STEWARDSHIP MANUAL

METAM SODIUM AND METAM POTASSIUM

EASTMAN

STEWARDSHIP MANUAL

METAM SODIUM AND METAM POTASSIUM

EASTMAN

CONTENTS

Introduction 5

1. Principles of soil disinfection 6
    1.1. Soils and why they are disinfected 6
    1.2. The basics of soil disinfection 7
        1.2.1. Soil compartments and their role 7
        1.2.2. Disinfectants and their transport/migration in soil 8
        1.2.3. Factors determining disinfectant activity 8

Summary chapter 1 11

2. Metam-based soil disinfectants and their major active gaseous compound 12
    2.1. Generalities 12
    2.2. Characteristics of products containing metam 13
        2.2.1. Metam sodium and metam potassium 13
        2.2.2. Methyl isothiocyanate (MITC) 13
        2.2.3. Biological activity as a soil disinfectant 13
    2.3. The natural occurrence of MITC and other isothiocyanates 14

Summary chapter 2 15

3. Mode of application of metam products in soil disinfection 16
    3.1. Injection 16
        3.1.1. Shank injection 16
        3.1.2. Goosefoot or blade injection 17
        3.1.3. Tractor-mounted machinery illustrated 18
        3.1.4. Localized point injection 18
    3.2. Drip irrigation 18

Summary chapter 3 21

4. Measures that enhance metam and MITC biological activity . . . 22
4.1. Soil compaction . . . 22
4.2. Water seal . . . 23
4.3. Plastic film tarpaulin . . . 24
4.3.1. Generalities and classification . . . 24
4.3.2. Plastic film tarpaulins as part of IPM strategies . . . 25
4.3.3. Care of installed soft disinfectant plastic films . . . 25
4.3.4. Plastic film installation modes . . . 26

Summary chapter 4 . . . 27

5. Metam soil disinfectant step-by-step stewardship . . . 28
5.1. Storage and handling . . . 28
5.1.1. Storage . . . 28
5.1.2. Handling . . . 28
5.2. Check on local conditions . . . 29
5.3. Soil preparation . . . 30
5.3.1. Removal of plant debris from foregoing crop . . . 30
5.3.2. Soil humidity . . . 30
5.3.3. Soil temperature . . . 33
5.3.4. Soil crumbling . . . 33
5.4. Disinfectant application . . . 33
5.4.1. Preliminary steps . . . 33
5.4.2. Metam application . . . 35
5.4.3. Warnings and warning signs . . . 36
5.5. Reentry period . . . 37
5.6. Cleaning of material and drum disposal . . . 37
5.7. Removal of plastic film seal and/or soil aeration . . . 38
5.8. Cleaning of personal protection equipment (PPE) . . . 39
5.9. General rules about the use of filter cartridges . . . 39
5.10. Monitoring residual MITC . . . 40
5.10.1. Checking the work environment for safety . . . 40
5.10.2. Checking for potential phytotoxicity risk after disinfection and soil aeration . . . 41

Summary chapter 5 . . . 43

ADDENDA . . . 44
Abbreviations . . . 44
Glossary . . . 44
Legal notice . . . 46

INTRODUCTION

The storing, handling, and application of soil disinfection products such as metam sodium and metam potassium requires knowledge both about the specific behavior of these products and the volatile active gas generated following product application.

Having background knowledge of soil disinfection in general and of the factors involved enables a common-sense approach toward product use where different application techniques can be used according to specific conditions.

This manual focuses on the conditions to check and measures to take at the different stages of handling and use, including the after-treatment period. Reference is made to existing regulations and recommendations.

Each chapter contains essential information about why and how general and specific measures should be observed, a detailed description of the relevant measures, and a summary of highlights.

1. PRINCIPLES OF SOIL DISINFECTION

1.1. SOILS AND WHY THEY ARE DISINFECTED

Soil is a complex environment composed of mineral and organic constituents, offering a biotope for beneficial as well as plant pathogenic organisms.

Mineral soil particles and organic material are present in different forms and quantities, determining finer or coarser granular structure, sorption phenomena, and inter- and intragranular open space that allows water and gas transport.

Some soil-inhabiting organisms, such as nitrification bacteria, are beneficial. However, crop pathogens (which are particularly found in cultivated soil with poor crop rotation) can cause soilborne diseases, and soil-inhabiting crop pest organism populations such as nematodes can increase beyond crop damage threshold densities. Other types of crop-threatening organisms are weeds and their soil-surviving seeds or structures. After harvest or crop removal, plant debris and plant roots that have not been totally removed enhance the risk of soil-surviving plant pathogens or pest organisms. Depending on the type of crop, different risk organisms survive at lesser or greater depths. A possible solution to avoid these threats is the application of soil fungicides, nematicides, or herbicides.

However, very few of the currently available plant protection products are appropriate for soil treatment. Many of them need repeated cultural treatments and present a potential danger for residue accumulation in the crop.

Soil disinfection as a precultural measure is a more favorable solution. Most of the soil disinfectants have broad spectrum activity, i.e., they are often fungicidal, nematicidal, and herbicidal and, depending on the application mode or technique, they can reach and treat deeper soil layers according to need.

The following table illustrates the most likely depth distribution of soilborne pathogens and pest organisms.

SOIL DEPTH OF VARIOUS PLANT DISEASES AND PESTS

SOIL DEPTH (inches)	DISEASE OR PEST ORGANISMS
0–8	*Pythium* spp., *Phytophthora* citricola Bacteria *(Erwinia, Pseudomonas)* Free-living nematodes *(Longidorus, Pratylenchus, Paratylenchus)*
8–16	*Sclerotium cepivorum, Rhizoctonia* spp., *Phoma* spp., *Didymella lycopersici* *Phytophthora fragariae, Verticillium albo-atrum, Plasmodiophora brassicae* *Thielaviopsis, Botrytis cinerea, Pyrenochaeta lycopersici* Root-knot nematodes *(Meloidogyne)* Cyst-forming nematodes *(Heterodera)*
16–24	*Sclerotinia sclerotiorum, Corticium solani*
> 24	*Fusarium oxysporum, Rosellinia necatrix*

(From: Mappes, D., 1995, *Acta Horticulturea* 382: 96-103)

There is no sharp boundary of pest or disease occurrence at the different soil depths, but the increased risk for plant disease or pest depends also on the rooting depth of the intended crop. Rooting depths of different plant species also illustrate the risk of diseased roots from a foregoing crop when left in the soil.

ROOTING DEPTHS OF VARIOUS PLANT SPECIES

ZONE	SOIL DEPTH (inches)	PLANT SPECIES
Shallow	0–8	Lettuce, peas, cucumbers, carrots, radishes, onions, groundnut
Medium	8–16	Potatoes, spinach, leeks, celeriac, strawberries, beans, pepper and tomatoes
Deep	> 24	Late brassicas, Brussels sprouts

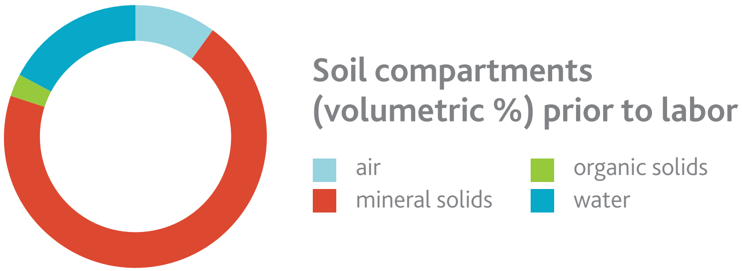
(Extended from: Mappes, D., 1995, *Acta Horticulturea* 382: 96-103)

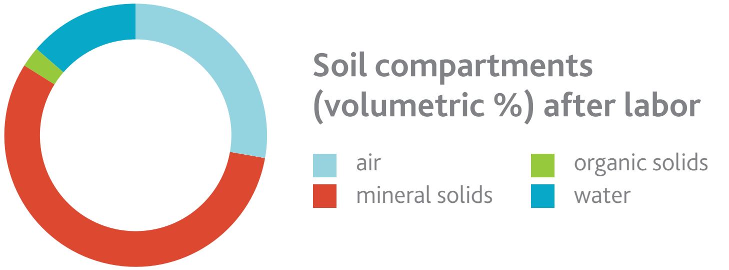
1.2. THE BASICS OF SOIL DISINFECTION

1.2.1 SOIL COMPARTMENTS AND THEIR ROLE

Soil has four major compartments: (1) a solid mineral fraction, (2) a solid organic fraction, (3) air in the intersolid space and between the solid soil clods, and (4) soil water forming a film around solid particles, partially filling up soil particle pores and/or freely flowing between particles.

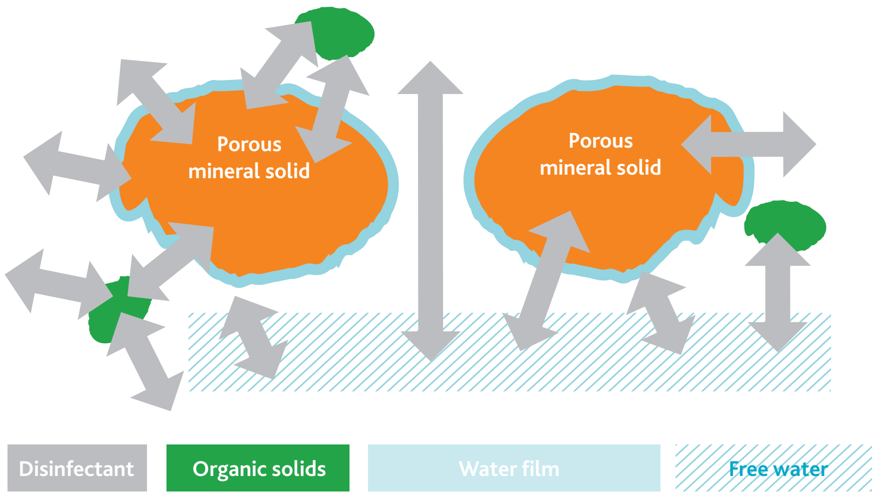
Open channels allow easier gas diffusion and remote disinfectant activity from the point of application, although further dilution of the active gas in air will result in inefficient concentration (see the following: C x t value or concentration x time product). Increase of pore space in the soil to be disinfected is achieved by soil labor and crumbling. The following charts show the effect of soil labor or fine crumbling on pore space (light blue):





Soil labor may also give rise to a chimney effect once a disinfectant has been applied. As will be explained in the mode of application section, risk of premature loss of disinfectant should be reduced or even avoided by topsoil layer compaction, moistening, and/or soil sealing with plastic film.

