk of wind-blown seeds contaminating treated plots, weeds on field headlands in close proximity to the trail area were strimmed prior to establishing the trials. In experiment 2, 100 imbibed oilseed rape seed were scattered over 1 m^2 in the centre of each plot, and the number of emerged plants recorded at 5 weeks after uncovering.

Additionally at 8 weeks after treatment, pits were dug in the centre of all plots of treatments 1, 2 and 5 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, in a frost-protected glasshouse (experiment 1) or polythene tunnel (experiment 2) and the number of weeds assessed after 40 days.

RESULTS

Experiment 1 - autumn 1999

Re-planting interval

No cress seed germinated seven days after the soil sterilisation treatment. For soil collected 14 days after treatment, there was good germination in all replicate jars of all treatments (Table 1).

It should be noted that the soil was only lightly raked to release residual fumes, and not rotavated. Therefore this is likely to be close to the maximum necessary re-planting interval under these particular treatment and soil conditions.

Control of soil - borne fungi

Methodology

From 120 sets of fungi buried in the soil, 117 were successfully recovered. The vast majority were recovered at the depth at which they had been buried, though many had been moved laterally. Ten root or stem pieces or sclerotia were recovered from most pouches. In a few pouches, some of the tissue pieces (especially aster roots) had disintegrated and fewer were recovered. The selective agars generally restricted growth of contaminating soil fungi and allowed identification of the target pathogen. All fungi from the untreated soil were recovered at a high incidence, with the exception of *Phytophthora,* where many of the aster roots had disintegrated completely (Table 2).

Viability

Soil sterilisation resulted in a significant reduction in the viability of the buried fungi. Treatment again *Rhizoctonia* was particularly effective with recovery reduced from 98% to 3% (Table 2). Viability of all other fungi was reduced to less 20%. None of the fungi were completely eliminated at 500 l/ha of Metham Sodium 400.

Expressed as a % kill of viable fungus in untreated plots, treatment efficacy with Metham Sodium 400 at 500 l/ha ranged from 75% for *Fusarium* to 97% for *Rhizoctonia*.

The effectiveness of treatment according to burial depth varied slightly between fungi. There was a slightly greater % kill of *Fusarium, Pythium* and *Rhizoctonia* at 20 cm (87, 97 and 100 % respectively) than at 10 cm (51, 88 and 95%) (Table 3 and Figure 4).

Treatment with Metham Sodium 400 at intended rates of greater than 500 l/ha produced surprising results. There was a complete lack of pathogen kill, abundant weed seed germination and early cress seed germination. This led to the conclusion, subsequently confirmed, that due to a technical problem no Metham Sodium 400 was injected in these treatments. Treatments 3, 4 and 5 therefore all became surface layer treatment with dazomet only, uncovered with polythene, and this was insufficient to kill fungal pathogens even at 10-15 cm depth.

Weed control

The degree of weed control achieved in this trial was relatively poor. At 10 weeks after treatment, although the mean number of weed seedlings was greatest in untreated plots (19.0/quadrat), and least where metham sodium was applied at 500 l/ha (6.4/quadrat), the difference was not statistically significant (Table 4). At 17 weeks after treatment, the % ground area covered by weeds was reduced from 3.7 % (untreated) to 1.0-2.5% (treatments 2-5, where Basamid was applied to all plots at 200 kg/ha).

Weeds found most commonly were fumitory, shepherd's purse, mayweed and small nettle (Table 5). Reductions of numbers of these weeds by treatment 2 were 88%, 70%, 64% and 63% respectively.

Examination of different soil layers for viable weed seeds strongly suggested that no Metham Sodium 400 was applied except in treatment 2 (Table 6). From untreated soil, the weed burden increased with depth, being 16.4 at 0-5 cm and 30.8 at 20-25 cm. From treatment 2 (Basamid in upper 5 cm, Metham Sodium 400, at 30 cm), the weed number was zero at 20-25 cm, suggesting effective kill by the Metham Sodium 400, and moderate numbers at 0-5 and 10-15 cm, suggesting partial kill from Basamid and Metham Sodium 400 respectively. From treatment 5 (Basamid in upper 5 cm, no chemical at 30 cm), the viable weed number at 20 - 25 cm depth was no different from that of untreated soil, and the weed number at 0 - 5 cm depth was no different from treatment 2, where Basamid had also been applied.

Table 1. Release of residual fumes after soil sterilisation - Moulton, autumn 1999

Treatment	Cress germination after treatment:	
	7 days (19 Oct)	14 days (26 Oct)
1. Untreated	++++	++++
2. MeNa-500 l/ha	-	++++
3. [MeNa-750 l/ha[a]]	+++	++++
4. [MeNa-1000 l/ha[a]]	+++	++++
5. [MeNa 1250 l/ha[a]]	+++	++++
6. Control	++++	++++

- No cress seed germination; +++ good germination in 3 jars; ++++ good germination in all 4 jars.
[a] Subsequent investigation indicated no Metham Sodium 400 (MeNa) was applied in these treatments. These treatments were therefore Basamid only, at 20 g/m^2 in the surface layer.

