Soil Fumigation

A tool to consider for soil health

SOIL FUMIGATION USES

QUARANTINE REMEDIATION
AGRICULTURE
ORCHARDS
NURSERIES
ORNAMENTAL BEDDING
FOREST SYSTEMS
GOLF COURSES
ATHLETIC FIELDS

Fumigation

Soil

Chloropicrin discovered to be a Nematicide

- **1927 pineapple in Hawaii – Experiment Station. Association of Hawaii pineapple canners:**

- Chloropicrin applied as soil fumigant at 163-190 lbs/acre with "paper mulch" led to:

  "remarkably increased vigor of resulting pineapple growth"

  " notable decrease in the amount of nematode root knot in the treated boxes"

Nematode: *Heterodora radicicola*

First reports of chloropicrin as a nematicide

Hawaii – 1927 - Pineapple

Chloropicrin for Nematode Control

M. O. Johnson and G. H. Godfrey

Experiment Station, Association of Hawaiian Pineapple Canners, University of Hawaii, Honolulu, Hawaii

Chloropicrin treatment of root-knot (Heterodera radicicola) infested soils in pineapple fields of Hawaii have brought about striking reductions in infestation and equally striking increases in vigor of plant growth and in yield of pineapples. Whereas no claim is made that nematode control is the only factor involved in the improved plant growth, this paper deals with that factor alone, and includes actual measurements, by means of cowpea indicator crops, of extent of nematode reduction. The most effective treatments were those which consisted of the introduction of chloropicrin in liquid form into holes 5 to 6 inches deep, spaced 18 inches apart and covered immediately with mulching paper, the rates of application being 163 pounds or more per acre.

In 1927 the senior author treated soil from bad failure areas in pineapple fields with chloropicrin and obtained remarkably increased vigor of resulting pineapple-plant growth, as compared with untreated controls. The soils were in root observation boxes, and it was evident that the increased vigor was due to a direct effect on the roots. Among the results was a notable decrease in the amount of nematode root knot in the treated boxes. This was verified repeatedly by similar experiments without, however, any actual measurements being taken of the amount of decrease. These preliminary tests led to carefully conducted field experiments the same year (1927) and subsequent years by the senior author, which showed striking increases in growth and yield of fruit. This paper discusses in detail certain of the field tests which were studied by the junior author, primarily from the point of view of nematode control. Results are reported in terms of actual nematode reduction, measurements being by means of indicator crops.[1]

While chloropicrin has been used more or less extensively for fumigation, its use for soil treatment has been very limited, as indicated by the chloropicrin bibliographies prepared by Roark (*3*) and Gersdorff (*1*). The present authors have not been able to review the original papers cited by these men, but refer to their annotations on the work of Piutti and Bernardini, Spencer, Matthews, Russel, Hasson, Dingler, Fryer, Parker, Feytaud, and Annie Matthews, particularly to Matthews (*2*) who appears to have included nematodes in her studies. None of this work seems to have been followed by practical field applications.

Preliminary Experiments on Pineapple

Most of the preliminary field tests referred to above, in which chloropicrin was introduced into nematode-infested soil in measured doses by means of a Vermorel injector, demonstrated remarkable increase of plant growth over the untreated controls within 2 or 3 months after planting. This increased vigor persisted throughout the growth of the plant, and at plant-crop stage, about 20 months after planting, manifested itself by striking increases in yields. In fact, the increase in vigor was still manifest in some plots at first ratoon-crop stage, 1 year later.

Completely satisfactory quantitative data on effects on plants are lacking, but observations on one or two of the experiments are recorded for what they may be worth. In one test that showed, by striking differences in plant growth, outstanding value from the treatment, chloropicrin had been applied at the rate of 180 pounds per acre. Three adjacent pineapple plants selected as representative were removed intact, roots and all, from this plot, and three from a comparable control plot, just following harvesting the fruit when the plants were approximately 20 months old. Greater extent of root growth, including abundance of fine feeding-branch rootlets in the treated plots, was strikingly evident. The three control plants showed *Heterodera radicicola* infestation in 90 per cent of all roots, while treated plants showed only 30 per cent infestation. These differences in root systems were paralleled by very obvious differences in the aerial parts of the plants. The untreated plants had an average lateral spread or total width of 45 inches and a height of 35 inches; the treated plants showed 55 inches spread, and 45 inches height, a difference of well over 20 per cent in both measurements. Pineapple-yield differences were striking. The 180-pound chloropicrin bed yielded in plant crop 11.8 tons more than the control, a difference of 57.0 per cent. Figure 1 illustrates the condition of these two rows at first ratoon-crop stage, the third summer after planting.

In another experiment chloropicrin applications were made by means of the Vermorel applicator, at rates varying between 45 and 185 pounds per acre, just prior to planting on August 23, 1929. On October 18, 1930, approximately 14 months after planting, two plants chosen by the authors as representative were removed with roots intact from each of several of the treatments which showed above-ground differences in vigor of growth. Since the size of samples was so inadequate (two plants only, out of several hundred in each lot), a detailed classification of results could not be considered as having much significance. It will be recorded only that:

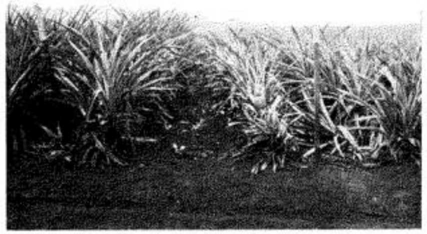


Figure 1. Row of Pineapple Plants Treated with 180 Pounds Chloropicrin per Acre, and Untreated Row at First Ratoon-Crop Stage, Approximately 3 Years after Planting

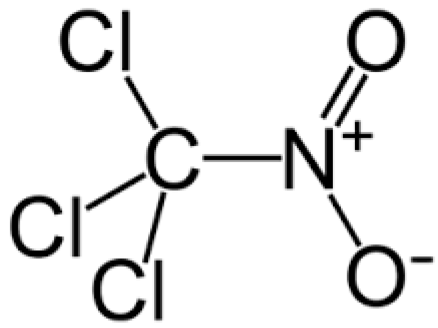
The yield difference between the two was over 20 tons per acre in the two crops

[1] The junior author is preparing a paper on the indicator-crop method of determining effects of various soil treatments on nematode infestation of the soil, pointing out its usefulness and its limitations.

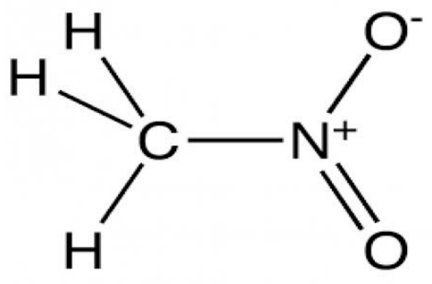
Chloropicrin Fumigant properties

- Rapid diffusion in agricultural soils
- Broad biocidal properties
- Kills target fungi and susceptible organisms < 48 hr
- Degradation is quick and primarily by microbial pathways
- Microbial recolonization is a key factor – saprophytes,
  <u>Soil sterilization is not a consequence</u>