Minerals such as clay and the presence of organic matter will determine sorption of the active gases. High levels of both categories of solids might necessitate an increase of the effective dose rate. Soil water will dissolve disinfectants and, at high presence, block efficient disinfectant diffusion through the soil. This is different for the water film surrounding the solids where the continuous exchange between the liquid and gas phase allows longer distance transport as shown in the following illustration:



1.2.2. DISINFECTANTS AND THEIR TRANSPORT/MIGRATION IN SOIL

The distance of transport or migration of disinfectant gases in sufficient high concentration from the point of application is studied thoroughly either by chemical monitoring (gas analyzers and gas sampling for further GC analysis) or, at greater depth, by introducing biological test materials (fungal cultures, nematodes, or seeds). Re-isolation of these test materials and measuring of their growth after incubation on specific media, or making counts after the needed disinfectant contact periods, will illustrate the efficacy.

Apart from the following factors for disinfectant activity, disinfectant gas properties co-determine transport in soil as their chemical structure and molecular size will determine sorption, solution, and diffusion through micropores; physical properties such as vapor pressure and gas density will determine spread in the soil atmosphere through the bigger pores and air channels.

1.2.3. FACTORS DETERMINING DISINFECTANT ACTIVITY

1.2.3.1. SOIL HUMIDITY

Humidity is needed to sensitize target organisms by making them (more) active prior to soil treatment and to regulate disinfectant diffusion processes. Sufficient humidity is needed to avoid the development of more stress-resistant survival structures such as sclerotia or resistant spores which are less sensitive to soil disinfectants, as in the case of fungal soilborne pathogens. Best disinfectant performance is achieved within certain water-holding capacity (WHC) limits. It is difficult to determine the sometimes narrow optimal value, as it should be empirically determined for each plot to be treated and would change based on the crop.

A general recommendation of soil humidity at the time of application is between 50% and 75% WHC, depending on soil type and product. For metam, 60% WHC is recommended.

A guideline for noninstrumental field evaluation of actual soil moisture is given further on when discussing application operational stages.

1.2.3.2. SOIL TEMPERATURE

Gases and fumigants tend to occupy the maximum available space in a closed containment environment and tend to expand more with increasing temperature. In a closed containment environment, pressure will rise with increasing temperature. The necessary volatility for a fumigating gas depends on the vapor pressure that is also temperature dependent.

Temperature also determines disinfectant solubility in soil moisture and the equilibrium of gas exchange between liquid and gas phase, as well as the adsorption and desorption phenomena at the soil solids phase.

The activity of target organisms and their sensitivity to soil disinfectants will also depend on temperature.

Adverse (too high or too low) soil temperature may lead to early morning or late afternoon/evening disinfection, either to avoid risk of premature loss of the applied disinfectant at too high a temperature or where it is decided to carry out delayed application to avoid low activity at too low a temperature.

1.2.3.3. CLAY CONTENT

Clay or clay minerals have particularly strong binding capacities for most chemicals as they are often electrically charged and may show molecule-trapping spaces in their layered structure. In the case of soil disinfection, it is sometimes necessary to considerably increase dose rate (e.g., double the standard dose rate) to achieve efficient soil treatment results. Dose increase can sometimes be solved by treating only soil strips at high dose rate if the type of cropping system or field configuration allows this.

In some countries, product labels specify dose rates depending on “light” or “heavy” soils.

1.2.3.4. ORGANIC MATTER CONTENT

Organic matter content in soil is mostly a result of the presence of former crops. As a standard rule, as much plant debris from former crops as possible (i.e., aerial parts and roots) should be removed before soil disinfection and next cropping. This is to avoid disinfectant loss by sorption of the gases in and on the plant debris and to remove remaining pest or disease inoculums in the possibly diseased foregoing crops.

It is accepted that, from an organic matter content of 5%–6% onward, disinfectant dose rate might need to be increased by 50%. If possible, and depending on crop type or pest/disease, strip application or treatment at a shallower depth could reduce overall dose rate to the normal rate.

Always follow local dosage regulations.

1.2.3.5. SOIL AMENDMENTS

Growers tend to add amendments to the soil when preparing a greenhouse or a field for cropping. The question is often raised whether it can be performed at the same time as soil disinfection.

The increase of organic matter content in the soil profile can easily be calculated—amendment at 8 ton/acre incorporated over 8 inches soil profile corresponds with approximately a 1% organic matter increase, assuming soil density is approximately equal to 1.0.

Adding green manure or compost just prior to disinfection is not recommended and will necessitate increased dose rate of disinfectant when exceeding 5%–6% organic matter. Adding it, for example, one month before disinfectant application may allow organic material to decompose if soil temperature and moisture content are favorable. If administration of such materials is intended post-soil disinfection, they should certainly not contain plant pests or pathogens.

1.2.3.6. DOSE RATE AND SOIL TARPING

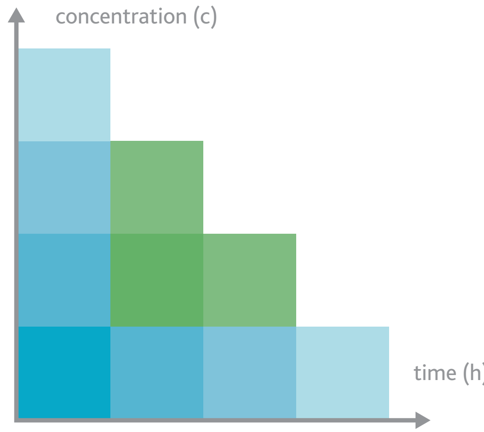
Dose rates for soil disinfection are obtained by dose-rate studies, but for soil application, they will depend on the soil type and the profile (depth) of the soil to be treated with respect to target habitat and rooting depth of the intended crop.

Maximum registered dose rates per area may present some issues for deep treatment as they are expressed in terms of weight or volume per surface unit (lb or gal/acre or oz or oz/yd²). In this case—as already suggested under 1.2.3.3. and 1.2.3.4.—a possible solution would be strip application.

Plastic film soil tarping or sealing can have a huge influence as the subsequent reduction of disinfectant loss during the necessary disinfection period allows reduced dose rates compared to, e.g., smear rolling of the upper layer (the upper inch of soil).

1.2.3.7. EXPOSURE TIME AND CONCENTRATION X TIME CONCEPT

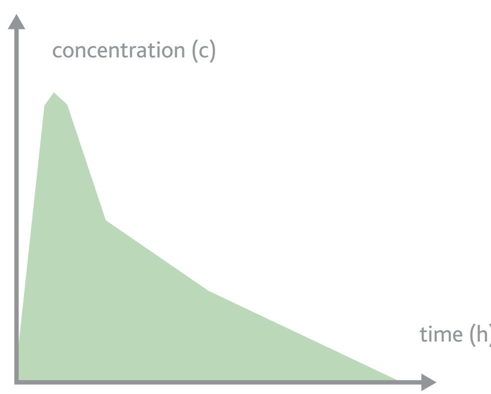
Target organisms are effectively controlled when the actual disinfectant concentration is high enough during sufficient time under certain conditions of humidity and temperature. Efficacy is often expressed in terms of concentration x time product (oz per yd³ x hour). This could be visualized graphically by a rectangle with concentration as the height and time as the width.



Theoretical (rectangular) presentation of C x t: green rectangles may be effective, whereas blue areas are not (very high concentration during very short time or very low concentration during very long time).

In the case of MITC (methyl isothiocyanate) generation from metam, there is a quick buildup of a peak concentration of MITC followed by a decrease as MITC immediately starts to dissipate (gas expansion, sorption, and degradation or metabolism). That means that presence of disinfectant either at very low concentration during a very long period or at very high concentration during a very short period may be inefficient.

The following graph illustrates the practical cases where gradual dissipation of the disinfectant is considered.



Concentration x time product presentation as in the case of MITC generation from metam with subsequent dissipation.

1.2.3.8. RECONTAMINATION OF TREATED FIELDS

Avoid recontamination of treated fields with pathogens through transfer of soil by machinery or workers' boots from one field to another.

SUMMARY CHAPTER 1

PRINCIPLES OF SOIL DISINFECTION

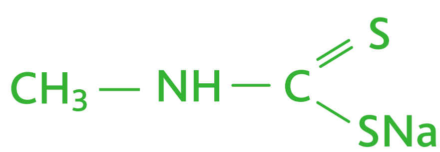
- Plant pests and diseases can originate from soil. In this case, they are called soilborne pests and diseases.
- The soil disinfection result or fumigant performance depends on the concentration x time product; i.e., the necessity to maintain a sufficiently high concentration of the gaseous active compound during a minimum amount of time.
- Many factors affect the fumigant performance and may determine the dose-rate choice: soil humidity, soil temperature, soil clay content, soil organic matter content, organic amendments, and soil sealing.
- Basic hygiene should be observed to avoid recontamination of treated soils by plant pathogens.

2. METAM-BASED SOIL DISINFECTANTS AND THEIR MAJOR ACTIVE GASEOUS COMPOUND

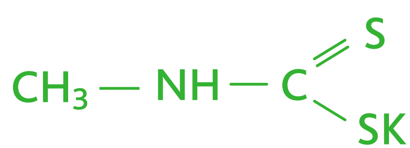
2. 1. GENERALITIES

Metam sodium and metam potassium are both salts of *n*-methyldithiocarbamate. They are commercially available in aqueous solutions. Structural formulas are:

Metam sodium



Metam potassium



Applied to the soil, they decompose into MITC, carbon disulfide, hydrogen sulfide, and other compounds, depending on the soil pH.