Table 2. Efficacy of soil sterilisation against six fungal pathogens - Moulton, autumn 1999

Treatment	% fungal viability on recovery from soil					
	Fus	Phy	Pyt	Rhi	Scl	Ver
1. Untreated	77	3	99	98	87	58
2. MeNa-500 l/ha	19	7	13	3	7	9
3. [MeNa-750 l/ha[a]]	60	2	93	92	90	-
4. [MeNa-1000 l/ha[a]]	61	6	92	93	86	-
5. [MeNa 1250 l/ha[a]]	58	1	95	99	91	86

[a] subsequent investigation indicated no Metham Sodium 400 (MeNa) was applied in these treatments. These treatments were therefore Basamid only, at 20 g/m^2 in the surface layer.

Fus- *Fusarium culmorum* on pieces of carnation stems
Phy- *Phytophthora cryptogea* in aster roots
Pyt- *Pythium* sp. in radish seed
Rhi - *Rhizoctonia solani* in carnation stems
Scl - *Sclerotinia sclerotiorum* sclerotia (grown on celery)
Ver - *Verticillium dahliae* in chrysanthemum stem bases

Table 3. Variation in treatment efficacy with depth - Moulton, autumn 1999

Depth and treatment	% viability on recovery from soil					
	Fus[a]	Phy	Pyt	Rhi	Scl	Ver
Buried at 10 cm (mean recovery depth 12-14 cm)						
1. Untreated	62.8	5.8	100.0	95.6	90.4	54.2
2. MeNa (500 l/ha) + Basamid (200 kg/ha)	30.8	10.4	22.1	4.4	3.8	5.1
3. Basamid (200 kg/ha)	64.2	3.4	86.2	88.3	87.3	60.8
Significance (df)	NS(14)	NS(14)	***(14)	***(10)	***(14)	*(l6)
SED (min. rep.)	18.90	5.63	9.63	13.35	6.84	15.32
Buried at 20 cm (mean recovery depth 19-21 cm)						
1. Untreated	86.7	0	98.2	100	83.9	61.6
2. MeNa (500 l/ha) + Basamid (200 kg/ha)	11.7	0.93	3.3	0	7.9	9.9
3. Basamid (200 kg/ha)	56.4	2.57	100.0	99.3	91.5	70.4
Significance (d.f.)	***(14)	NS(14)	***(14)	***(10)	***(14)	***(16)
SED (min. rep.)	11.80	2.60	1.65	0.87	5.57	7.79

Statistically significant differences between treatments are shown as: *** - P< 0.001; *<0.05; NS - no significant differences.

[a]See footnote below Table 2 for full fungal names.

Table 4. Effect of soil sterilisation on weed seed germination - Moulton, autumn 1999

Treatment	Mean no. weed seedlings/0.25m^2 quadrat[b] (17 Dec)	Mean % ground cover by weeds per quadrat[b] (10 Feb)
1. Untreated	19.0	3.7
2. MeNa-500 l/ha	6.4	2.5
3. [MeNa-750 l/ha[a]]	10.0	1.0
4. [MeNa-1000 l/ha[a]]	17.9	2.6
5. [MeNa 1250 l/ha[a]]	9.7	2.2
Significance	NS	NS

[a] Subsequent investigation indicated no Metham Sodium 400 (MeNa) was applied in these treatments.

[b] Mean results from 5 quadrats in the central area of each plot (17 Dec) or 15 quadrats throughout the plot (10 Feb).

NS - no significant differences

Table 5. Weed species occurring after soil sterilisation - Moulton, 17 December 1999

Common name	Latin name	Mean number seedlings/treatment (MeNa)				
		Unt	500	750	1000	1250l/ha
Annual meadow grass	*Poa annua*	0.0	0.0	0.1	0.0	0.0
Chickweed	*Stellaria media*	1.9	1.3	0.9	1.7	1.9
Cleavers	*Galium aparine*	0.0	0.1	0.0	0.0	0.0
Fumitory	*Fumaria officinalis*	5.7	0.7	0.3	1.3	1.6
Groundsel	*Senecio vulgaris*	0.1	0.6	0.1	0.4	0.1
Mayweed	*Matricaria.* spp.	3.3	1.2	2.1	4.7	1.1
Shepherd's Purse	*Capsella bursa-pastoris*	5.6	1.7	4.0	7.0	2.5
Small nettle	*Urtica urens*	2.4	0.9	2.6	2.9	2.6
Speedwell	*Veronica* spp.	0.1	0.1	0.0	0.0	0.0

Table 6. Viability of weed seeds in different soil layers after soil sterilisation

Treatment	Total number of weed seedlings from different soil layers[a] (after 40 days incubation in trays in a heated greenhouse[b]):		
	0-5 cm soil layer	10-15 cm soil layer	20-25 cm soil layer
1. Untreated	16.3	26.0	30.8
2. MeNa - 500 l/ha + Basamid	7.0	9.3	0
5. Basamid - 200 kg/ha	5.8	16.5	28.0