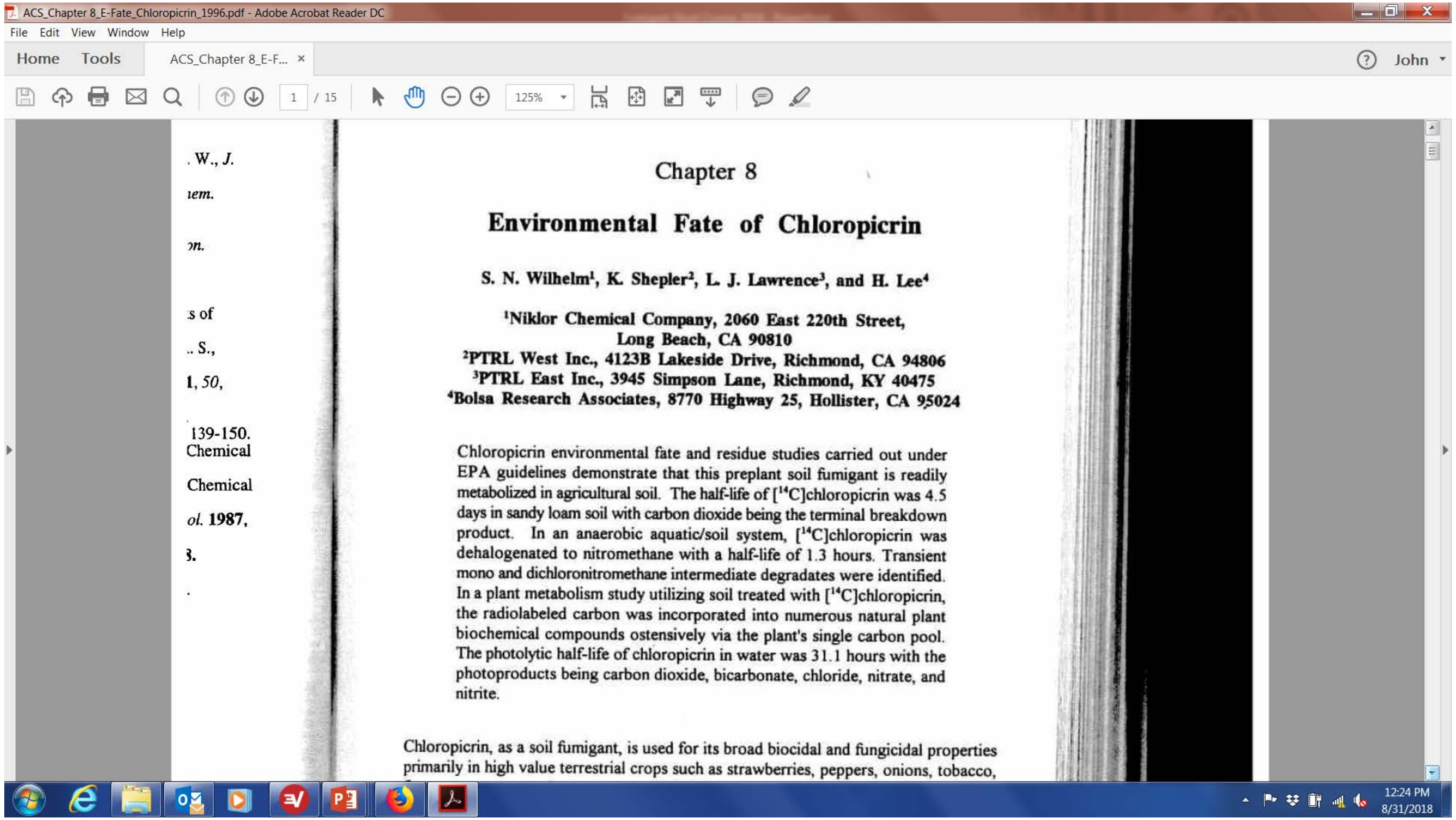
Chloropicrin properties



Vapor pressure: 3.2 kPa



nitromethane



Chapter 8

Environmental Fate of Chloropicrin

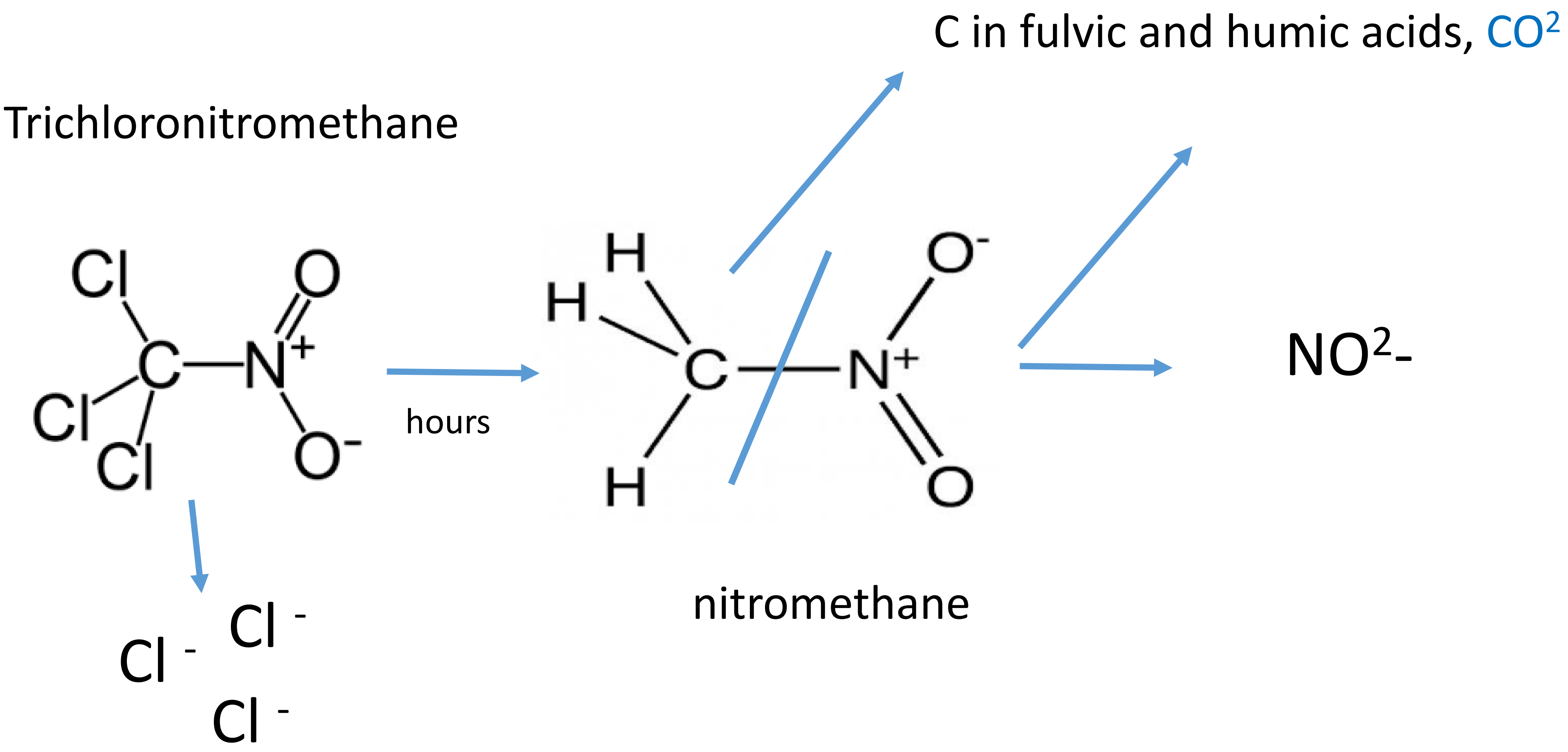
S. N. Wilhelm[1], K. Shepler[2], L. J. Lawrence[3], and H. Lee[4]

[1]Niklor Chemical Company, 2060 East 220th Street, Long Beach, CA 90810
[2]PTRL West Inc., 4123B Lakeside Drive, Richmond, CA 94806
[3]PTRL East Inc., 3945 Simpson Lane, Richmond, KY 40475
[4]Bolsa Research Associates, 8770 Highway 25, Hollister, CA 95024

Chloropicrin environmental fate and residue studies carried out under EPA guidelines demonstrate that this preplant soil fumigant is readily metabolized in agricultural soil. The half-life of [^{14}C]chloropicrin was 4.5 days in sandy loam soil with carbon dioxide being the terminal breakdown product. In an anaerobic aquatic/soil system, [^{14}C]chloropicrin was dehalogenated to nitromethane with a half-life of 1.3 hours. Transient mono and dichloronitromethane intermediate degradates were identified. In a plant metabolism study utilizing soil treated with [^{14}C]chloropicrin, the radiolabeled carbon was incorporated into numerous natural plant biochemical compounds ostensively via the plant's single carbon pool. The photolytic half-life of chloropicrin in water was 31.1 hours with the photoproducts being carbon dioxide, bicarbonate, chloride, nitrate, and nitrite.

Chloropicrin, as a soil fumigant, is used for its broad biocidal and fungicidal properties primarily in high value terrestrial crops such as strawberries, peppers, onions, tobacco,

Degradation pathways of chloropicrin



Wilhelm et. Al. 1996

DIFFUSION OF CHLOROPICRIN VAPOR IN SOIL

- The liquid vaporizes outward from the lines or points of injection.

- The largest % of vapor dissolves into the films of soil moisture.

- A comparable quantity sorb onto soil solids.

- THE ABILITY OF CHLOROPICRIN TO CONTROL SOIL PESTS IS DETERMINED BY THE CONCENTRATION AND TIME THAT IT IS PRESENT IN THE SOIL WATER FILMS. **C X T**

- Diffusion (movement from high concentration to low) of chloropicrin through soil is determined by air space. It is not affected by gravity.