MITC is the major gaseous, active metam decomposition product and is known to act as a broad-spectrum soil disinfectant.

Metam products are corrosive, and to guarantee the good functioning of application devices and avoid leakage—guaranteeing the safe storage, handling, and transfer of products—use the materials most appropriate for encountering metam. The following table gives an overview of compatible and incompatible materials.

OVERVIEW OF MATERIALS COMPATIBLE AND INCOMPATIBLE WITH METAM

COMPATIBLE	INCOMPATIBLE
High-density polyethylene (HDPE), polypropylene, polyamide (nylon 6), polytetrafluoroethylene (PFTE; Teflon™)	Copper, soft steel, aluminum, brass
	Galvanized steel and zinc
	Polyvinylchloride (PVC)
Fluoroelastomer (Viton)*	Nitrile butadiene rubber (NBR; Buna-N)
Glass fiber	Ethylene propylene diene monomer rubber (EPDM)
Stainless steel	Chlorosulfonated polyethylene rubber (CSPE; Hypalon)
	Neoprene, butyl rubber
**To be gradually replaced*	Low-density polyethylene (LDPE)

2.2. CHARACTERISTICS OF PRODUCTS CONTAINING METAM

2.2.1. METAM SODIUM AND METAM POTASSIUM

PROPERTY	METAM SODIUM	METAM POTASSIUM
Content of active ingredient	4.25 lb/gal or 42.1% w/w	5.8 lb/gal or 54% w/w
Formulation type (code)	SL (soluble liquid concentrate)	SL (soluble liquid concentrate)
Vapor pressure of the active ingredient	5.75 x 10^{-2} Pa at 77°F moderately volatile	Moderately volatile
Volatility from water (Henry's law constant)	8.34 x 10^{-6} Pa·m³/mol at 68°F, very slightly volatile from water	
Decomposition temperature of the active ingredient	303°F	302°F
Shelf life of formulation	2 years at ambient temperature	2 years at ambient temperature
Dilution stability	Stable after accelerated storage (14 days at 129°F)	

2.2.2. METHYL ISOTHIOCYANATE (MITC)

PROPERTY	VALUE
Vapor pressure	1739 Pa at 68°F Highly volatile substance
Solubility in water	8.94 g/L at 68°F and pH 7.5 Readily soluble in water
Volatility from water (Henry's law constant)	14.2 Pa·m³/mol at 68°F Moderately volatile from water
Gas density (air = 1.0)	2.5

The overviews of properties demonstrate the favorable stability, solubility, and volatility behavior of the metam products as well as the disinfectant capability of the generated active MITC.

2.2.3. BIOLOGICAL ACTIVITY AS A SOIL DISINFECTANT

Metam products are broad-spectrum soil disinfectants. The registered activities cover the large group of nematodes, fungi, and weeds.

Metam and MITC are also known to control certain stages of soilborne pest insects.

Examples of different species among these groups are summarized in the following table.

NEMATODES	FUNGI	WEEDS
Root-knot nematodes:	*Fusarium* spp.	*Amaranthus* spp.
- *Meloidogyne* spp.	*Phialophora* spp.	*Galium aparine*
Cyst nematodes:	*Phoma* spp.	*Malva* spp.
- *Globodera* spp.	*Phytophthora* spp.	*Matricaria* spp.
- *Heterodera* spp.	*Pythium* spp.	*Mercurialis annua*
Free-living nematodes:	*Rhizoctonia* spp.	*Poa annua*
- *Paratylenchus* spp.	*Sclerotinia* spp.	*Senecio* spp.
- *Pratylenchus* spp.	*Verticillium* spp.	*Solanum* spp.
- *Rotylenchulus* spp.	*Aphanomyces* spp.	*Sorghum halepense*
- *Trichodorus* spp.	*Macrophomina* spp.	*Stellaria* spp.
Stem nematodes:	*Sclerotium* spp.	*Taraxacum officinale*
- *Ditylenchus* spp.	*Monosporascus* spp.	*Portulaca* spp.
- *Aphelenchoides* spp.	*Thielaviopsis* spp.	*Orobanche* spp.
		Cuscuta spp.
		Echinochloa spp.
		Polygonum spp.
		Chenopodium spp.
		Cirsium spp.

2.3. THE NATURAL OCCURRENCE OF MITC AND OTHER ISOTHIOCYANATES

MITC and many other isothiocyanates (ITCs) are generated by maceration of specific crops (e.g., *Brassicaceae*) conducting enzymatic (myrosinase) conversion of glucosinolates into corresponding ITCs. Many of them show biological activity. This is also the basis of biodisinfection, i.e., growing appropriate crops on the field to be treated, followed by incorporation of the fully grown crop. Alternatively, the crop can be harvested in one field and subsequently spread and incorporated at another field location. The problem is that glycosinolate content may fluctuate and, as a consequence, the content of the active compound is not well known.

MITC is known to be generated from its precursor glucoapparin particularly in capers (*Capparis spinosa*), horseradish (*Armoracia rusticana*), spider flower (*Cleome spinosa*), and in the seeds of other species of the genus *Cleome*.

A few references from literature are:

Kjaer A., 1960. "Naturally derived isothiocyanates (mustard oils) and their parent glucosides." *Fortschr. Chem. Org. NatStoffe* 18: 122-176.

Ahmed Z.F., Rizk A.M., Hammouda F.M., and Seif El-Nasr M.M., 1972. "Glucosinolates of Egyptian *Capparis* species." *Phytochemistry* 11: 251-256.

Matthäus B. and Özcan M., 2002. "Glucosinolate composition of young shoots and flower buds of capers (*Capparis* species) growing wild in Turkey." *J. Agric. Food Chem.* 50 (25): 7323-7325.

Kaur R., Rampal G. and Pal Vig A., 2011. "Evaluation of antifungal and antioxidative potential of hydrolytic products of glucosinolates from some members of *Brassicaceae* family." *Journal of Plant Breeding and Crop Science* 3(10): 218-228.

The latter publication of 2011 reports on up to 12 different glucosinolates (precursors of ITCs) with content between 6.55 µmol/g in raw flower buds of *Capparis spinosa* (i.e., the edible capers) and up to 45.56 µmol/g in young shoots of *Capparis ovata*. About 90% of the total glucosinolates found is glucoapparin, the precursor of MITC.

Human consumption of many types of edible crops leads to the generation of ITCs from the plant glucosinolates and the absorption of ITCs in the digestive tract. Moreover, diets that include the associated crops such as Brussels sprouts, brassicas, cress, etc., are known to exert anticancer activity in mammals—a phenomenon which is being increasingly recognized.

SUMMARY CHAPTER 2

METAM-BASED SOIL DISINFECTANTS AND THEIR MAJOR ACTIVE GASEOUS COMPOUND

- Metam products are available either as aqueous solutions of sodium or potassium salts (code SL: soluble liquid concentrate).
- Both formulations are stable at room temperature and, once applied in soil, they generate the more volatile MITC as the most biologically active decomposition compound.
- MITC shows solubility and volatility characteristics suitable to act as a soil fumigant.
- MITC and other isothiocyanates are known either to occur naturally or to be enzymatically generated in damaged or macerated plant species.

3. MODE OF APPLICATION OF METAM PRODUCTS IN SOIL DISINFECTION

The goal of this chapter is to make the most appropriate choice of application mode according to local conditions and available equipment.

The choice for a metam application technique can depend on different factors:

- Area or surface to be treated
- Open field or protected area (greenhouse, tunnel)
- Presence of drip irrigation installation
- Distance from residential zones
- Local uses of professional applicators

The techniques are:

- Soil injection
- Drip irrigation

3.1. INJECTION

The principle is the deep application of the soil disinfectant mainly by shank injection or goosefoot injection.

The advantage of deeper soil profile treatment is that it allows a faster and more homogeneous application.

3.1.1. SHANK INJECTION

Shanks are knife shaped and the applied liquid disinfectant escapes through the tubing opening at the deep end of the shank. The configuration preferably contains an anti-drip border to avoid dripping when the application machine is lifted out of the soil, e.g., when moving to another strip to be treated.

The shank position on the machinery can be adjusted according to soil type and target application depth. This means that, for heavy soils, the shanks' interspacing could be smaller. For deep injection or more homogeneous soil profile spread, the depth positioning of shanks could be adjusted or shank depth could alternate.

The following pictures illustrate a variety of shanks.

Deep shanks for field use

Shallow shanks for greenhouse use

3.1.2. GOOSEFOOT OR BLADE INJECTION

This configuration is very suitable for heavy soils and big, open field areas. As the tractor-mounted machine advances, the goosefoot-shaped blade lifts the soil while the disinfectant piping exit underneath allows good spread of the liquid disinfectant on the soil at the chosen depth under the entire surface of the blade if equipped with a spraying nozzle.

The following pictures illustrate this type of application machine as well as different types of goosefoot blades. The presence of a spading section after the injection part (as shown top right) homogenizes the treated soil.