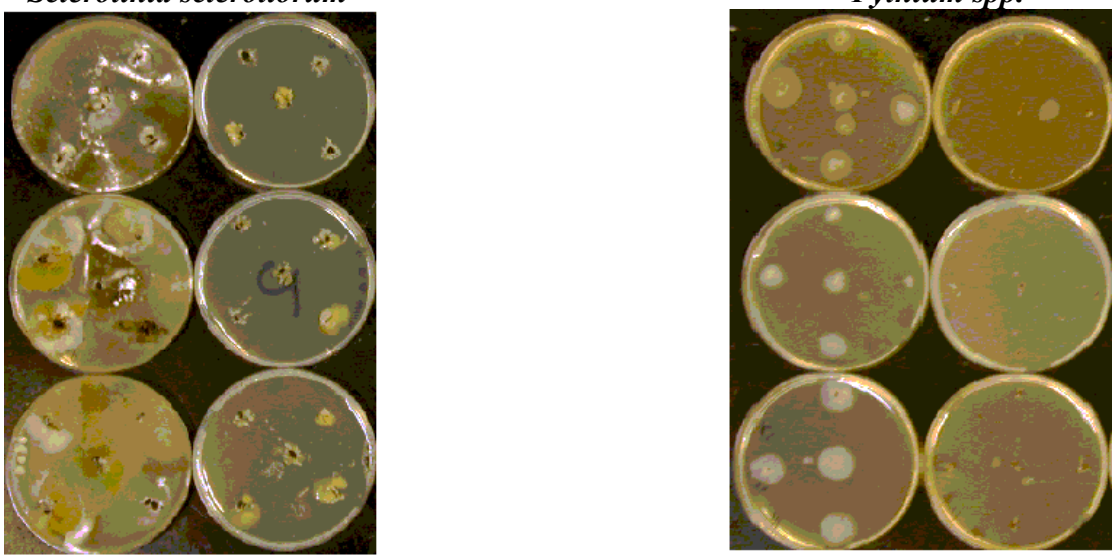
[a] Soil sampled 3 December 1999.
[b] Mean of 4 replicate trays per treatment.

Figure 1 Burial of plant pathogen pouches

Figure 2 Machinery used to apply treatments

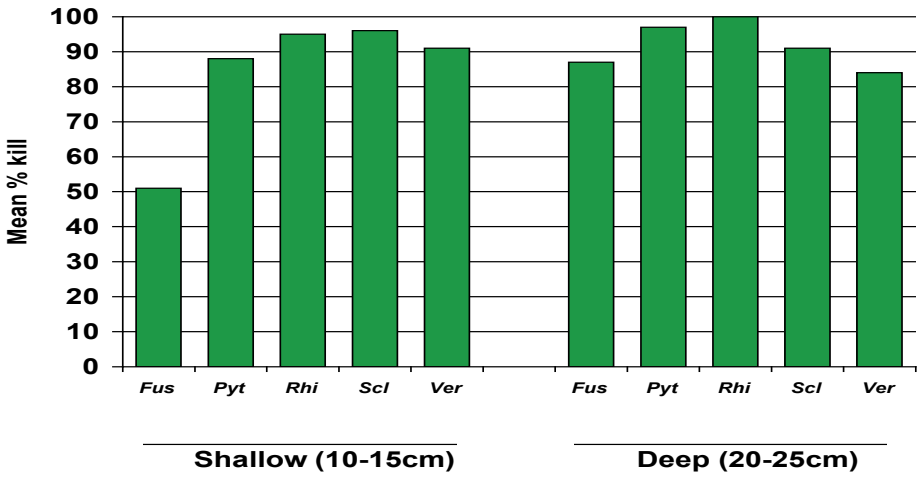
Figure 3 Selective agar plates

Sclerotinia sclerotiorum ***Pythium spp.***



Untreated 500 l/ha **Untreated 500 l/ha**

Figure 4 Effect of treatment on fungal pathogens buried in soil at two depths - October 1999



Basamid at 20 g m $^{-2}$: Metham Sodium 400 at 500 l ha^{-1}

Experiment 2 - spring 2000

Practicality of treatment

In contrast to experiment 1, the Metham Sodium 400 was successfully applied at all the target rates. Application rate at 10 m intervals along each plot length was noted from the digital display in the tractor cab (Appendix 1). There was little wind and Basamid was applied uniformly as required. Polythene film was applied within a few minutes of chemical application except for 2 plots when a mechanical problem with the polythene layer occurred; polythene here was applied by hand within 10 minutes. Treatment conditions were ideal for good efficacy. Soil temperature at 15 cm depth in covered and uncovered soil is shown in Appendix 2. Covering the soil with polythene raised the temperature at 15 ºC by up to 4 ºC on sunny days; the difference was generally around 1-2 ºC at night.

Re - planting interval

In soil collected 9 days after treatment (1 day after raking), there was some germination of cress seed over soil from 15 cm depth but little or no germination over soil from 30 cm depth. By 13 days after treatment, there was no inhibition of cress seed germination with any samples (Table 7).

Control of soil - borne fungi

A test on infected root and stems pieces prior to burial showed high levels of colonisation (Table 8).

From 120 sets of fungi buried in the soil, 95 were recovered. The others were moved by the rotavator and became magnetically held on the application machine. There was an average of 4.75 replicate pouches recovered per plot (minimum of 3.0; maximum of 6.0) on which to conduct viability tests. The selective agars generally worked well giving clean recovery of fungi from the plant tissues, with the exception of the *Verticillium* agar; no *Verticillium* was recovered.