Upward mass flow greater because diffusion of gas molecules is greater
In air above the soil surface

Perspective - Soil

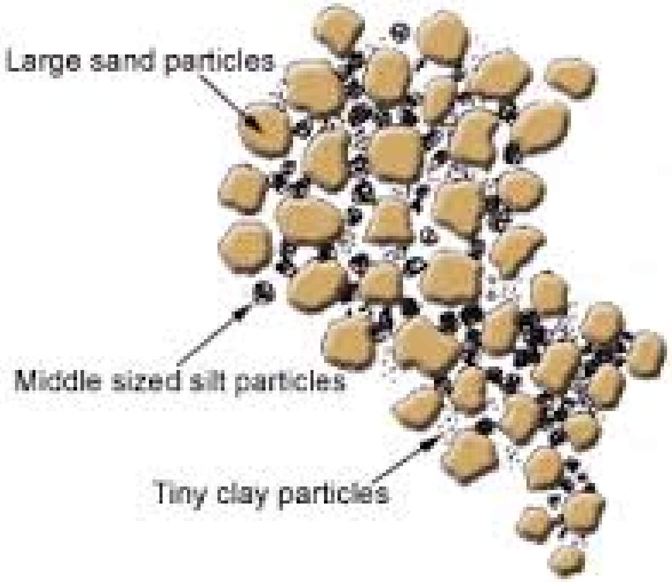
4-12 million lbs/soil/acre-foot

Chloropicrin @ 250 lbs/acre = 0.006 %   = 62 parts per million (ppm)

PHYSICAL + CHEMICAL characteristics of soil determine:

- Diffusion rates
- Distribution between soil air and water
- Sorption onto and into soil particles

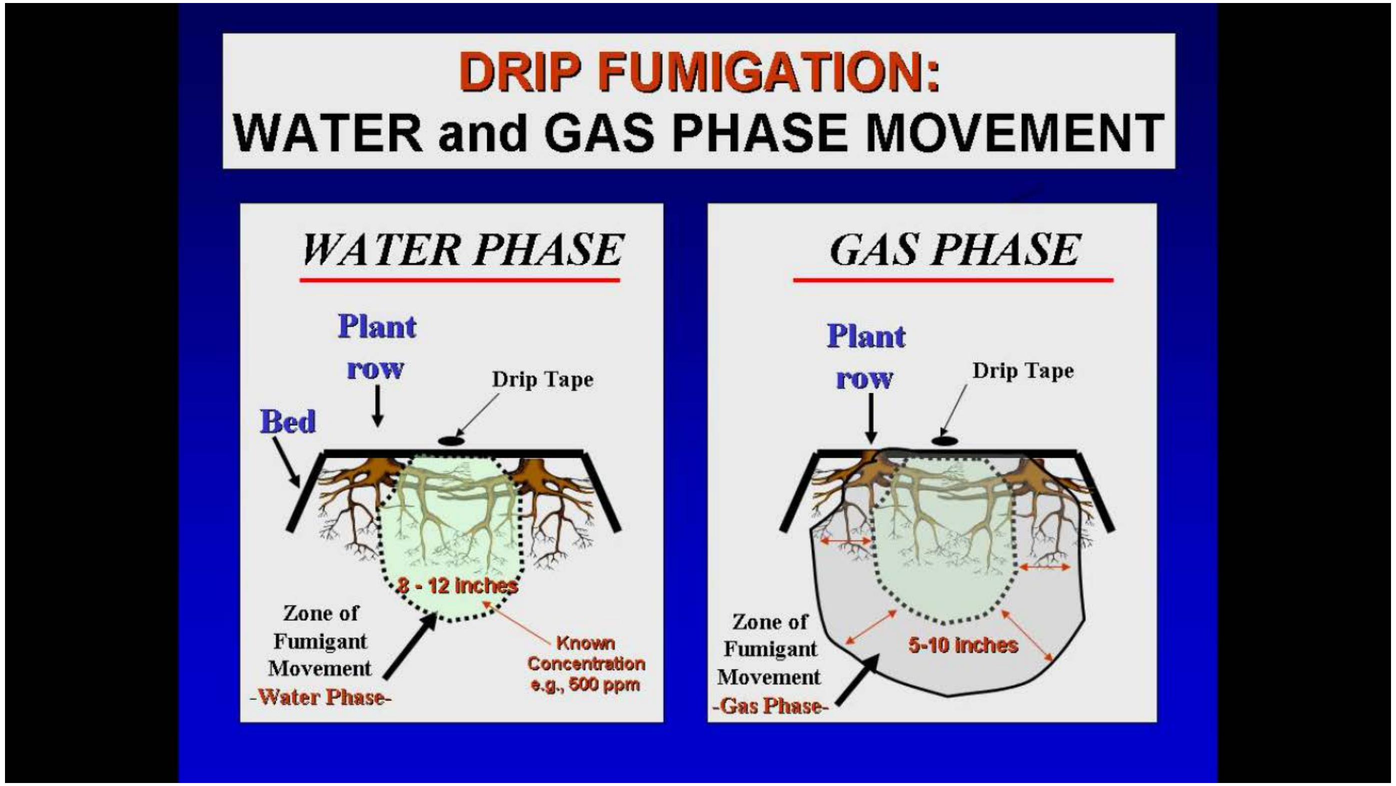
Germinating spore needs 100% RH



What we are doing when we fumigate is….

creating a temporary diffusion zone of a lethal compound

Volatility in soil air space as well as diffusion in water allows fumigant to expand in soil medium



Soil Fumigant

- Volatile chemical which diffuses through soil air and water medium and exerts a direct toxic effect on soil organisms.

- Toxicity is determined by both concentration and time of exposure.

- The magnitude of their diffusion determined by physical properties of fumigant and soil type and soil moisture levels.

- Soil fumigants do not eradicate soilborne pests nor do they sterilize soil. Fumigants temporarily reduce pest populations through both toxicity effects as well as through indirect, suppressive effects, ie proliferation of competitive saprophytes. For example, *Trichoderma* spp. fungi are known to proliferate after soil fumigation with chloropicrin.

- The proximity of untreated soil is an important factor, deeper soil profile and untreated row middles.

Problem: high populations of plant pathogenic organisms in soil

Pathogens/Pests

- Nematodes
- Fungi
- Insects
- Weeds

TOXICITY to target organisms

Toxicity = Inherent toxicity X Metabolic state X Dose X Time of Exposure

PRINCIPAL SOIL FACTORS AFFECTING EFFICACY

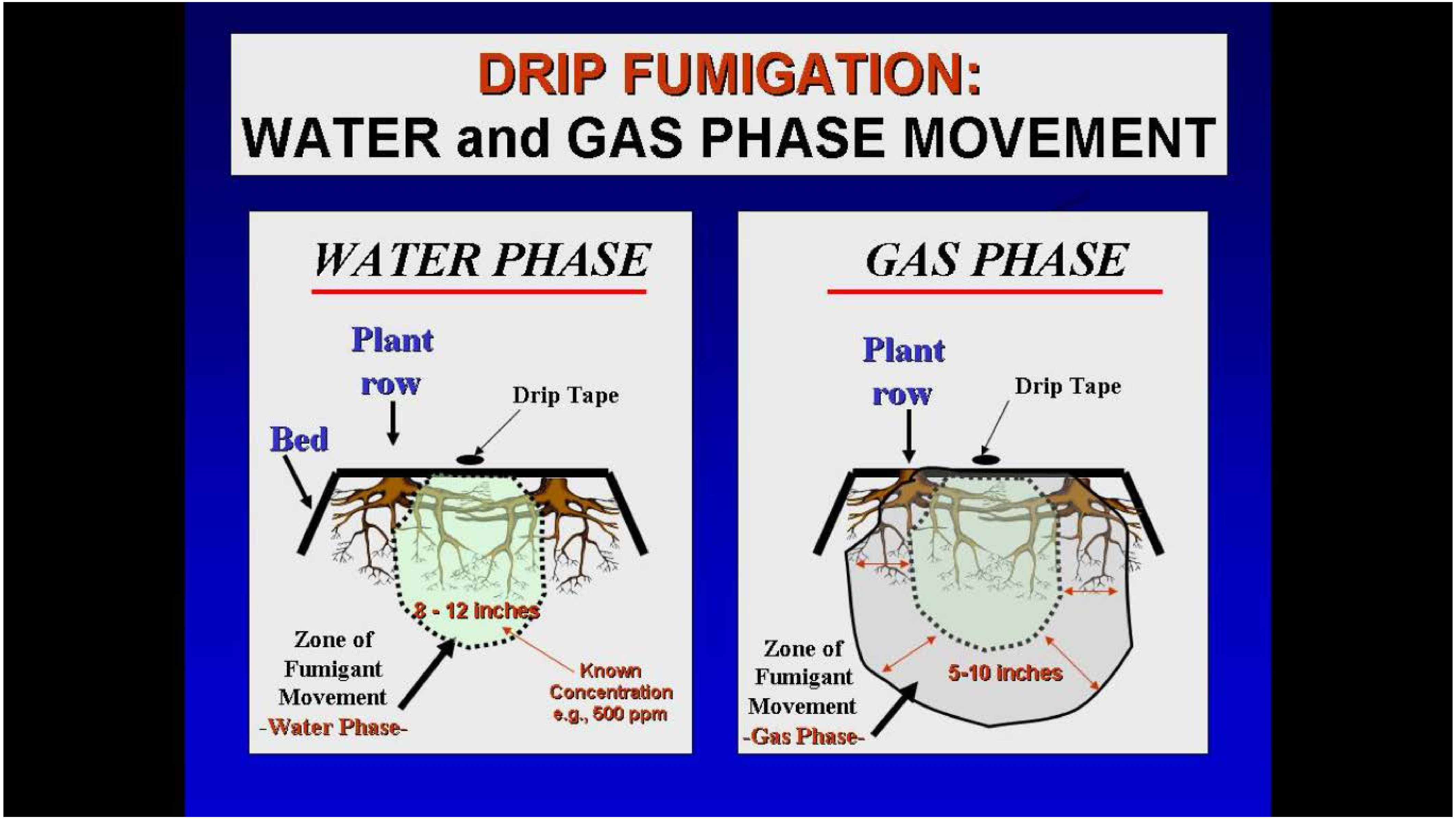
- Pore space –size of air space (30% air space ideal)
- Moisture – needed for microbe metabolism
- Temperature
- Organic matter
- Pathogen populations – "inoculum potential"
- Plant residue – old roots !
- **Fumigant placement vs pest biology/location**
- **Soil Sealing**