Various types of goosefoot blade injection systems

Various types of goosefoot blade injection systems

Highly successful, commercially produced machine versions are shown:

Mix-Tiller Deeper soil disinfection machine (manufactured by Forigo)

Rotary spading machine with injection (manufactured by Imants)

3.1.3. TRACTOR-MOUNTED MACHINERY ILLUSTRATED

Back-mounted tanks

High-volume tanks

Front-mounted tanks

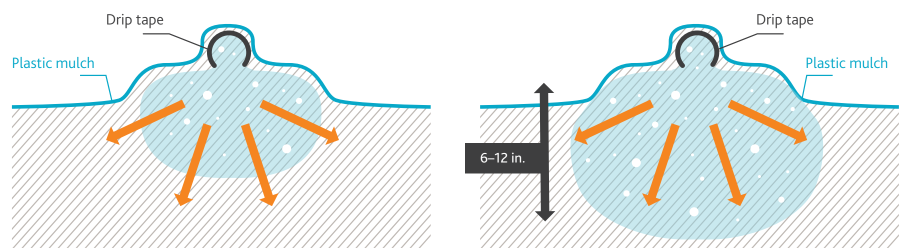
3.1.4. LOCALIZED POINT INJECTION

A very specific application device is a manual point deep injector. This application method is typically used in vineyards for the control of *Armillaria mellea* fungus, the causal agent for mushroom root rot, and *Xiphinema* spp. nematodes that are vectors of the grapevine fan leaf virus (GFVL) disease.

3.2. DRIP IRRIGATION

A very common method is drip irrigation, which is employed in many high-value crop greenhouses and fields. Drip irrigation tubes are spaced 8 to 20 inches apart and perforated every 6 to 12 inches. They should be buried at 2 inches soil depth or covered by plastic film soil tarpaulin. Metam is then applied as a water-diluted solution/mixture where the metam is supplied by an automatic dosage controller/dosing pump such as a Dosatron. A dilution of 0.1% to 2.0% should be achieved. The system must be fitted with an anti-return valve. It takes 1 to 4 hours to apply 0.4 to 1.6 inches of dilution. To obtain good metam solution diffusion, the soil should be reasonably compacted (especially in the case of sandy soil.)

Metam diffusion



Metam diluted in water **Diffusion with the water front**

EXAMPLE OF MOBILE DRIP IRRIGATION SYSTEM

EXAMPLE OF FIXED-DRIP IRRIGATION INSTALLATION

(Photos courtesy Biotek Ag Spain)

Irrigation house

Central control unit to program irrigation time and flow

Metam is introduced at the head of the irrigation system by pouring it into the tank made available for this purpose (not a common method).

Alternatively, a pump can be connected directly to the drum containing metam (most common method).

A) Pump powered by electricity

B) Pump powered by water flow

When there is no injection pump available, the product can be incorporated into the water by suction through a Venturi system.

The system can be regulated to maintain the desired concentration of metam in water.

SUMMARY CHAPTER 3

MODE OF APPLICATION OF METAM PRODUCTS IN SOIL DISINFECTION

- Metam can be applied by two methods: soil injection and drip irrigation system.

    > Soil injection allows the product to be applied at 4 to 16 inches deep with machines equipped with shanks or goosefoot-shaped blades. The machines are mounted at the rear of a tractor. Localized injection for small areas can be done with a manual point deep injector.

    > Application through the existing drip irrigation system is done by incorporating metam in the irrigation water with the help of a dosing pump.

4. MEASURES THAT ENHANCE METAM AND MITC BIOLOGICAL ACTIVITY

This chapter describes the measures that should be taken to optimize successful soil disinfection.

From the concentration x time product concept (see chapter 1.2.3.7), a longer disinfectant contact time combined with disinfectant concentration will give a better result.

The goal is to avoid premature loss of the applied chemical. This can be achieved by quick homogenization of the applied metam in the soil and sealing of the soil. Another important factor is the observation of recommended temperature limits for application. At too low a temperature, the product will not work (too low a volatility of the active compound and inactivity or thus lower sensitivity of the target organisms), and at too high a temperature, the active compound will dissipate or be lost by too fast an emission. High emission rates should also be avoided to protect workers, bystanders, and residents.

For soil sealing, three major techniques or combinations are available:

- Soil compaction
- Water seal
- Plastic film tarpaulin

4.1. SOIL COMPACTION

Soil compaction is often inherent to the application by mechanical soil injection through the presence of a compaction roll on the application machine.

A view of the soil surface after passage of a compaction roll

The compaction roll is mounted directly behind the rotavating machinery or spading section and rotates in opposite motion to the machine to get a smooth, sometimes mirrorlike surface on fine crumbled soil. The upper 0.5 to 0.75 inches of soil is very compacted and slows MITC emission. On more sophisticated models, the roller is driven hydraulically and pressure and rotation speed can be programmed. An alternative to flat compaction is the compactor/bed shaper. In some applications, the additional wetting of the topsoil increases barrier properties. Additional wetting should be avoided when soil is too clayish; completely blocked soil pores may reduce product efficacy in the top layer.

The following pictures illustrate some commercial versions of the application machine fitted with compacting rollers.

Soil compacting rolls on Imants machines (left) and on a Forigo machine (right)

4.2. WATER SEAL

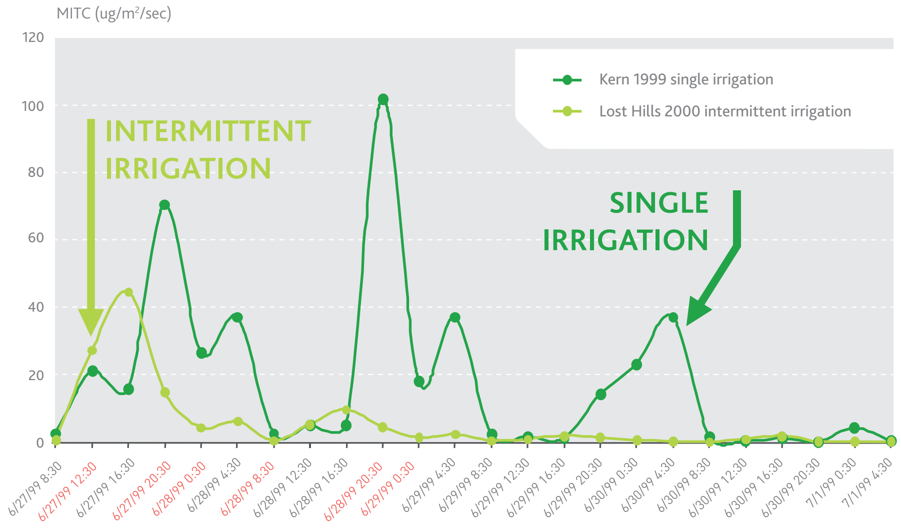
Wetting of the upper one inch of soil will reduce premature disinfectant loss. As indicated under 4.1., soil that is too clayish is less appropriate because completely blocked soil pores may reduce product efficacy in the top layer.

Under warm or hot conditions or wind in an open field, a dry crust may quickly form, giving rise to cracks and loss of its disinfectant-emission-reducing qualities. Intermittent irrigation could offer a solution, as illustrated by the following results.

Shank injection studies were performed to study off-gassing rates of MITC following metam application. The following table summarizes intermittent irrigation times and quantities at the Lost Hills site (Merricks, L.D., 2001, Agrisearch study) and single irrigation time and quantity at the Kern site (Merricks, L.D., 2002, Agrisearch study).

IRRIGATION SESSION		1	2	3	4	5
TIME BETWEEN METAM APPLICATION AND IRRIGATION SESSION		4 hr	12 hr	16 hr	24+4 hr	24+12 hr
INTERMITTENT IRRIGATION	QUANTITY OF WATER	0.6 in.	0.2 in.	0.2 in.	0.2 in.	0.2 in.
	TIME OF IRRIGATION	11:00–13:00	19:00–20:00	23:00–24:00	11:00–12:00	19:00–20:00
SINGLE IRRIGATION	QUANTITY OF WATER	0.8 in.				
	TIME OF IRRIGATION	11:00–13:00				

Results showing low off-gassing of MITC from metam-treated soil by intermittent irrigation at the Lost Hills site as compared to single irrigation at the Kern site are summarized in the following graph:



Comparison of MITC flux to the atmosphere during a 96-hour monitoring period with 24 samplings with 4-hour intervals between intermittent irrigated and single irrigated metam-treated fields.

4.3. PLASTIC FILM TARPAULIN

4.3.1. GENERALITIES AND CLASSIFICATION

Plastic film can be applied to improve efficacy while simultaneously reducing disinfectant emission risks. Standard low-density polyethylene (LDPE) film of 20–30 µm thickness is widely used. Although LDPE presents a certain permeability to gases, the use of such films helps greatly reduce MITC emissions in two ways. First, the plastic tarpaulin will prevent the upper layer of the soil from drying and thereby reduce upward water and MITC movement that would result in more MITC escaping from the soil surface. Second, MITC is highly soluble in water, and the fraction that escapes from the soil surface will be trapped by the water present in the form of film and droplets on the inner plastic tarpaulin surface. MITC may ultimately return to the soil.

When used in an open field, another very good reason to use plastic film is that it can combine the soil disinfection action of metam with that of the solarization (see section 4.3.2.).

There is a large variety of plastic film for soil disinfection available on the market globally. While criteria such as mechanical resistance and workability are imperative, the gas barrier properties are the most important for an optimal treatment result. Unfortunately, the more gastight plastic films are more expensive.

The so-called virtually impermeable film (VIF), totally impermeable film (TIF), and fully impermeable film (FIF) often have a three-, five-, or even seven-layered structure where the central layer, often of only a few micrometers' thickness, is the real gas barrier layer; it is surrounded by adhesive layers and layers present simply for mechanical resistance of the embedded barrier. The total film thickness is often in the 35–40 µm range. An overview of all commercially available film is out of the scope of this manual, but the following is a useful classification table.

CLASS	ABBREVIATION	BARRIER COMPOUNDS
Not completely impermeable		LDPE, PVC, biodegradable starch and polylactic acid (PLA)-based films, and metal oxide coatings
Virtually impermeable film	VIF	Ethylene vinyl alcohol (EVOH), polyamide (PA), and others
Totally impermeable film	TIF	
Fully impermeable film	FIF	

Biodegradable film should be about twice the thickness of LDPE for comparable barrier properties.

Although plastic film sealing for soil disinfection is very useful from a safety and dose-rate reduction perspective, it represents an extra application cost as well as removal and waste treatment costs. Cleaning or washing of used soil disinfection film is not easy. However, recycling is possible and worthwhile with the higher-grade impermeable film containing the more expensive gas barrier compounds.