Soil sterilisation resulted in a significant reduction in the viability of *Sclerotinia*, *Fusarium* and *Pythium* (Table 9) and substantially reduced viability of *Phytophthora* and *Rhizoctonia*. Treatment against *Pythium* and *Fusarium* was most effective, with 100% kill at 750 l/ha Metham Sodium 400. Treatment against *Sclerotinia* and *Phytophthora* was least effective with 4.3% and 11.0% of buried sample pieces, respectively, remaining viable after treatment at the maximum rate. Although there was a general trend towards increasing % kill with increasing Metham Sodium 400 rate, there was not a clear dose - rate effect (Figures 5-6)

There was more disturbance of bags than in the first experiment resulting in recovery of bags from a wide range of depths. Treatment efficacy according to depth and rate is shown in Tables 10 - 14. Control of *Sclerotinia* was better at depth than near the surface. For the other fungal pathogens, control was good or excellent at all depths.

Weed control

Weed control in all treatments was excellent. None of the buried oilseed rape grew, except in the untreated control (mean of 10.8 plants/plot). Five weeks after removal of polythene covers, the % ground area covered by weeds was reduced from more than 50% to less than 2% by all treatments (Table 15). There was no difference in the degree of weed control according to whether the polythene cover had been left on for one week or two. The predominant weed species was mayweed (Table 16). Weed control in the surface layer and at 20-25 cm was excellent (Table 17). Weed control at 10-15 cm depth was good with Metham Sodium 400 at 500 l/ha and excellent where this chemical was used at the maximum rate.

Approximate cost of treatment for a 1 ha block of outdoor land

- Assuming cost of Basamid is £6/kg, Metham Sodium 400 is £1.50/litre and 38 μm polythene film is £1,000/ha
- Assuming Basamid is applied at 200 kg/ha and Metham Sodium 400 at 750 l/ha.
- Estimated cost of materials to treat 1 ha of land is then £1,200 + £1,125 + £1,000 = £3,325/ha (£1,385/acre)
- Contractor application and polythene disposal costs to be added
- Approximate cost to treat with Methyl Bromide at 100 g/m^2 (contractor cost included) is around £5-6,000 /ha (£2,083-2,500/acre)

Note: In the near future, the metam-sodium product marketed in the UK is due to change from a 400 g a.i. formulation (Metham Sodium 400) to a 510 g a.i. formulation (Discovery). Equivalent rates of use of the two products are:

Metham Sodium 400 (litre/ha)	Discovery (litre/ha)
500	392
750	588
1,000	784
1147	900 (maximum rate)
1250 (maximum rate)	-