SOIL PREPARATION and FUMIGATION TECHNIQUE IS KEY

Soil Fumigant diffusion factors

- Air space – soil type, compaction, moisture
- Soil moisture
- Soil temperature
- Organic matter, colloids, sorption surfaces
- Soil preparation
- Crop, plant residue

Volatility allows fumigant to diffuse in soil medium



Injection of a liquid fumigant in the soil at a controlled rate

Nematodes

Weeds


Injection of fumigant through a single irrigation drip tape

Quantification of ppb or ppm of fumigant molecules in the field

Other Soil Fumigant actives

METHYL BROMIDE

H

H C Br

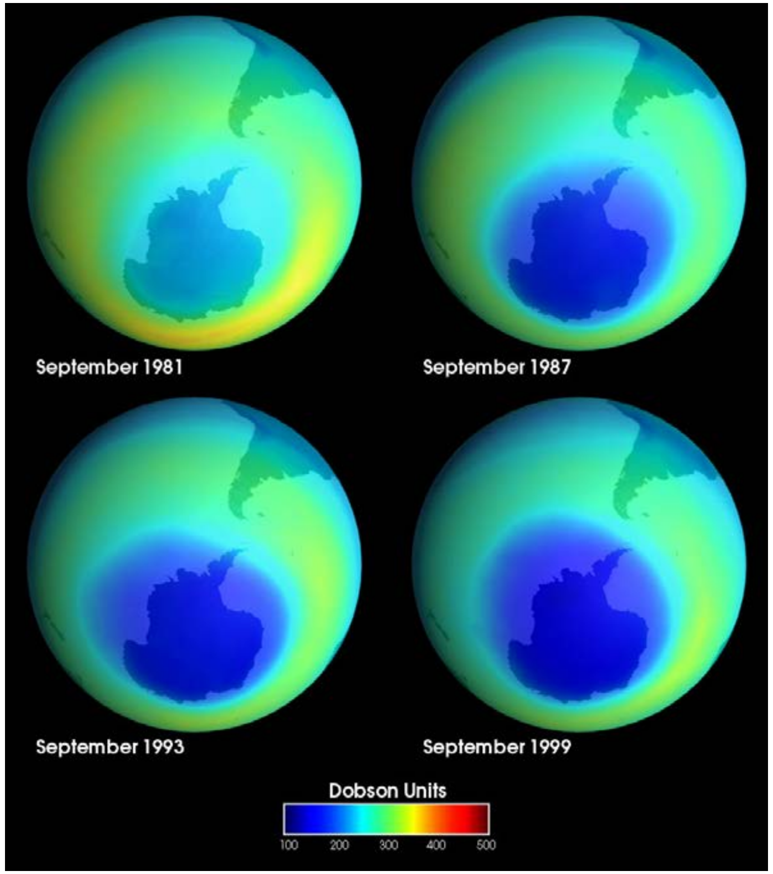
H

METHYL BROMIDE

- Naturally occurring molecule
- Non-flammable
- Boils at 38.5 degrees F
- 3.27 times heavier than air
- Practically insoluble
- Odorless and Colorless

Methyl Bromide

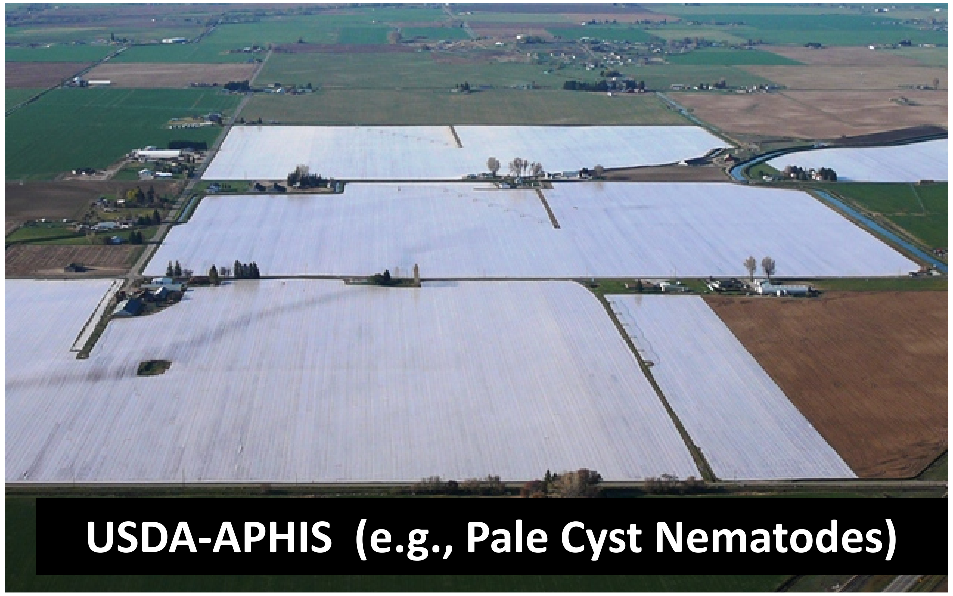
Montreal Protocol: International ban on substances that deplete the Ozone Layer

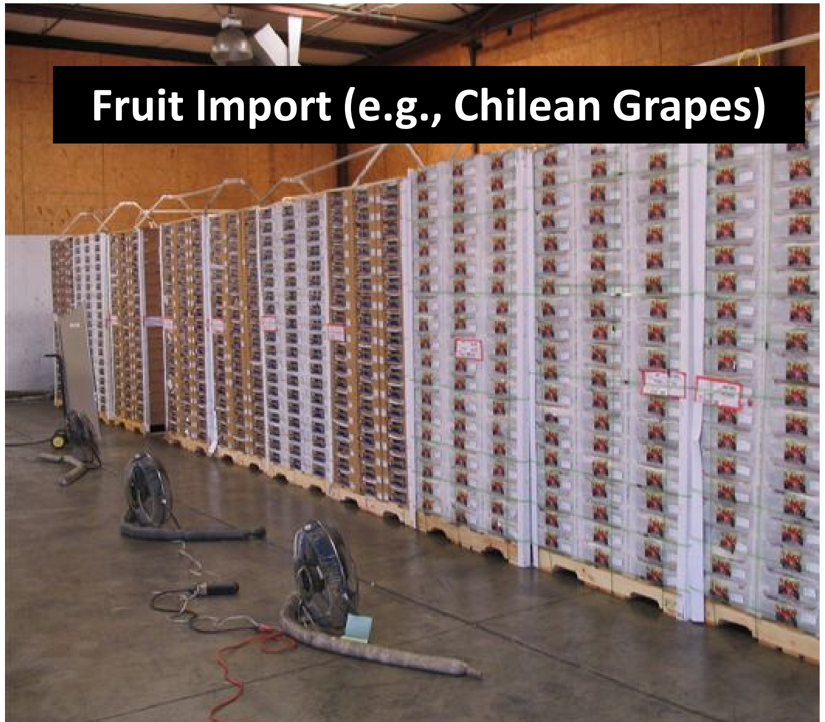


<u>Elimination / Phase-Out of:</u>

- **Refrigerants, insulating foams, and solvents**
  - **Chlorofluorocarbons (CFCs)**
  - **Hydrofluorocarbons (HFCs)**
- **Halons (fire extinguishers) and others**
- **Methyl Bromide:**
  - **Quarantine/Pre-Shipment (QPS) is exempt**
  - **Crop, Post-Harvest, and Structural Use Phase-Out**
    - **Developed Countries: phase-out by 2005**
      - **Critical Use Exemptions post-2005**
    - **Developing Countries: phase-out by 2015**
      - **Developing Critical Use Exemptions**