4.3.2. PLASTIC FILM TARPAULINS AS PART OF INTEGRATED PEST MANAGEMENT (IPM) STRATEGIES

In more southern regions (such as the South of France, Mediterranean countries and their isles, and Northern Africa), soil disinfection can be combined with soil solarization as part of IPM strategies where the disinfectant action considerably reduces or weakens target organism populations for consecutive control by the longer solarization phase. Analogously, precultural soil disinfection can precede a later application of soil-applied antagonistic preparations.

Plastic films for soil solarization should contain ultraviolet blockers to offer longer resistance to decay.

4.3.3. CARE OF INSTALLED SOIL DISINFECTION PLASTIC FILMS

Applicators/workers and farmers/growers should be aware that the smallest pinhole, especially in the more expensive impermeable film types, considerably reduces the active concentration of disinfectant over the underlying soil surface.

It is imperative to remove from the soil, as much as possible, all sharp stones and plant materials that could harm the plastic film.

Stepping on an installed film should be avoided as it increases the risk of pinholes, especially if stones or other sharp materials are left in the soil. A footstep on the film on top of the relatively loose soil will stretch out the film and considerably reduce the local thickness, giving rise to a less gas impermeable zone.

It is useful to apply some water on top of the installed film, not only to reduce the space between soil and film to a minimum but also to avoid tearing the film in outdoor treated fields due to the wind. In greenhouses, sprinklers could be used.

4.3.4. PLASTIC FILM INSTALLATION MODES

There are two ways to install plastic film:

- The film is installed in one run with the combined application and homogenizing machine as shown in the following pictures:

Single-pass equipment:
Application/incorporation/plastic film sealing machine

- In the case of drip-irrigation product application, plastic film is applied over the drip lines prior to the disinfectant administration.

Indoor drip irrigation

Outdoor drip irrigation

If manually unrolling and digging the film is necessary, workers should use personal protective equipment (PPE) to protect themselves from exposure. Additional information regarding PPE and reentry is provided in subsequent sections of this manual.

SUMMARY CHAPTER 4

MEASURES THAT ENHANCE METAM AND MITC BIOLOGICAL ACTIVITY

- The efficacy of applied metam as a soil disinfectant can be increased by avoidance of premature loss of the generated MITC.
- Soil sealing measures can be summarized under three types:
  - > Soil compaction
  - > Water sealing (preferably with intermittent irrigation)
  - > Plastic film sealing (with good gas barrier properties)
- It is compulsory to carry out one measure—or a combination of measures—immediately after disinfectant application from a worker-, bystander-, and resident-safety perspective.
- The application of plastic film enables additional solarization effects under appropriate climatic conditions.
- To optimize plastic film sealing performance, extreme care should be taken not to damage film by sharp objects or footsteps.

5. METAM SOIL DISINFECTION STEP-BY-STEP STEWARDSHIP

This chapter provides information to optimize the soil disinfection result, maintain safety at work, and minimize impact on the environment. It includes information on storage and handling, checking local conditions, soil preparation, different application purposes and particular situations, and after-care and monitoring. **Always keep the Safety Data Sheet close at hand.**

5.1. STORAGE AND HANDLING

5.1.1. STORAGE

Metam products should always be stored in closed, original packaging showing original label and applicable hazard logos. The storage room should be cool and ventilated and should always be locked. It should be located far from buildings with human activity and habitations as well as animal habitats. The maximum volumes to be stored at one site should correspond with local regulations.

Apart from the original plastic drums, only stainless steel metal containers should be used for storage. Empty packaging should not be reused.

The storage area should be inaccessible to children and those not involved in farm operations. Display no-entry signs and signs indicating the presence of hazardous/corrosive materials.

The room should have a basin-shaped floor in case of product leakage, and roof and wall materials should prevent the stored products from heating up. The temperature should not exceed 95°F.

5.1.2. HANDLING

Product handling is the most critical phase.

The choice of material is important for the product transfer connecting systems. A list of metam-compatible and incompatible materials was given under 2.1.

Before handling, the worker should dress in the appropriate PPE:

- Goggles
- Rubber gloves
- Product-resistant synthetic coverall
- Rubber boots
- Respiratory mask with a canister approved for organic vapor with a boiling point higher than 149°F. Combined filters such as A2B2-P3 are filled with activated carbon impregnated with a gas molecule-retaining substance. The filter protects, for example, against organic and inorganic gases and vapor (max 5000 ppm) as well as against toxic substances. It is for general use against plant protection chemicals. In a confined space, a self-contained breathing apparatus (SCBA) with full face mask is recommended.

Air-purifying respirators (APRs) are available in both half-face and full-face models.

Half-face APR

Full-face APR

When filling the application machine tank, leak-free connections should be used. Avoid any spill, drain, or drip to soil.

On the transfer site, the floor should be impermeable to collect product in case of spillage. Risk of evacuation to drains and ditches is prohibited. Never perform such handling close to waterways or ditches.

5.2. CHECK ON LOCAL CONDITIONS

Prior to application, the contractor should know or check the local conditions of the greenhouse or field to be disinfected.

A checklist should be used to assess the necessary measures to take and to help decide on execution in the case of temporary adverse conditions.

The following overview could serve as a checklist:

POINT NUMBER	DESCRIPTION	COMMENTS	TICK BOX
1	Localization	Check for neighboring buildings (public and habitations), presence of water surfaces, drainage ditches, adjacent crops, and animals.	✓
2	Field condition	Check for presence of plant debris, appropriate soil preparation (crumbled and prewetting for target organisms sensitization), soil temperature, and soil humidity.	✓
3	Greenhouse	Check for broken windows and cracked or torn plastic roof or walls.	✓
4	Wind	Check for wind direction and consult forecast, including the days immediately following.	✓
5	Temperature	Consult temperature forecast and the risk of temperature inversion,* including the days immediately following.	✓

* *Temperature inversion is a meteorological situation where temperature increases in higher air layers with lower temperature in the lower layer creating a trap for pollutants by preventing their dilution into the atmosphere.*

Prior to disinfection, the weather forecast for the day of application and the 48-hour period following the disinfection must be checked to determine if unfavorable weather conditions exist or are predicted and whether disinfection should proceed (refer to section 5.4.1.1.).

The grower and the operator may each have their own responsibilities, especially in carrying out correct soil conditioning favorable to soil disinfection.

If necessary, the application should be postponed until conditions are more favorable.
To protect aquatic organisms:

- Do not apply to drained soils.
- In fields vulnerable to surface runoff, respect an untreated vegetative buffer zone of 33 feet to surface water bodies.

5.3. SOIL PREPARATION

5.3.1. REMOVAL OF PLANT DEBRIS FROM FOREGOING CROP

As explained in the basics on soil disinfection (1.2.3.4.), the target field to be treated should be as free as possible of plant debris as it could raise the organic matter content to a critical level or present a source for reinfection of the soil. Particular attention should be given to the removal of deep-rooting crops.

5.3.2. SOIL HUMIDITY

As indicated under 1.2.3.1., there are two main reasons to check and, if necessary, adjust soil humidity.

5.3.2.1. PREWETTING TO SENSITIZE TARGET ORGANISMS

Soil moisture content should be high enough to activate the target organisms responsible for soil-borne plant pests and diseases and weed seeds. If soil humidity adjustment is necessary, the period prior to soil disinfection may be 5 to 10 days' long, depending on the type of target organisms and the resistance of inactive surviving structures or stages as well as the ambient temperature influencing the speed of reactivation after soil wetting. In outdoor situations, the soil to be disinfected may have a sufficiently high moisture content level, depending on recent rainfall.

Where possible or available, sprinkler or drip irrigation is the easiest way to prepare the soil for this purpose. Outdoors and for large surface areas, mobile sprinklers can be used. In some cases, when soil humidity is as high as 6 inches below surface, soil tillage could mix up with the drier top layer. The latter technique could also be used if soil moisture needs to be adjusted again at the time of application (5.3.2.2.)

5.3.2.2. SOIL HUMIDITY AT THE TIME OF APPLICATION

In contrast to soil prewetting for the sensitization of target organisms, soil moisture content for the product application itself is more critical from a gas diffusion perspective and for sorption processes during soil disinfection. It is compulsory to perform soil humidity testing just before application to adjust if necessary.

5.3.2.3. SOIL HUMIDITY TESTING

Field testing is preferably done by measurement and can be confirmed by a simple "feel and appearance" method.

A well-known, quick method for not-too-extreme soil types consists of taking a firm lump of soil that should easily crumble into pieces when it is dropped back onto the ground.

The most optimal humidity level lies between 50% and 75% (even beyond 75% in case of bed shaping) of the water-holding capacity. The most accurate measurement method is by laboratory weighing and drying, but this is time consuming. A more practical option is an electronic device that can be used in the field.

Instruments for soil humidity reading are often based on electrical resistance or on soil suction (pF or water potential) measurement. Readout is then respectively absolute moisture content in percent or in pF/centibar/MPa. For a soil with known percent water retention capacity, percent relative moisture content can be calculated. Other instruments contain an arbitrary scale that could be compared and roughly calibrated for a percentage.