Figure 5. Effect of treatment on fungal pathogens - May 2000

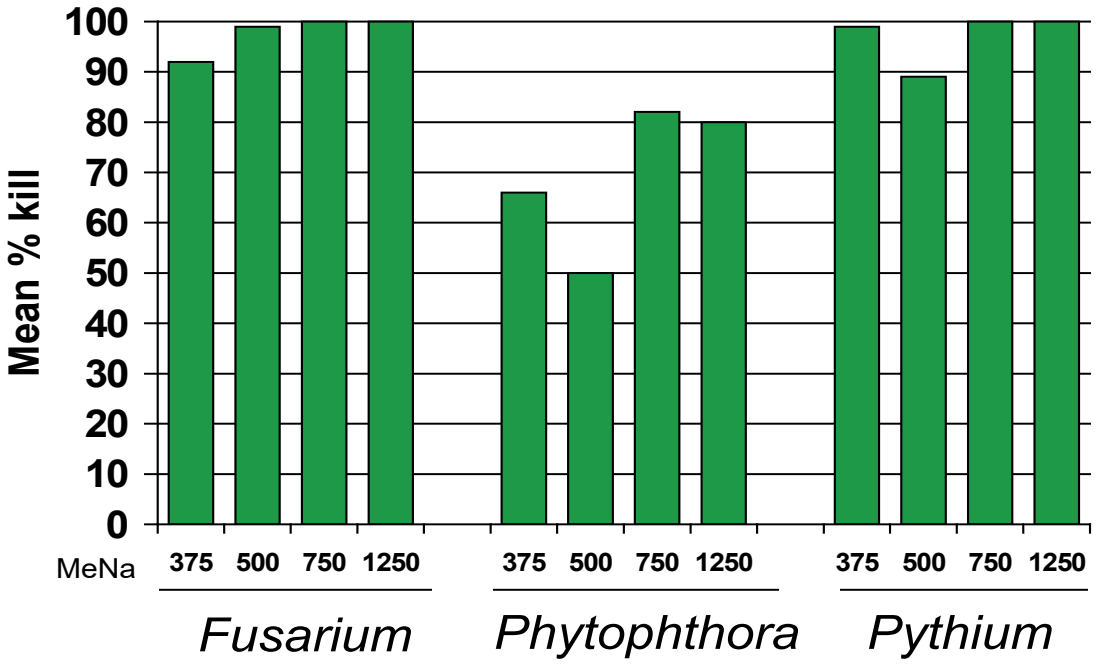


Figure 6. Effect of treatment on fungi - May 2000

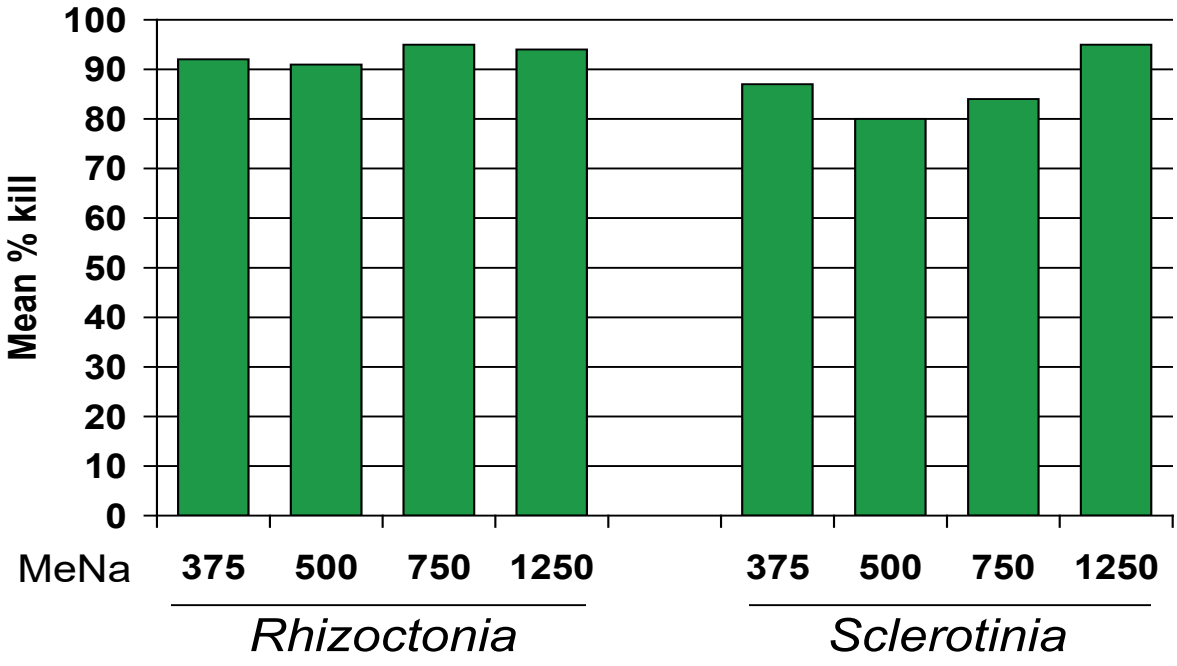


Table 7. Release of residual fumes after soil sterilisation - Moulton, spring 2000

Treatment	Cress germination after treatment [a]			
	9 days (19 May)		13 days (26 May)	
	15 cm	30 cm	15 cm	30 cm
1. Untreated	4	4	4	4
2. MeNa - 375 l/ha	4	3	4	4
3. MeNa - 500 l/ha	3	0	4	4
4. MeNa - 750 l/ha	3	0	4	4
5. MeNa - 1250 l/ha	3	0	4	4

[a] No. of jars of 4 with germinated seed.
MeNa - Metham Sodium 400

Table 8. Recovery of fungi from infected root and stem pieces before burial in soil - May 2000

	Fungus[a]				
	Fusarium	Phytophthora	Pythium	Rhizoctonia	Sclerotinia
% recovery	98	86	71	100	100

[a] 40 - 50 stem or root pieces, or sclerotia, tested.

Table 9. Efficacy of soil sterilisation against five fungal pathogens - Moulton, spring 2000

Treatment	% fungal viability on recovery from soil[a]				
	Fusarium	Phytophthora	Pythium	Rhizoctonia	Sclerotinia
1. Untreated	73	50	69	95	87
2. MeNa - 375 l/ha	6	17	1	8	11
3. MeNa - 500 l/ha	1	25	8	10	17
4. MeNa - 750 l/ha	0	9	0	5	14
5. MeNa - 1250 l/ha	0	10	0	6	4
Significance[b] (df 4)	0.012	0.065	0.009	0.064	0.038

[a]6 positions per plot meaned
[b]Analysed by Friedman's test. Values less than 0.05 indicate statistically significant differences between treatments.

Table 10. Effect of burial depth and Metham Sodium 400 rate on control of *Fusarium culmorum* (mean % kill) - spring 2000

Depth (cm)	Rate of Metham Sodium 400 (l/ha)			
	375	500	750	1,250
0-5	-	100	100	100
6-10	100	(88)	100	100
11-15	100	100	(100)	(100)
16-20	100	100	100	100
21-25	77	100	100	100
26-30	-	-	-	(100)

- No pieces recovered at this depth; ( ) - one sample only at this depth and rate

Table 11. Effect of burial depth and Metham Sodium 400 rate on control of *Phytophthora cryptogea* (mean % kill) - spring 2000

Depth (cm)	Rate of Metham Sodium 400 (l/ha)			
	375	500	750	1,250
0-5	-	3	82	70
6-10	0	(0)	63	51
11-15	82	64	(100)	(100)
16-20	68	52	(100)	76
21-25	86	95	69	82
26-30	-	-	-	(100)

- No pieces recovered at this depth; ( ) - one sample only at this depth and rate