Quarantine/Pre-Shipment (QPS) treatments are exempt



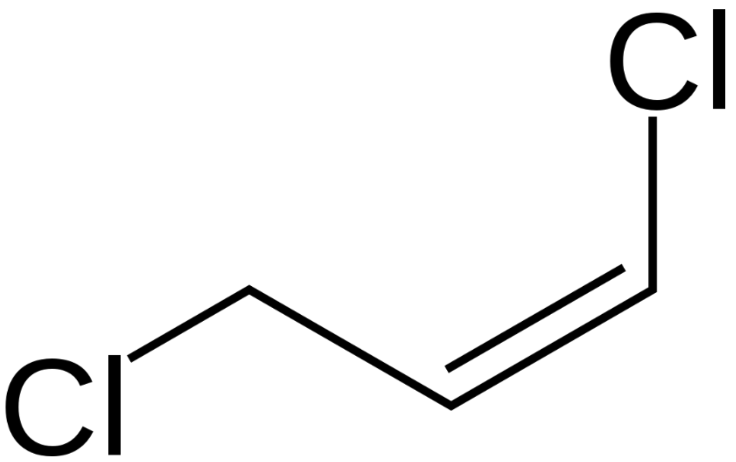


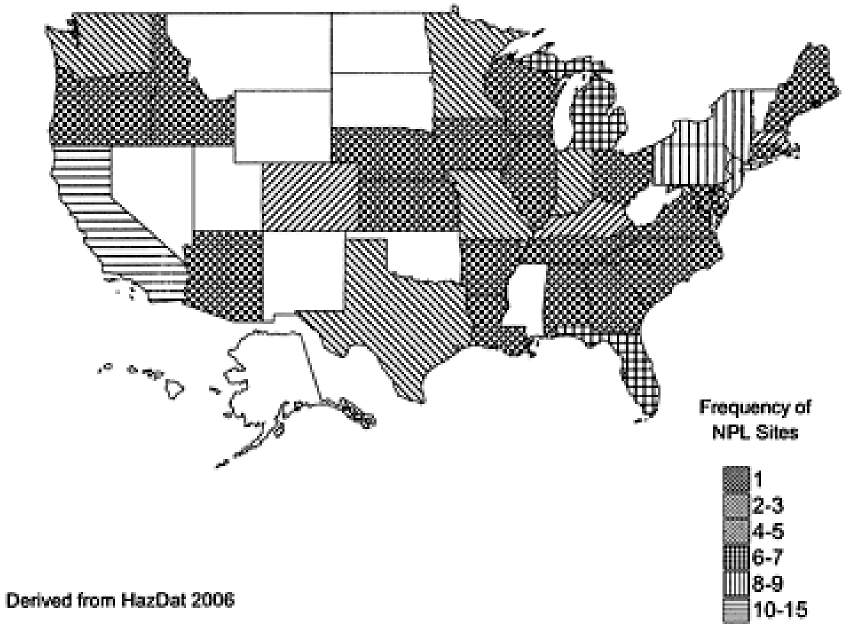
Alternatives to Methyl Bromide

- Chloropicrin
- 1,3 D
- DMDS
- Allylisothiocyanate (AITC)
- Methylisothiocyanate (MITC)
- Sulfuryl Fluoride
- Propylene Oxide
- Ethanedinitrile (EDN)

1,3-D - TELONE®

Since the 1950's

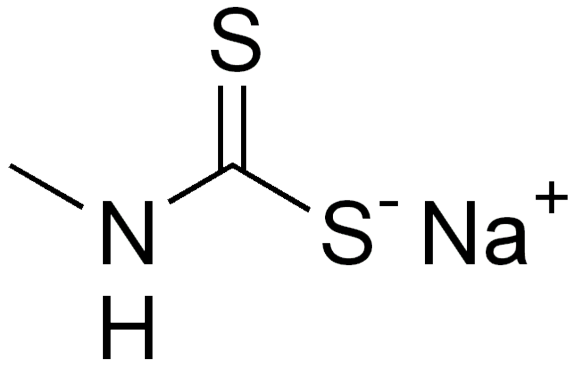




- Superb nematicide
- Some weed and pathogen activity
- Economical
- 2nd largest sales volume of all fumigants
- Generics/Global Supply

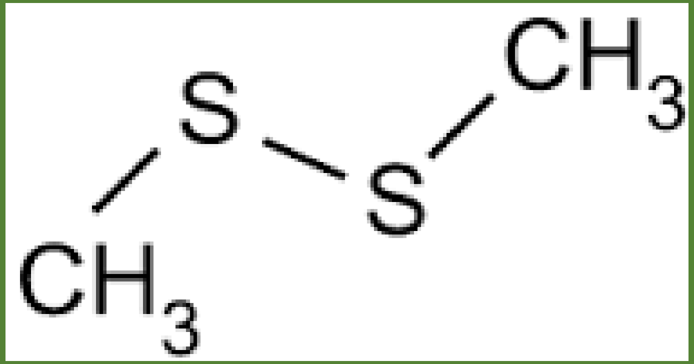
Metam – MITCs – methyl isothiocyanate

- Most widely used soil fumigants ---- 90 million lbs annually
- Economical/generic/global supply
- Movement in soil is limited, depends on water to convert to active
- Particularly effective against weeds



In 1991 a tank car with 19,000 gallons of Metam sodium spilled into Sacramento River above Lake Shasta. This killed all fish in a 41-mile stretch of the river. 20 years later the rainbow trout population has recovered.[

DMDS



- Highly efficacious nematicide
- Exploring 60 and 50 % chloropicrin instead of 21% (Paladin 79:21)
- Exploring increased depth of placement for nematode control
- Custom Blends and Co-application as options

Fumigant Combinations

- Chloropicrin + 1,3-D (+ metam)
- Chloropicrin + DMDS

Agronomy and Economics

Soil fumigation is one practice in a total agronomic package. Fumigation must be viewed within the Integrated crop management scheme, including soil chemistry, soil biology, crop nutrition, irrigation etc.

The economics of soil fumigation must be analyzed in each crop production scenario.

Application and Efficacy Factors

KEYS TO SUCCESSFUL SOIL FUMIGATION

Soil Preparation

KEYS TO SUCCESSFUL SOIL FUMIGATION

- Soil Moisture

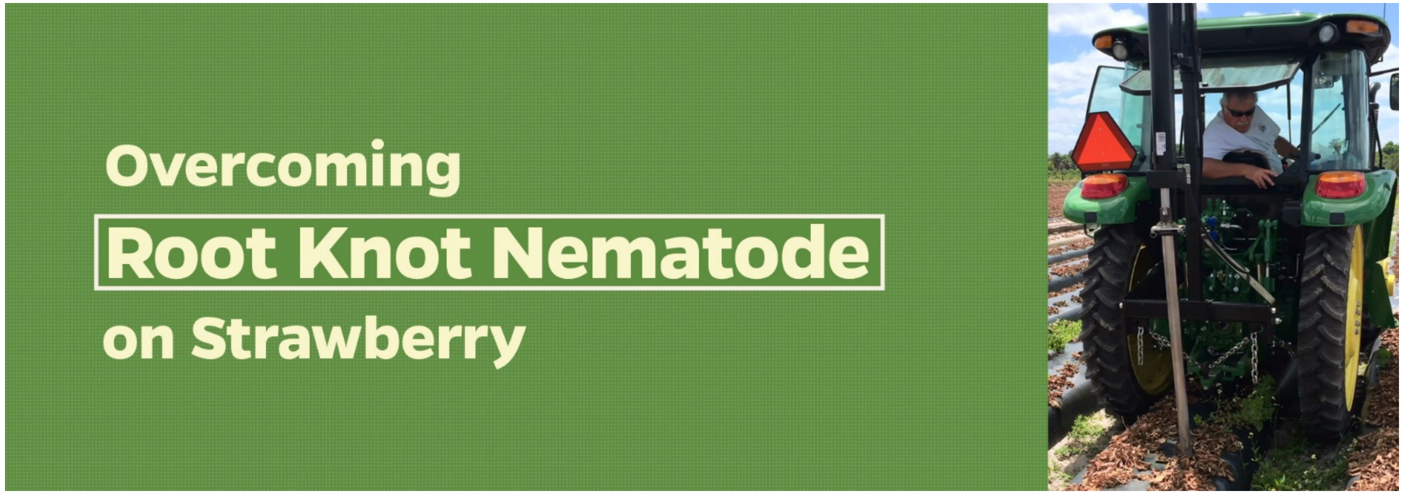
FUMIGANT PLACEMENT AND DISTRIBUTION FOR OPTIMUM EFFECT

Research in soil fumigation for nematode management in the southeast by Dr. Joe Noling, University of FL, has illustrated the factor of vertical movement/migration of nematodes in the soil.

Nematodes escape mortality at greater soil depth.