A detailed overview of how to use feel and appearance criteria to estimate soil moisture can be found in the following overview from the USDA National Resources Conservation Service:

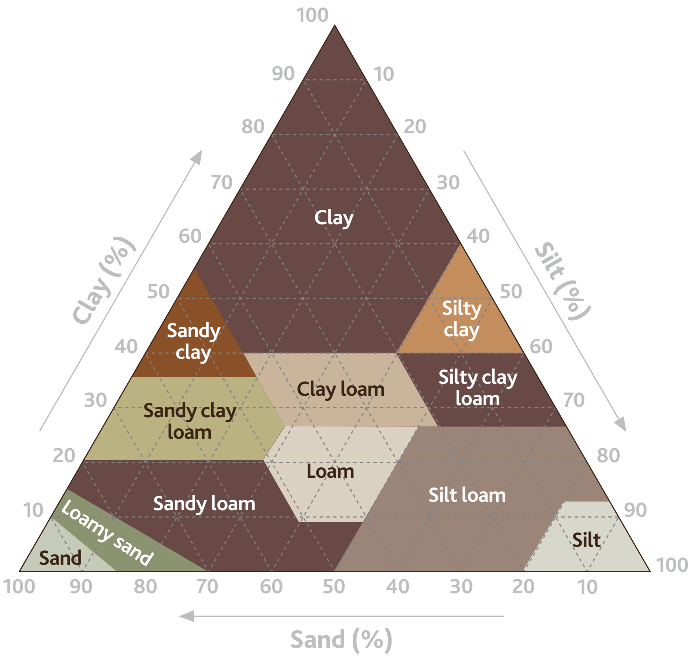
The feel and appearance of soil varies with texture and moisture content. Soil moisture conditions can be estimated, with experience, to an accuracy of about 5%. Soil moisture is typically sampled in 12-inch increments to the root depth of the crop at three or more sites per field. It is best to vary the number of sample sites and depths according to crop, field size, soil texture, and soil stratification. For each sample, the feel and appearance method involves:

- Obtaining a soil sample at the selected depth using a probe, auger, or shovel
- Squeezing the soil sample firmly in your hand several times to form an irregularly shaped "ball"
- Squeezing the soil sample out of your hand between thumb and forefinger to form a ribbon
- Observing soil texture, ability to ribbon, firmness and surface roughness of the ball, water glistening, loose soil particles, soil/water staining on fingers, and soil color. A very weak ball will disintegrate with one tap of the hand. A weak ball will disintegrate with two to three taps
- Comparing observations with photographs and/or charts to estimate percent water available and the water level depleted below field capacity

Appearance of different types of soil at various moisture conditions:

- Fine sand and loamy, fine sand soils
- Sandy loam and fine, sandy loam soils
- Sandy, clay loam, and loam soils
- Clay, clay loam, and silty clay loam soils

Details of each soil category with accompanying pictures are included in a document titled "Estimating Soil Moisture by Feel and Appearance," which can be found here: *http://msue.anr.msu.edu/uploads/235/67987/lyndon/FeelSoil.pdf*



The following table also gives a useful overview of different soil types.

SOIL MOISTURE IDENTIFICATION CHART

% MOISTURE	SAND	SANDY LOAM	CLAY LOAM	CLAY
Close to 0%	Dry, loose, single grained; flows through fingers	Dry, loose; flows through fingers	Dry clods break down into powdery condition	Hard, baked, cracked surface; loose crumbs on surface
50% or less	Appears dry; will not form ball	Appears dry; will not form ball	Crumbly; holds together with pressure	Pliable; will form a ball under pressure
50%– 70%	Same as above	Will ball, but will not hold together	Forms a ball; slight slick with pressure	Forms a ball ribbon between fingers
75% to field capacity	Sticks together; forms a weak ball	Forms a weak ball; will not become slick	Forms a ball very pliable; readily forms a slick	Easily ribbons between fingers
Field capacity	Under pressure, moisture appears on hand	Same as sand	Same as sand	Same as sand

5.3.3. SOIL TEMPERATURE

Soil temperature prior to soil disinfection, together with soil humidity, affects the target organisms' sensitivity. As a basic rule for metam soil disinfection, a minimum temperature of 50°F and a maximum temperature of 77°F are required. The average temperature during the disinfection period determines the minimum number of days before proceeding to soil aeration prior to sowing or planting.

Soil temperature should be checked at 4- to 6-in depths. Both traditional and electronically operated thermometers are commercially available and can be used for this purpose.

Soil temperature is not always under control, especially in outdoor conditions.

For both outdoor and indoor disinfection, alternate timing of the application in the early morning or evening could meet the temperature requirements.

For soil disinfection under protection, soil and air temperature can sometimes be controlled. This would apply if the prewetted period and disinfection conditions were too cold or too high for optimal activity.

However, in cases where soil and air temperature are too low, expensive energy is needed to reach or exceed lowest temperature requirements.

In the case of too high a temperature, risk application timing can be considered and, in case of availability, the use of shadow screens could help to solve such issues.

5.3.4. SOIL CRUMBLING

Homogenization of the soil layer, at least over the soil profile to be disinfected, can be performed during the plant debris removal operation or when rewetting or adjusting soil moisture content. The goals are to obtain suitable homogeneous sensitization and avoid the presence of gas impenetrable soil clods that would limit the control of enveloped target organisms.

Large clods can reduce soil sealing by causing a chimney effect.

The mechanical tools used for soil crumbling are spading and rotating machinery, preferably used several days prior to the disinfectant application for the previously mentioned target sensitization reasons.

It is pointless to carry out soil labor on undisturbed soil prior to soil disinfection.

5.4. DISINFECTANT APPLICATION

Safety measures to be taken and the required PPE will depend on the type of handling and application activity and are discussed in more detail in the Safety Data Sheets (SDS) and under the following respective sections. **Always keep SDS available in case a spill or other incident occurs.**

5.4.1. PRELIMINARY STEPS

As emphasized under 5.2., the checking of local conditions is compulsory and may be the deciding factor about method of application. However, the check of the product transfer, application equipment, and safety equipment shortly before use is just as important.

Good Agricultural Practices (GAP) must be followed during all disinfectant applications.

5.4.1.1. CHECKING THE WEATHER CONDITIONS

Do not apply in adverse weather conditions.

Conditions to avoid:

- The presence of temperature inversion or air stagnation in the area where the disinfection is planned
- Strong winds, heavy rain, or thunderstorms in the application phase and in the hours immediately following (check the weather forecast)
- The phenomena of drift gas where the air mass moves in unpredictable directions even at considerable distances from the treated site

When disinfecting field plots upstream of waterways, ponds, water wells, etc., retention works should be foreseen downhill by making soil heaps or a basin.

5.4.1.2. PRODUCT TRANSFER

Metam transfer from drum to tank should be carried out with appropriate connections away from water surfaces, ditches, and habitations. The handlers' PPE should meet general and local requirements.

All tanks, hoses, fittings, valves, and connections must be serviceable, tightened, sealed, and not leaking.

Dry disconnect couplings (closed transfer system) must be installed on all tanks and transfer hoses.

Sight and pressure gauges must function properly.

Tanks, hoses, and fittings should be designed to withstand the pressure of the system and be resistant to metam (for compatible and noncompatible materials see section 2.1.).

Packaging pressurization for emptying operations:

- **IBCs (intermediate bulk containers of about 265 gal):** We recommend emptying the container by gravity through the bottom outlet valve without pressure. If pressure is applied inside the container, the overpressure should not exceed 40 mbar (0.04 bar = 0.6 psi).
- **Drums:** Overpressure inside the drums should not exceed 150 mbar (0.15 bar = 2.2 psi).

Replace drum closure lids after transfer, even on empty drums. For disposal/recycling of empty drums, see section 5.6.

PPE FOR PRODUCT TRANSFER

- Chemical-resistant rubber gloves
- Chemical-resistant rubber boots
- Synthetic coverall (trousers preferably slipped over the rubber boots to avoid entry of liquids)
- Eye or facial protection
- Air-purifying respirator (APR): A2B2-P3 or similar filter cartridges mounted on half-face mask, or preferably, full-face mask
- In a closed environment, a self-contained breathing apparatus (SCBA) is preferred.

5.4.2. METAM APPLICATION

A distinction should be made between the two major application methods:

- Soil injection
- Drip irrigation

Depending on the tractor type used, indoor or outdoor application, drip irrigation, and the activities of the workers involved, PPE may vary.

5.4.2.1. SOIL INJECTION

Only tractors with closed cabins may be used for the mechanical incorporation of metam.

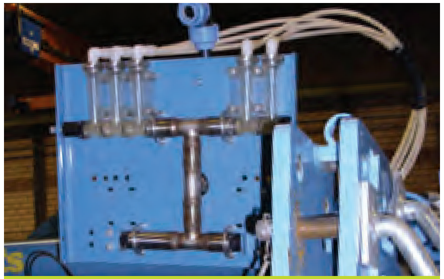
The machine can either be equipped with a smooth roll at the rear to form an even and smooth upper soil layer or with a plastic film application device. The aim of both systems is to reduce the gas emission in the air, to reduce bystander and operator exposure and, at the same time, to increase the soil disinfection efficacy.

It is not advisable to use a tractor with open or no cabin for the application of metam products.

Machine check prior to application:

- Application equipment must be in good working order.
- Sight gauges and pressure gauges must function properly.
- Nozzles or shanks and metering devices must be of correct size, sealed, and unobstructed.
- Each nozzle/shank must be equipped with a flow monitor (this can be mechanical, electronic, or "red-ball" type).

The following pictures illustrate different types of flow monitoring equipment.



Multichannel flow meter

Single flow meter

Electronic flow controller for individual product release channels (TeeJet)

Before using a disinfection rig for the first time or when preparing it for use after storage, the operator must check the following items carefully:

- Check and clean or replace the filter element if necessary.
- Check all tubes and chisels/shanks to make sure they are free of debris and obstructions.
- Check and clean the orifice plates.

Injectors must be below the soil surface before product flow begins. Each injection line must either have a check valve located as close as possible to the final injection point or a drain to purge the line of any remaining disinfectant prior to lifting injection shanks from the ground.

Do not lift injection shanks from the soil until the shutoff valve has been closed and the disinfectant has been depressurized. Remaining product can be passively drained or actively purged by compressed air.

PPE IN CASE OF MECHANICAL INCORPORATION

Only tractors with closed cabins may be used.