Table 12. Effect of burial depth and Metham Sodium 400 rate on control of *Pythium* sp. (mean % kill) - spring 2000

Depth (cm)	Rate of Metham Sodium 400 (l/ha)			
	375	500	750	1,250
0-5	-	100	100	100
6-10	100	(100)	100	100
11-15	100	100	(100)	(100)
16-20	98	72	100	100
21-25	100	100	100	100
26-30	-	-	-	(100)

- No pieces recovered at this depth; ( ) - one sample only at this depth and rate

Table 13. Effect of burial depth and Metham Sodium 400 rate on control of *Rhizoctonia solani* (mean % kill) - spring 2000

Depth (cm)	Rate of Metham Sodium 400 (l/ha)			
	375	500	750	1,250
0-5	-	98	94	96
6-10	100	(41)	85	100
11-15	100	100	(100)	(80)
16-20	93	82	100	95
21-25	84	97	97	88
26-30	-	-	-	-

- No pieces recovered at this depth; ( ) - one sample only recovered at this depth and rate

Table 14. Effect of burial depth and Metham Sodium 400 rate on control of *Sclerotinia sclerotiorum* (mean % kill) - spring 2000

Depth (cm)	Rate of Metham Sodium 400 (l/ha)			
	375	500	750	1,250
0-5	-	89	73	91
6-10	69	(50)	71	84
11-15	100	90	(90)	(100)
16-20	91	78	82	98
21-25	84	91	100	100
26-30	-	-	-	-

- No pieces recovered at this depth; ( ) - one sample only recovered

Table 15. Effect of soil sterilisation on weed seed germination - Moulton, spring 2000

Treatment	Mean % ground covered by weeds[a]			
	Polythene on for 1 week		Polythene on for 2 weeks	
	21 June	28 June	21 June	28 June
1. Untreated	77.3	87.6	52.2	82.3
2. MeNa - 375 l/ha	0.7	0.7	0.5	0.8
3. MeNa - 500 l/ha	1.1	0.9	0.3	0.2
4. MeNa - 750 l/ha	1.0	0.8	0.3	0.4
5. MeNa - 1250 l/ha	1.0	0.7	1.5	1.7
6. Outwith trial area (untreated, uncovered, unraked)	99.3	100	99.3	100

[a] Mean of 10 x 0.25m^2 quadrats, assessed 5-6 weeks after treatment

Table 16. Weed species occurring after soil sterilisation - Moulton, spring 2000

Common name	Latin name	Mean number seedling/treatment[a]				
		Unt	375	750	1000	1250
Annual meadow grass	*Poa annua*	2.33	0.08	0.05	0.00	0.05
Chickweed	*Stellaria media*	2.93	0.00	0.03	0.03	0.00
Dead-nettle	*Lamium purpureum*	0.03	0.00	0.00	0.00	0.00
Fat-hen	*Chenopodium album*	0.38	0.00	0.00	0.00	0.00
Groundsel	*Senecio vulgaris*	2.90	0.05	0.03	0.05	0.08
Knotgrass	*Polygonum avicutare*	0.83	0.03	0.00	0.00	0.00
Mayweed	*Matricaria.* spp.	29.70	0.13	0.18	0.08	0.10
Redshank	*Polygonum persicana*	0.30	0.00	0.03	0.00	0.00
Shepherd's purse	*Capsella bursa-pastoris*	10.90	0.03	0.25	0.03	0.08
Small nettle	*Urtica urens*	0.10	0.00	0.00	0.00	0.00
Sowthistle	*Sonchus spp.*	0.25	0.00	0.00	0.03	0.00
Oilseed rape	*Brassica napus*	0.03	0.00	0.00	0.00	0.00

[a]Average of 10 x 0.25m^2 quadrats

Table 17. Viability of weed seeds in different soil layers after soil sterilisation - Moulton, spring 2000

Treatment	Total number of weed seedlings from different soil layers [a] (after 40 days incubation in trays in a greenhouse)[b]		
	0 - 5 cm	10 - 15 cm	20 - 25 cm
1. Untreated	32.7	36.0	38.0
3. MeNa - 500 l/ha	0	4.8	1.0
5. MeNa - 1250 l/ha	0.3	0.3	0

[a] Soil sampled 9 July; weeds assessed 22 August
[b] Mean of 4 replicate trays/treatment

DISCUSSION

Effective and practical treatment

Effective chemical sterilisation of soil with Basamid and Metham Sodium 400 depends on good soil conditions (a uniform tilth with no clods; approximately 50% MHC; minimum of 10^0C at 15 cm depth), accurate and uniform placement of the chemical(s), and effective soil sealing to prevent loss of volatile chemicals to the atmosphere. In the first experiment, the lack of adequate weed control was most probably due to a failure of the smear seal to retain MITC, the active gas released on breakdown of Basamid, for sufficient time. In the second experiment, soil temperature and moisture were ideal for effective treatment and the soil surface was rapidly sealed with polythene film after treatment. Excellent weed and soil-borne disease control resulted.

The failure of Metham Sodium 400 application at rates above 500 l/ha in the first experiment demonstrates the need to monitor carefully the quantity of chemical applied in order to be assured that the desired treatment has been achieved.