Surviving nematodes migrate back up to crop root zone after new planting the following season.

Thus, soil fumigation must go to greater depth if nematode management is to be improved/optimized.



Tarp/Sealing

Chloropicrin as a Soil-borne disease control fumigant

Australia, January 2018.

Charcoal rot
(*Macrophomina phaseolina*)
Of strawberry

TIF film is making a highly significant Improvement in charcoal rot reduction !

Pic 80 @ 350 lbs, PE film,
More disease

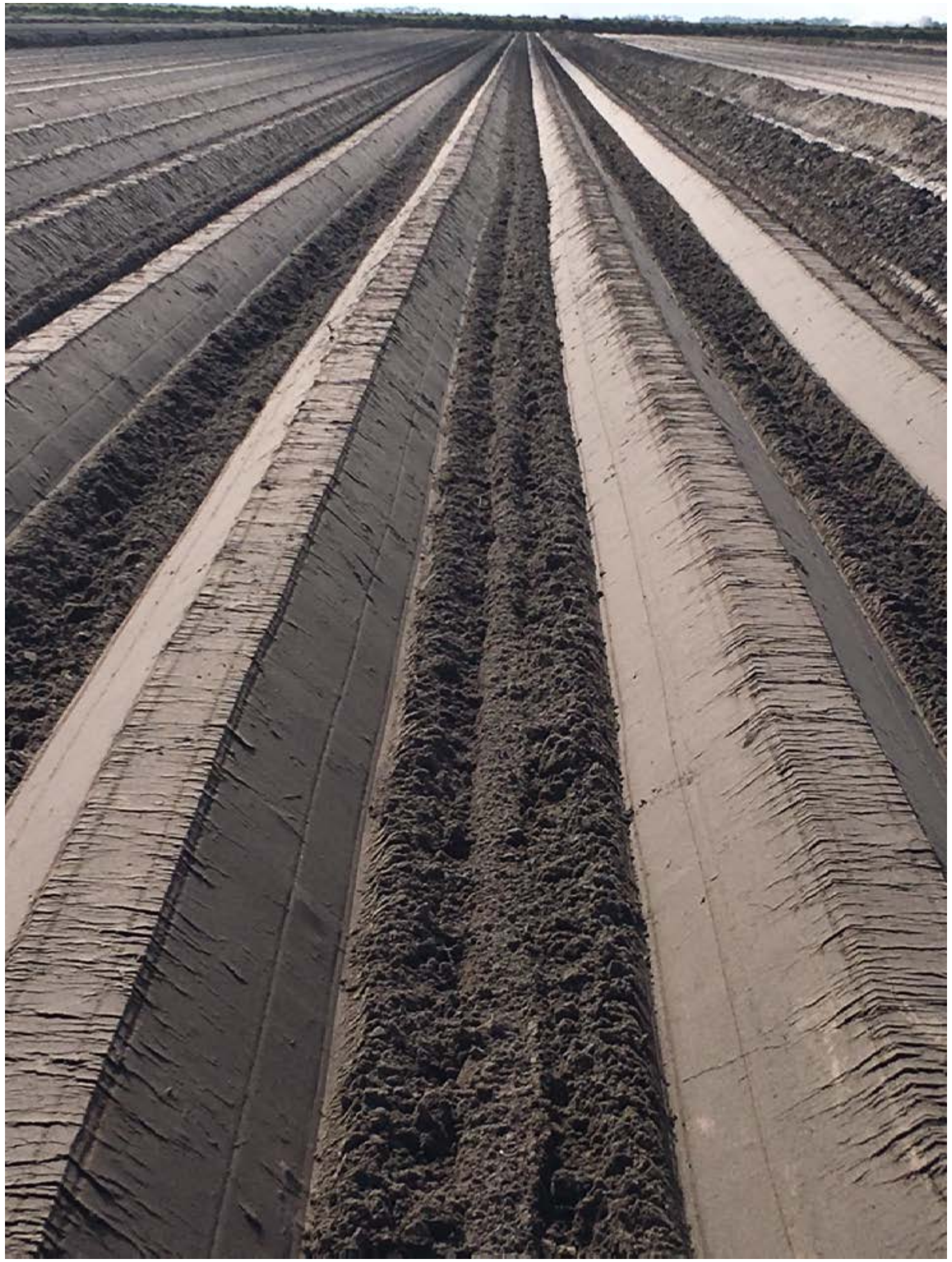
Untreated

Pic 80 350 lbs/acre, TIF
Better control

Broadcast/Flat Fume

Potato – non tarped

Shaped and Packed



Potato

Row Shaping

+ Raised Row +

≈ 50% Compression

70% Field Capacity
USDA hand test

Low Trash

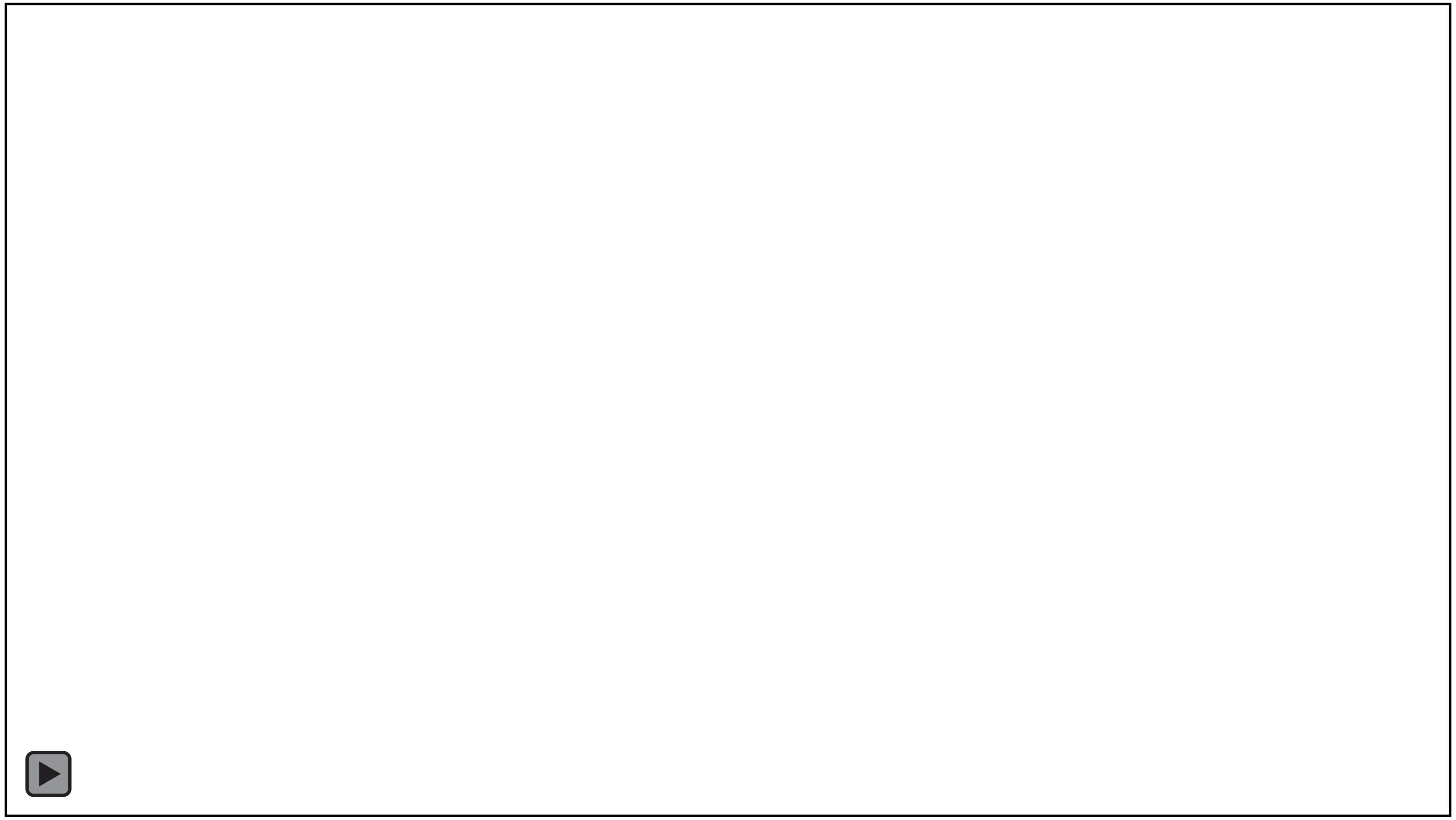
Saint Agatha, Maine 2016

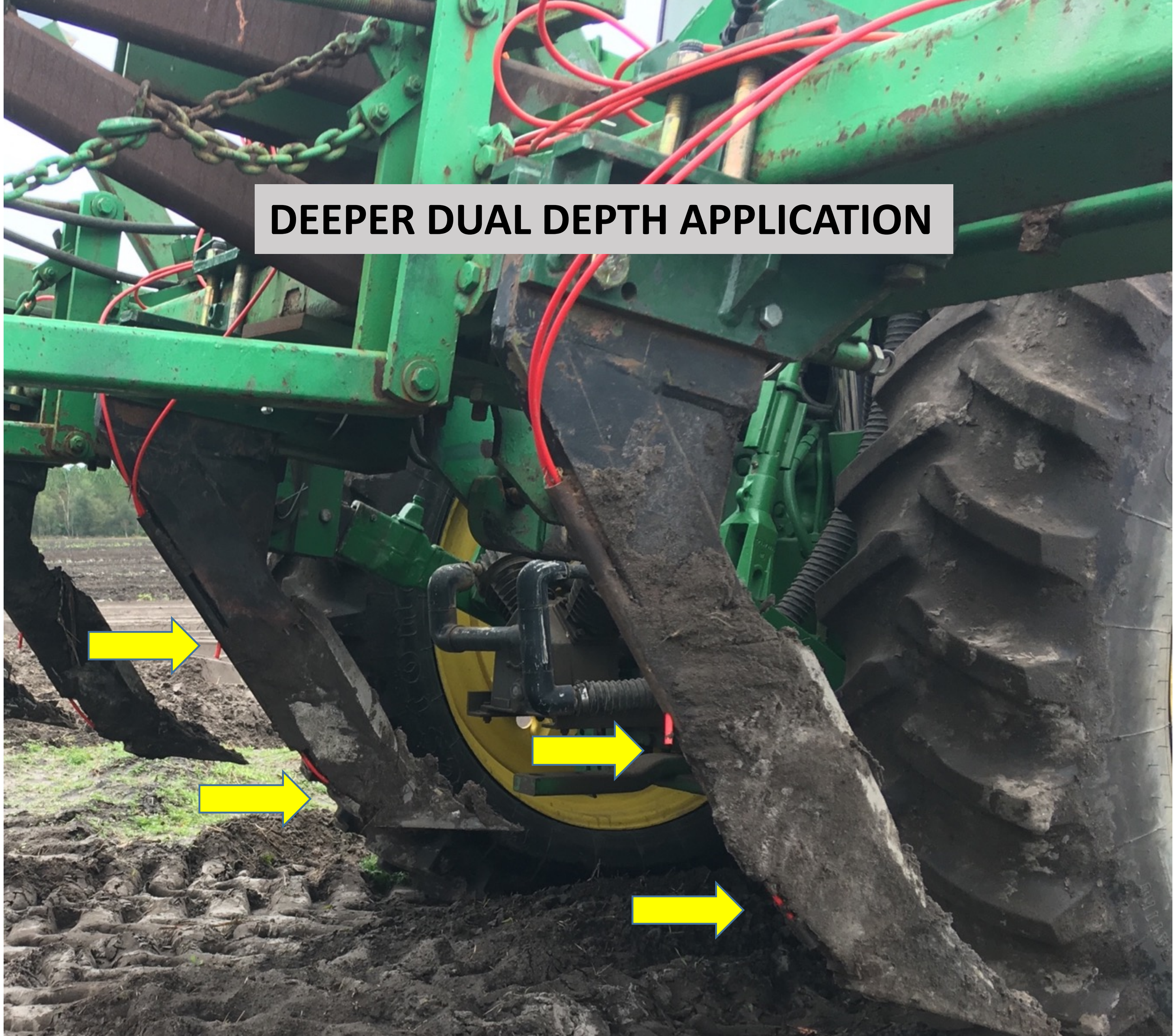
Equipment
& Application Methods

Horsepower Needed

- No. of shanks
- Soil Type/Structure/Profile
- Depth
- Soil moisture
- Rocks, logs etc
- Planting scheme