It is advisable to use closed cabins of Category 4 (EU Standard EN 15695-1). This will protect the operator in the cabin from vapors, aerosols, and dust. PPE must include:

- Rubber boots
- Cotton coveralls

In case of other type of cabins (Categories 1, 2, or 3), the following PPE must be worn in addition to those listed previously:

- Facial mask with active carbon filter type A (brown color code) for gases and organic vapors with boiling point > 149°F

It is important not to bring any clothes, boots, or devices spoiled with metam into the cabin and to wear the above-mentioned PPE for any intervention on the field or application machine.

5.4.2.2. DRIP IRRIGATION

The application itself does not necessitate close exposure of the operator once the system is coupled to the metam source.

Prior to product handling, the water supply metering system, dilution pump, non-return valve and drip lines should all be checked for correct functionality. The main water pipe should be free of obstruction.

When applying the product indoors, it is strongly recommended that greenhouses or tunnels be kept closed until venting.

The most critical phases are the coupling and uncoupling of the metam drum or container to the drip-irrigation device/pump. It is, therefore, recommended that operators be equipped the same way as for product transfer from drum or container to an application machine tank.

PPE IN CASE OF DRIP DISINFECTION

- Chemical-resistant rubber gloves
- Chemical-resistant rubber boots
- Synthetic coverall (trousers preferably slipped over the rubber boots to avoid entry of liquids)
- Eye or facial protection
- Air-purifying respirator (APR): A2B2-P3 or similar filter cartridges mounted on half-face mask or, preferably, full-face mask

5.4.3. WARNINGS AND WARNING SIGNS

We strongly advise growers that, prior to every campaign, they should inform residents in a 220-yard radius of the plots to be treated about the periods of application. Treated fields and greenhouses should be indicated by no-entry warning signs.

Greenhouse entrance doors should be kept closed until ventilation. “No trespassing” or “Fumigation in progress” signage could be used.

5.5. REENTRY PERIOD

Due to the volatile chemical properties of metam and MITC and the potential for worker exposure, entry into a treated field is restricted during a certain period to handlers wearing appropriate PPE. Reentry period is a specific amount of time during which entry into treated fields by anyone other than a trained handler, dressed in the correct PPE, is prohibited.

The reentry period starts from the end of the product application. The length of the reentry period depends on whether the application was done in an open field or in a greenhouse.

Open field
Depending on the climate of the region, the recommendation is to wait a minimum of 7 days before entering a treated field. Always follow local label requirements.

Greenhouse
The reentry period is 14 days.

In general, there is no need to enter the greenhouse during the first 7 days after application of metam. However, if it is necessary, respiratory protective equipment is required. Workers should also wear respiratory protective equipment when reentering after 7 days to initiate ventilation of the treated structure (greenhouse or polytunnel). Reentry to the greenhouse without respiratory protective equipment is possible after 14 days, provided the greenhouse is thoroughly ventilated prior to reoccupation.

PPE IN CASE OF ENTRY INTO A TREATED FIELD DURING THE RE-ENTRY PERIOD

- Chemical-resistant rubber gloves
- Chemical-resistant rubber boots
- Cotton coveralls
- Facial mask with active carbon filter type A (brown color code) for gases and organic vapors with boiling point > 149°F

5.6. CLEANING OF MATERIAL AND DRUM DISPOSAL

After application, it may be necessary to dilute with water any product remaining in the tank—1:100—and apply it to the treated soil. Machinery should be cleaned of soil and debris before moving to another disinfection site or prior to storage.

In drip-irrigation application, drip lines should be flushed with water after application but without oversaturating the treated soil.

Never reuse empty drums/containers for another application. Treat empty drums/containers as hazardous waste.

Drums: Rinse with clear water avoiding risk of ditch and water surface contamination and bring it to a certified collection center.

IBCs (of about 265 gal): recuperation assured by the container manufacturer.

PPE WHEN CLEANING MATERIAL AND DRUMS DISPOSAL

- Chemical-resistant rubber gloves
- Chemical-resistant rubber boots
- Hermetic coverall
- Eye or facial protection
- Facial mask with active carbon filter type A (brown color code) for gases and organic vapors with boiling point > 149°F

5.7. REMOVAL OF PLASTIC FILM SEAL AND/OR SOIL AERATION

This is another critical phase where a small risk persists for residual MITC gas emission, although it is expected that dissipation is almost complete after appropriate soil-sealing time.

This is important because of potential discomfort for residents, especially when adverse wind direction is present at the time of aeration, and for the workers who operate the seal removal.

Another option is the preliminary perforation of the film in different places to reduce the possibility of an overwhelming emission at the time of complete film removal (if the gases haven't sufficiently dissipated).

It is also possible that plastic film tarp should stay in place as mulch in the case of a planting-through crop such as strawberry or lettuce. In that case, holes should be cut in the film at appropriate distances.

Forced soil aeration or precultural tillage after soil disinfection by rotative tractor-driven devices should not be deeper than the disinfected target layer to avoid mixing up potential plant disease inoculum from untreated zone.

Whenever exposure of workers exists, appropriate PPE should be used.

**PERSONAL PROTECTION EQUIPMENT (PPE)
FOR REMOVAL OF PLASTIC FILM SEAL AND SOIL AERATION**

- Rubber gloves and rubber boots
- Coverall
- Air-purifying respirator (compulsory if sensory irritation is present)*

**Sensory irritation trigger value: MITC concentration in the air > 0.6 ppm (see section 5.9.)*

Removed plastic film tarp should not be reused and must be discarded for destruction or recycling, depending on the possibilities available locally.

5.8. CLEANING OF PPE

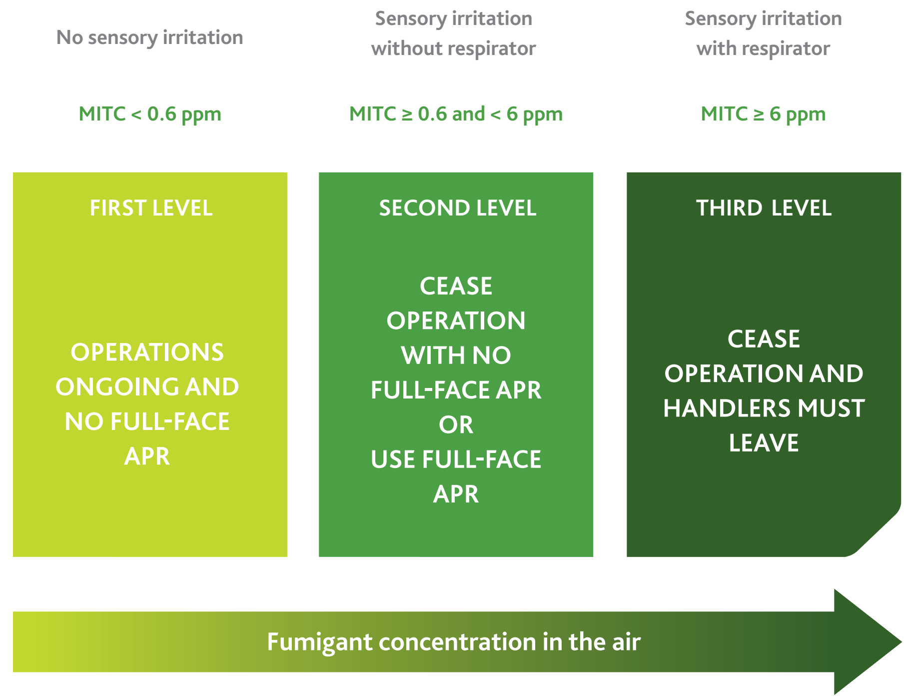
Follow manufacturers' instructions for cleaning/maintaining PPE. If no instructions for washables exist, use detergent and hot water. Keep and wash PPE separate from other laundry.

Discard clothing and other absorbent materials that have been drenched or heavily contaminated with this product's concentrate, and do not reuse them.

Do not transport contaminated clothing inside a closed vehicle unless stored in a sealed container.

5.9. GENERAL RULES ABOUT THE USE OF FILTER CARTRIDGES

Three main situations determine whether full-face masks should be worn with APR filter cartridges and their sensory irritation trigger values. At the third level, operation should cease and handlers must leave. This is visualized in the following diagram:



Filter cartridges or canisters must be replaced:

- Whenever odor or sensory irritation from this product becomes apparent during use
- If the measured concentration of MITC is greater than 6 ppm
- At the end of each day's work period in the absence of any instructions or indications regarding service life

5.10. MONITORING RESIDUAL MITC

Monitoring for residual air or soil MITC concentration has two major advantages: checking the work/residents' environment for safety and checking for potential phytotoxicity risk after disinfection and soil aeration.

5.10.1. CHECKING THE WORK ENVIRONMENT FOR SAFETY

A distinction should be made between air concentration just above the soil or plastic film surface, at workers' inhalation height, and in the surroundings for bystander/resident exposure. In the latter case, measurements at different distances downwind from the treated plot should be made.

Two major measuring principles are available:

5.10.1.1. PHOTOIONIZATION DETECTION (PID)

This sensitive, quick-response electronic device is easy to use. By choosing the 10.6 eV UV-lamp version, the response factor for MITC is high compared to the possible response with other gaseous metam degradation compounds. The monitoring device should preferably be zeroed on top of the same but untreated soil.

Ambient air is pumped along the inside UV lamp, and molecules are ionized and collected on a flow-through electrode where they are discharged again. Changes in electrical current between electrodes are amplified and are a measure for gas concentration after calculation with the specific response factor/correction factor. The lower this factor value, the more sensitive the PID for the measured compound.

5.10.1.2. DETECTION TUBES

Different manufacturers of safety and respiration protection equipment have developed specific tubes for MITC measurement.

Depending on manufacturers' instructions, a volume of ambient air is pumped through a sealed, glass gas-reaction tube after inlet and exhaust (pump-side) tips are broken off. The gas reacts with a coloring agent sorbed on carrier material. Readings are made of the discolored zone on a numeric MITC concentration scale.

The picture on the right shows a reading of about 20 ppm.