Weed control

Excellent weed control was achieved in the second experiment when plots were covered with 38 μm polythene film within a few minutes of treatment, and retained for 7 days. None of the imbibed oilseed rape seeds survived treatment. The warm soil temperature at this time (20^0C at 15 cm depth) ensured a rapid breakdown of Basamid; the product literature recommends a treatment time of 6 days, followed by 3 days of aeration, at this temperature. Increasing the rate of Metham Sodium 400 application at depth from 375 to 1250 l/ha had no effect on weed emergence, suggesting that weed control in the plots had resulted primarily from the 20 g/m^2 of Basamid incorporated into the top 5 cm. This result confirms the good control of weeds achieved by using a low rate of Basamid (10 g/m^2) and sealing the soil with polythene prior to direct drilling larkspur (Briggs, 1997). Subsequent testing of soil taken at 10-15 and 20-25 cm depth, revealed good control of these deeply buried seeds at 500 l/ha Metham Sodium 400, and excellent control at 1250 l/ha of the chemical.

Re - planting interval

The cress test results showed a greater persistence of phytotoxic chemical from the metham-sodium applied at depth than from the Basamid in the surface layer (Table 7). However, 13 days after treatment (5 days after aeration) cress seed germinated well above soil from both the 15 cm and 30 cm layers. The product literature for Discovery, the new 510g ai formulation of metam-sodium, states that crops must not be planted until the safety test involving the use of cress seed has been carried out and germination found to be satisfactory.

Disease control

The combined Basamid and Metham Sodium 400 treatment was demonstrated to be effective against six common soil - borne pathogen. In the first experiment, treatment with Basamid at 20 g/m^2 and Metham Sodium 400 at 500 l/ha resulted in a mean % kill of fungi as follows: *Fusarium*, 75%; *Pythium*, 87%; *Rhizoctonia* 97%; *Sclerotinia* 92% and *Verticillium* (85%); no results were obtained for *Phytophthora*. In the second experiment, treatment at these rates resulted in a mean % kill as follows: *Fusarium*, 99%; *Phytophthora*, 50%; *Pythium*, 88%; *Rhizoctonia* 89% and *Sclerotinia* 80%. No results were obtained for *Verticillium*. Complete elimination of *Fusarium* and *Pythium* was achieved in experiment 2 at rates of Metham Sodium 400 greater than 750 l/ha. Although giving substantial reductions in viability, treatment was least effective against *Phytophthora* and *Sclerotinia*. The *Phytophthora* was buried as colonised wheat seed and these

remained hard after treatment, probably explaining survival of this fungus. The *Sclerotinia* was buried as sclerotia and these are known to be very resistant survival structures. Previous work has shown that the dose of metham-sodium required to kill 50% of *S. sclerotiorum* sclerotia was approximately twice that of some other common soil fungi.

It should be borne in mind that treatment effectiveness might be less under less favourable soil conditions. It should also be noted that although some of the fungi were not eliminated, the large reductions in inoculum level are likely to result in significant reductions in disease risk; there are various studies which show that soil-borne disease risk is related to inoculum level (e.g. Verticillium wilt in strawberry).

Cost and speed of treatment

The cost of a contractor - applied joint Basamid and Metham Sodium 400 treatment, including a polythene cover, appears likely to be much less than that of treatment with methyl bromide at 100 g/m^2. It is also likely to be significantly less than that for steaming to the same depth. A precise costing for steaming is difficult to make as it depends on the specification of the machine purchased, the cost of diesel and the depth of steaming desired. The Regero plate steamer was recently shown to kill five fungal pathogens (*Botrytis squamosa, Fusarium oxysporum, Phytophthora cryptogea, Sclerotinia sclerotiorum* and *Verticillium dahliae)* in the top 5 cm and significantly reduced pathogen burden at 10 cm, but not at 15 cm or greater, with an 8 minute steam (White, 1999). Annual running costs were estimated at around £1,000/ha. The capital cost for a Regero steam generator capable of treating three beds is around £45,000.

Experience to date with the Sands Agricultural Services machine suggests that without applying a polythene cover, a treatment rate of around 5 ha/day is possible (D. Rickerby, pers. comm.). A separate machine is currently required to follow and lay the polythene film. The Regero steamer can treat 1 ha in 98 hours (e.g. 6 days at 16 hours operation/day), assuming a steaming time of 8 minutes per station and no mechanical breakdowns.

Enhanced degradation of MITC

Recent studies in Holland indicate that, with repeated use, the rate of breakdown of methyl-isothiocyanate (MITC) in soil can be significantly accelerated, resulting in insufficient control of nematodes (Verhagen *et al.,* 1996). Preliminary experiments in Australia indicate that persistence of MITC in soil decreases as the number of treatments with metam-sodium increases, and that reduced persistence is greater the higher the pH of the soil (Warton & Matthiessen, 2000). The effect is believed to result from enhanced population of microbes adapted to degrading MITC. Adaptation of the soils disappeared over a three year period when soil were not treated. The biological effect of enhanced degradation of MITC on fungal diseases is currently unknown.

It is recommended that treatment of soil in the UK with Basamid and Metham Sodium 400 is restricted to situations where there is a clear need for soil sterilisation, that frequency of treatment is limited (e.g. to a maximum of once every two or three years), and that it is combined with other measures against soil-borne diseases (e.g. crop rotation, good hygiene) in order to reduce the risk of selecting a microbial population capable of enhanced MITC degradation.