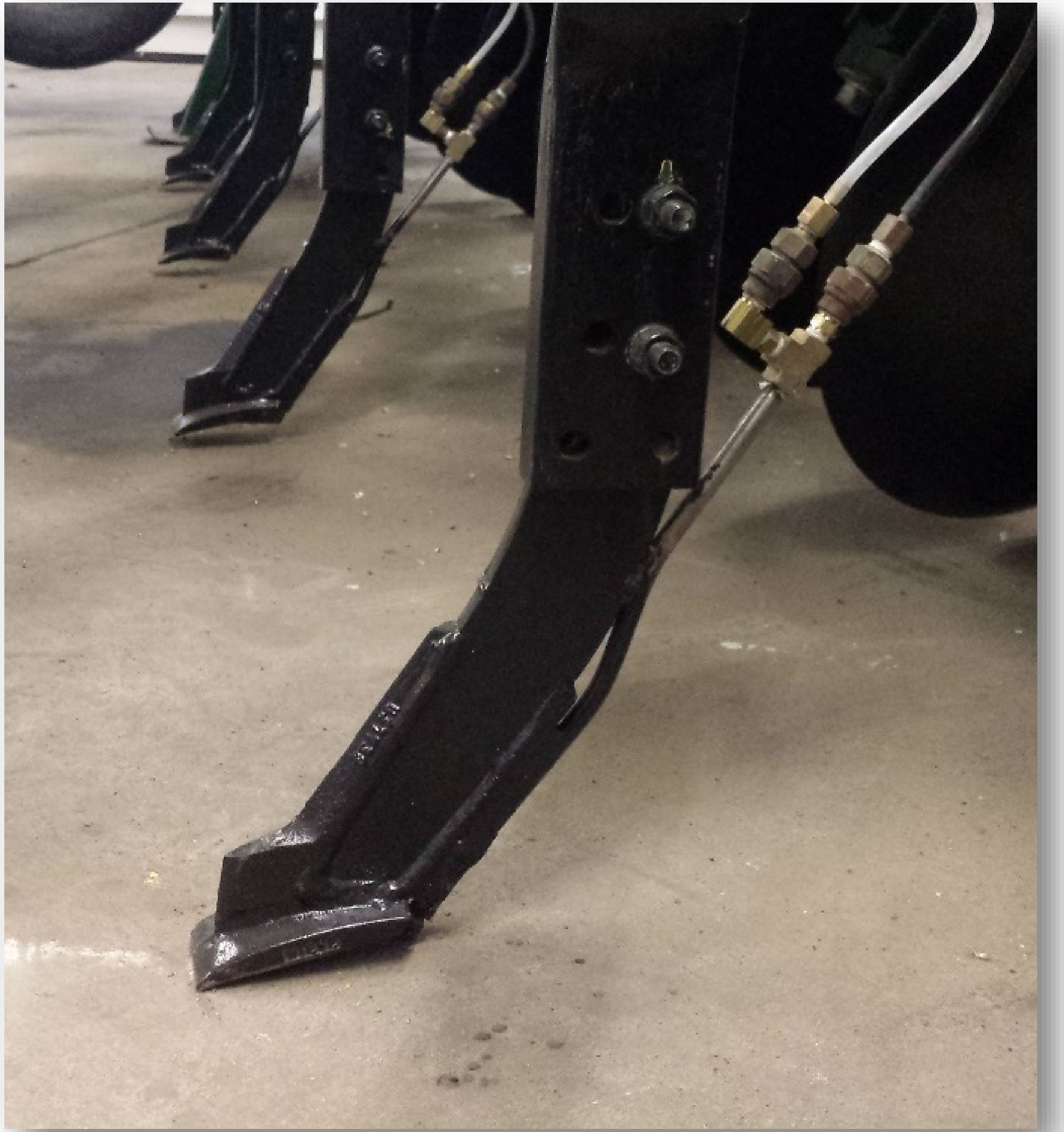
Draw Power & Traction




DEEPER DUAL DEPTH APPLICATION


SHELCO

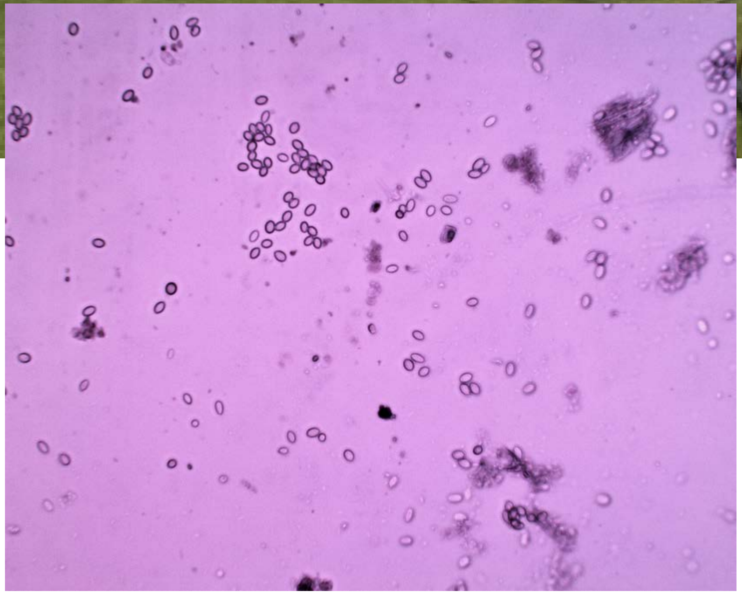
Mole Knife



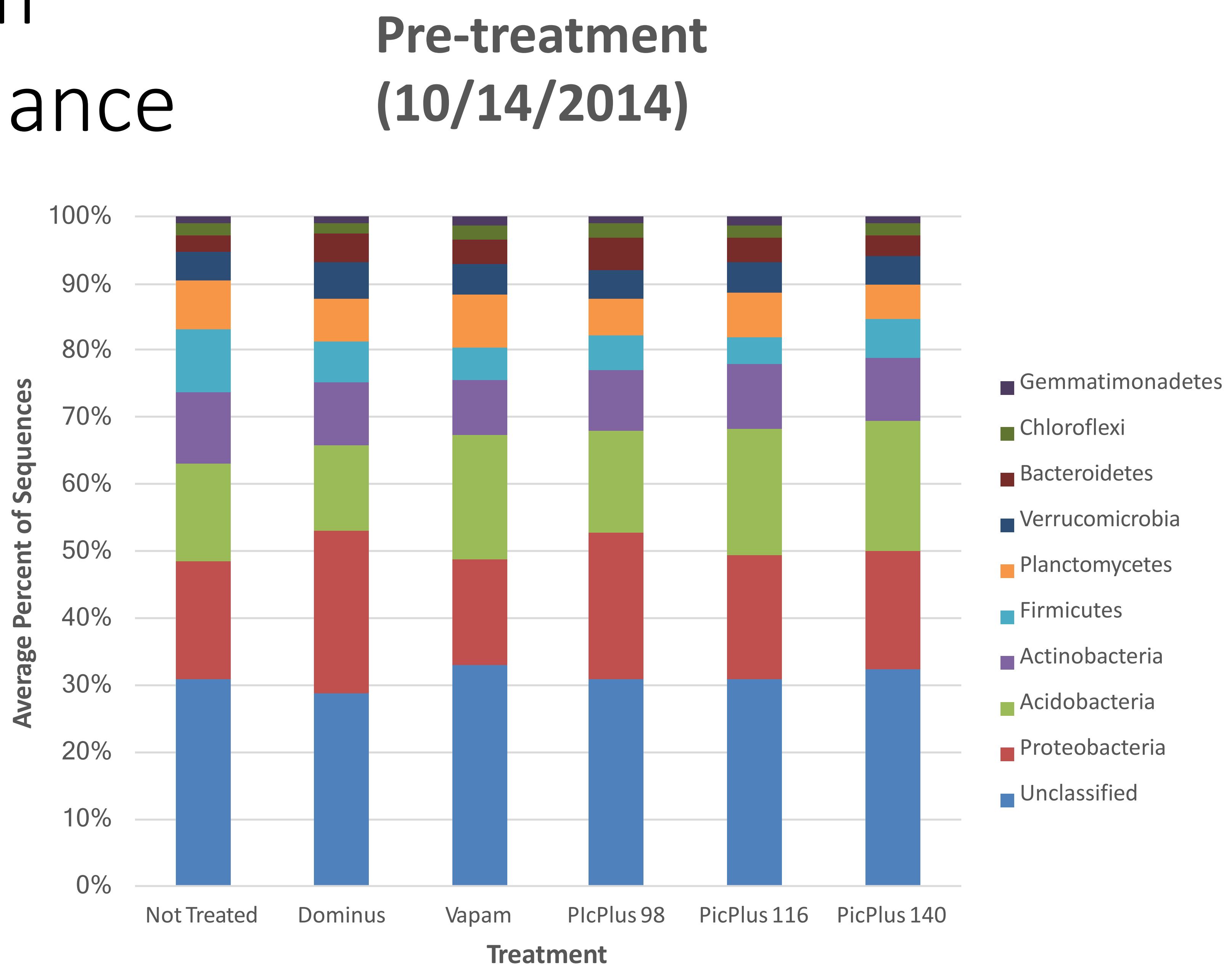
Equipment


INHALATION

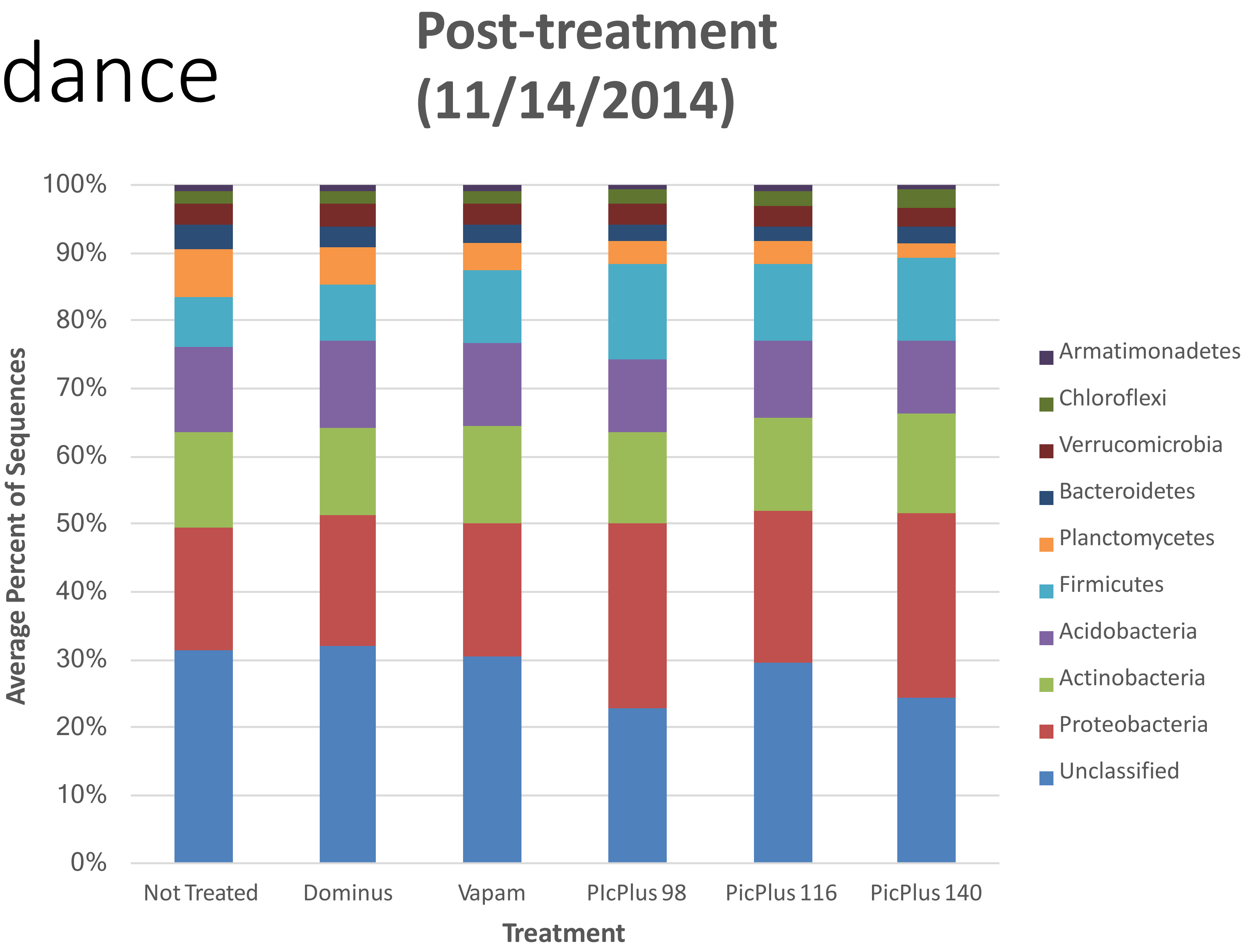
Recolonization of beneficial microflora following soil fumigation



Phylum Abundance



Phylum Abundance



Keys to Successful Fumigation:
Promote Good Movement

- ❑ Soil Preparation
- ❑ Soil Temperature
- ❑ Soil Moisture
- ❑ Fumigant
- ❑ Injection Depth
- ❑ Sealing
- ❑ Waiting Period
- ❑ Timing

SAFETY MEASURES TO AVOID RESPIRATORY INJURY

- Begin Application on the Downwind Side of Field
- Pressure Check All Plumbing on Tractor With Nitrogen
- Repair Any Rips or Holes in Plastic Promptly
- Never Install Fumigation Plumbing Inside Enclosed Tractor Cab
- Replace Worn Chisels