Each tube is for a single measurement and it takes some time to replace and perform the readings. Working with these disposables is of lesser interest when many measurements need to be performed.

5.10.2. CHECKING FOR POTENTIAL PHYTOTOXICITY RISK AFTER DISINFECTION AND SOIL AERATION

In this case, both air monitoring and soil monitoring should be considered. Air monitoring could be important for adjacent crops. It is obvious that when checking conditions prior to soil disinfection the eventual presence of adjacent crops is known and measures are taken to avoid phytotoxicity.

For this purpose, a PID instrument is the most appropriate device that can be used. Soil gas monitoring after disinfection focuses on preservation of the new crop to be sown or planted.

After tarp removal and/or aeration, the most classic test to perform is the so-called cress or lettuce seed germination test.

The principle is simple: MITC-sensitive and quickly germinating plant seeds are exposed to soil samples originating from the disinfected plot. This can be in the gas phase or by direct sowing. Such tests should to some extent be standardized.

Some local distributors/contractors offer phytotoxicity monitoring kits to their customers.

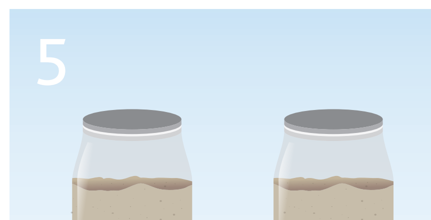
PROCEDURE TO PERFORM A CRESS OR LETTUCE SEED GERMINATION TEST

With a trowel, dig into the treated soil to, or just below, the depth of application.

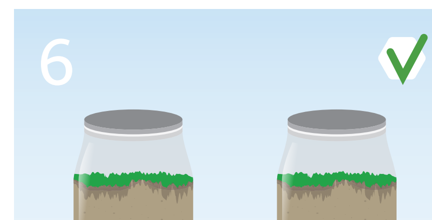
Remove 2 to 4 small (¼ to ½ cup) treated soil samples, mix lightly and immediately place a portion in an airtight jar so that fumes will not escape. Use glass jars with gastight lids.

Prepare a similar jar with untreated soil (untreated check) for comparison.

Sprinkle cress/lettuce seeds on the moistened surfaces of the soil and immediately seal the jars.



Keep the jars at 64° to 86°F; do not place in direct sunlight. Direct sunlight may kill the seed by overheating. Lettuce seed will not germinate in the dark.

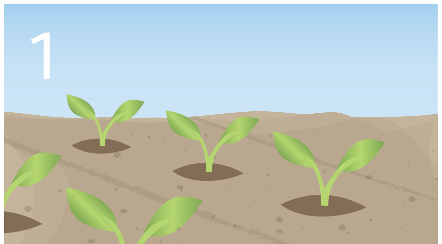


Inspect the jars for germination in 1 to 3 days. The soil is safe for planting if seeds in the treated jar germinate normally compared to the untreated jar.

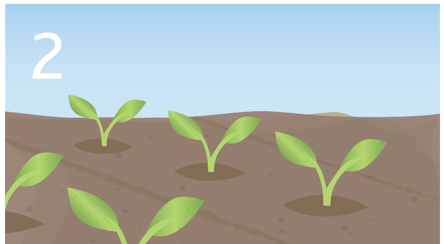
If phytotoxicity risk persists, it may be necessary to aerate the treated soil once more; wear appropriate PPE. A new test should then be performed.

As an alternative, sowing or (trans)planting a few of the crops to be installed in the treated area can be done. But this requires a longer period to observe an eventual residual phytotoxicity risk.

PROCEDURE TO PERFORM A TOMATO TRANSPLANT TEST

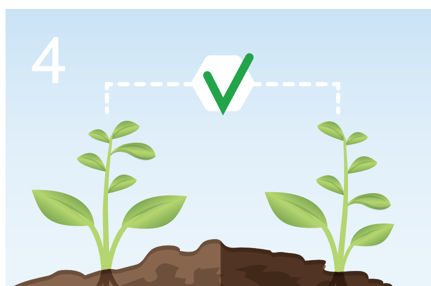


Transplant 5 to 10 succulent, fast-growing tomato seedlings into disinfected beds approximately 4 to 6 in. deep. If there is variation in the field, plant into the heaviest, wettest soil.



Do the same in a nondisinfected area.

Inspect the seedlings in 2 days for wilting or root burn.



If plants in the disinfected zone look the same as those in the nondisinfected zone, it is safe to plant.

SUMMARY CHAPTER 5

METAM SOIL DISINFECTION STEP-BY-STEP STEWARDSHIP

- Metam products, like many other plant protection products, need special attention and are subject to different safety rules for storage, handling, and application.
- Their corrosive and irritating properties and the generation of the gaseous MITC when applied to the soil necessitate a range of different actions.
  - Preliminary prospection of the disinfection site, including assessing risks for bystanders and residents, checking the weather forecast, and proper field preparation. This may result in postponing the application in the case of one or more adverse conditions.
  - Wearing of PPE appropriate to the type of operation being carried out
  - Posting of no-entry signs prohibiting entry to the treated fields
  - Respecting the reentry period
  - Cleaning of material and safe disposal of empty drums
  - Monitoring of residual MITC

ADDENDA

ABBREVIATIONS

APR: Air-purifying respirator

C x t: Concentration-time product

FIF: Fully impermeable film

IPM: Integrated pest management

LDPE: Low-density polyethylene

MITC: Methyl isothiocyanate

PID: Photoionization detector

PPE: Personal protective equipment

SCBA: Self-contained breathing apparatus

SL: Soluble liquid concentrate

TIF: Totally impermeable film

VIF: Virtually impermeable film

WHC: Water-holding capacity

GLOSSARY

Breakthrough: Timing where the process of gas or disinfectant diffusion starts through the plastic film tarpaulin or alternative soil sealing. This depends on film quality (composition; thickness), water condensation underneath the film, and temperature.

Concentration x time product (C x t): A numerical value expressed in oz x hr/yd^3 obtained by multiplying disinfectant concentration (oz/yd^3) and the time (hr) the concentration is maintained as a measure for biological activity

Disease: Plant diseases are caused by fungi, bacteria, and viruses.

Dissipation: Plant protection active compound dissipation after application is caused by chemical, physical, or biological decomposition, degradation, or metabolism. A soil-applied compound is also dissipated by loss to the atmosphere (fumigants), leaching, or by irreversible binding to soil particles.

Dormancy: Status of inactive seeds.

Dosatron: Type of dosing pump used in irrigation system allowing programmable supply of soil-applied plant protection products and plant nutrients

Drip irrigation: A water-saving technique to irrigate crops and to apply nutrients. The supply can be automated and installations can be used for soil disinfection.

Fungicide (fungicidal): Chemical compounds or biological organisms used to control plant parasitic fungi. Metam-based soil disinfectants have a broad fungicidal activity.

Goosefoot: Horizontal blade in the shape of a goose foot mounted on soil labor machine used to lift soil with the possibility to carry liquid disinfectant injection pipes

Heap disinfection: Disinfection can be used to disinfect soil heaps on an impermeable floor (container, concrete floor, or plastic film) in, for example, 10-inch-thick layers, and covered with gastight plastic film; for use in seeding containers or potting soil.

Herbicide (herbicidal): Chemical compounds used to control unwanted plants. Metam-based soil disinfectants are herbicidal for nondormant weed seeds, seedlings, and young weeds.

Nematicide (nematicidal): Chemical compounds or biological organisms used to control plant parasitic nematodes. Metam-based soil disinfectants are nematicides in contrast to granular cultural applied products which are nematostatic and need repeated application.

Personal protective equipment: Clothing, eye, and respiratory protection.

Pest: Plant pests are caused by insects, acari (mites), nematodes, and slugs.

Rotavator: Rotating (with S- or L-shaped blades) soil labor device that crumbles and homogenizes soil (with soil-applied products where appropriate).

Seal (soil): Technique to reduce disinfectant and soil humidity loss by compacting the topsoil with a roll, or by humidification of the topsoil, or by installing a gastight plastic film tarpaulin, or by combination of two.

Shank/chisel: Knife-shaped vertical blades mounted on soil labor machine to cut soil with the possibility of carrying liquid disinfectant injection pipes.

SL formulation: Miscible with water formulation.

Soil disinfection: Killing or reduction of soilborne plant pathogenic or pest targets without completely sterilizing the soil.

Solarization: Technique used for soil disinfection in southern or tropical countries by covering soil with plastic film from several weeks to months to reach high soil temperatures, also launching specific soil processes that can result in a high degree of soil disinfection. The combination with chemical soil disinfection at reduced disinfectant rates has shown interesting results.

Temperature inversion: Temperature inversion is a meteorological situation where temperature increases in higher air layers with lower temperature in the lower layer, creating a trap for pollutants by preventing their dilution into the atmosphere.

LEGAL NOTICE

The information regarding the use of the product is given for information purposes only. No guarantee is provided to the client that the product is adapted to the specific use for which is intended by the client. The client should perform his own test to determine the suitability for a particular purpose.

Metam CLR™ 42% and Metam KLR™ 54% are "Restricted Use Pesticides" in the U.S. Regulation of metam may differ between countries, and users should follow the local or national regulations over the guidance provided in this manual. The guidance in the manual is for information purposes only, and users must follow the information and instructions provided on the product labeling.

EASTMAN

Eastman Corporate Headquarters
P.O. Box 431
Kingsport, TN 37662-5280 U.S.A.

U.S.A. and Canada, 800-EASTMAN (800-327-8626)
Other locations, +(1) 423-229-2000

eastman.com/locations

CC-CROP-19253 9/24

eastman.com/cropprotection

Eastman Corporate Headquarters
P.O. Box 431
Kingsport, TN 37662-5280 U.S.A.

U.S.A. and Canada, 800-EASTMAN (800-327-8626)
Other locations, +(1) 423-229-2000

www.eastman.com/locations

EASTMAN

CC-CROP-19253 9/24