CONCLUSIONS

1. A combined treatment of Basamid shallowly incorporated at 20 g/m^2 into a well-prepared soil in good conditions, with Metham Sodium 400 at 500 litres /ha injected to 25 cm depth, and the soil sealed with polythene, provided excellent weed control. Growing-on tests from soil collected at 5-10, 15-20 and 25-30 cm depth indicated good control of weed seeds at all depths.

2. Treatment with Basamid at 20 g/m^2 and Metham Sodium 400 at 500 l/ha resulted in large reductions in the viability of *Fusarium culmorum*, *Phytophthora cryptogea*, *Pythium* sp., *Rhizoctonia solani*, *Sclerotinia sclerotiorum* and *Verticillium dahliae.*

3. A combined treatment of Basamid at 20 g/m^2 and Metham Sodium 400 applied at a higher rate of 750 l/ha resulted in elimination of *Fusarium culmorum* and *Pythium* sp. down to 25 cm and significant reductions (>80% kill) of *Phytophthora cryptogea, Rhizoctonia solani* and *Sclerotinia sclerotiorum,* in infested plant tissue. No results were obtained for *Verticillium dahliae.*

4. Under the conditions of these experiments, cress seed germination tests indicated the soil was suitable for planting at 13 days after treatment of warm soil in early May. Currently, the Metham Sodium 400 label stipulates that outside land should not be planted until 8 weeks after treatment. The label has no specific replanting interval for protected crops, but recommends digging over 2 and 3 weeks after application and again before planting. However Metham Sodium 400 is due to be replaced in the UK with 510 g ai/litre metham-sodium formulation (to be called Discovery), whose label conditions of use permit planting within 8 weeks of treatment, providing a cress test has shown it is safe to do so: viz, "Crops must not be planted until the safety test involving the use of cress has been carried out and germination found to be satisfactory".

5. The machine used in these trials has the capability of treating several hectares in a day. The cost for chemicals and polythene sheet (excluding contractor cost and polythene removal and disposal cost) is estimated to be around £3,300/ha (£1,385/acre) for treatment at 200 kg/ha of Basamid and 750 l/ha of Metham Sodium 400.

6. Crop performance in soil sterilised by this new, combined chemical treatment needs to be evaluated.

7. This is a new soil sterilisation system which permits continued production of outdoor cut flowers on intensively-cropped land at an economic cost. The treatment has broad activity against weed seed and soil-borne diseases, is relatively fast, treats the soil to 25 cm depth and permits re-planting within a short time. The treatment rates can be selected according to the perceived weed and disease risk and the duration of the crop being grown.

TECHNOLOGY TRANSFER

1. Presentation to growers by Tim O'Neill and Giles Budge at the HDC Cut Flower Walk, HRI Kirton, 21 September 2000.
2. Written summary of year 1 progress - Cut flowers and bulbs: development of an alternative to methyl bromide for soil sterilisation, 21 September 2000.
3. Good as methyl bromide? HDC News **68**, 20-21.
4. Project review meeting, Spalding, 5 October 2000.

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Appendix 1 Record of Metham Sodium 400 application

Date : 10-11/05/00 (T1&2 applied on 10/05/00; T3,4&5 applied on 11/05/00)

	PLOT	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
	BLOCK	1	1	1	1	1	2	2	2	2	2	3	3	3	3	3	4	4	4	4	4
	TREAT	2	1	3	5	4	1	5	4	2	3	5	1	2	3	4	4	2	3	5	1
	RATE	375	Unt	500	1250	750	Unt	1250	750	375	500	1250	Unt	375	500	750	750	375	500	1250	Unt
D	10	-	0	495	H	489	0	H	776	321	419	1348	0	379	480	758	371	322	550	1570	0
I	20	366	0	526	H	768	0	1373	740	H	506	1262	0	378	504	742	728	373	519	1377	0
S	30	386	0	497	1375	743	0	1373	735	381	510	**1258**	0	**379**	**501**	**736**	**759**	**372**	**550**	**1375**	**0**
T	40	**367**	**0**	**504**	**H**	**730**	**0**	**1374**	**729**	**385**	**507**	**1271**	0	**376**	**496**	**746**	**756**	**372**	**515**	**1384**	**0**
A	50	**385**	**0**	**496**	**H**	**763**	**0**	**1374**	**764**	**379**	**498**	1263	0	377	500	757	751	418	H	1367	0
N	60	480	0	500	H	762	0	-	764	346	-	1270	0	-	498	749	747	330	H	1369	0
C	70	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0
E	80	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0
Total MeNa applied (l)		8	0	10	24	16	0	26	15	8	9	25	0	-	10	15	15	-	11	28	0
Time taken to apply polythene cover (mins)		-	-	1	2	2	-	2	2	-	10	3	-	-	3	2	2	-	3	3	-

Notes

Bold areas indicate burial areas

Plots 17 and 18 both had first 20m applied twice due to mechanical failure

H - high reading

Appendix 2 - Record of soil temperature in polythene covered and uncovered plots (15 cm depth) - May 2000