# Soil Disinfestation in strawberry annual hill plasticulture in North Carolina

***<u>Pre-view!</u>***

Mark Hoffmann, Small Fruits Extension Specialist, North Carolina State University, Raleigh NC

Kathryn Holmes, Agriculture Extension Agent, NC Cooperative Extension, Rockingham Co.

## 1.) Why disinfest the soil and what are soil fumigants?

### Why Soil Disinfestation?

There are several reasons why pre-plant soil disinfestation is desirable in an annual hill plasticulture system. The most prevalent reason is however: pest control to increase yield!

Strawberry plants are susceptible to many deadly soil-borne pathogens. Among the soilborne fungal pathogens in our region, most prevalent are *Phytophthora cactorum, Pythium irregulare* or *Rhizoctonia solani.* These pathogens are often associated with Black Root Rot Symptoms, which build up over years, stunt plants and reduce fruit yield 20-40%. A series of nematodes can cause considerable damage to strawberry plants as well. An outbreak of soil-borne pathogens or nematodes can be so detrimental they led to a crop failure. Soil disinfestation can therefore be the decisive factor for a successful strawberry season. Soil disinfestation also can help to control weeds. Plasticulture with warm temperatures, high moisture, and abundance of fertilizer promotes the growth of plants. If weeds are allowed to grow, they compete with the strawberry plants causing reduced yield. Through the shading effect of plastic mulch in annual hill plasticulture systems, weeds are generally suppressed, compared to non-plastic mulch systems. Without soil disinfestation or the application of pre-plant herbicides however, some weeds like nutsedges may growth through the plastic and other weeds grow in the planting holes. In strawberry production, there are only a limited amount of post-transplant weed control options available. This makes the choice of pre-plant weed control necessary for a successful annual hill plasticulture system.

Soil disinfestation in North Carolina usually is accomplished by using soil fumigants, highly potent pesticides. However, several non-chemical soil disinfestation methods are being investigated and researched currently (see last chapter). In summary, pre-plant soil disinfestation is a critical pest management strategy to control soil-borne insects, weeds and pathogens. It is one stepping-stone towards a successful strawberry crop. The decision whether or not to disinfest your soil depends highly on the presence or absence of soil-borne pathogens, the weed pressure in the field, labor availability, space to rotate strawberry fields and your market target. In this article, we specifically address chemical soil disinfestation with pesticides, so called ‘soil fumigants’. Soil fumigants are among the most dangerous pesticides used in agriculture and are toxic to humans, other animals, microbial organisms and plants. The strict use of safety measures such as personal protective gear and no entry signs as well as respecting plant-back dates are essential to ensure both the safety of you, your personnel and a healthy crop.

**What are soil fumigants?**

Soil fumigants are a certain class of highly toxic pesticides! A true soil fumigant, when applied, forms a gas to control a wide range of pests, including nematodes, bacteria, fungi, insects, and weeds. Soil fumigants can also be used to improve plant growth.

The go-to fumigant for many decades was Methyl Bromide (MB), registered as a soil fumigant first in 1961. Methyl Bromide (or Bromomethane) is an odor less gas, which occurs naturally in certain plants and marine organisms and is industrially manufactured for agricultural use. Methyl Bromide has a high vapor pressure and has a wide range of pest control activity. Those two traits combined allows MB to move through soil pores efficiently and disinfest soil from organisms, including microbes, insects, nematodes and weeds. However, MB is classified as a class 1 ozone depleting agent. The U.S. has - along with many other countries - agreed to reduce the use of MB by signing the 'Montreal Protocol on Substances that Deplete the Ozone Layer' in 1987. MB was phased out of most agricultural use in 2005, but strawberry growers had a critical use exemption until 2015.

Today, MB is not available anymore for strawberry fruiting field production. However, multiple chemical and non-chemical soil disinfestation methods were introduced over the past decades and more are being developed currently (Table 1). Today, the commonly used soil fumigants contain one or more of the following *active* substances: Chloropicrin, 1,3-Dichloropropen (1,3 D), Methyl Isothiocyanate (Metam-Sodium, Metam Potassium), Dazomet, Allyl Isothiocyanate (AITC). Common fumigant names are: Pic-Clor 60, Pic-Clor 80, Telone 35, Sectagon, Metam, Dominus, etc. All those pesticides have a very wide range of pest control activity. The choice of the correct soil fumigation methods depends, as with every other pesticide, on many factors: The efficacy of soil fumigation highly depends on the chosen fumigant, the structure of the soil, soil moisture, the used plastic mulch and the method of application.

**Soil Preparation:**

To ensure an effective fumigation, soil should be cultivated about. 2-3 weeks before the application date. Soil should be free of clods and plant residue. Soil temperatures between 45 – 80 F are desirable. The right soil moisture is most critical to ensure an effective soil disinfestation. On the day of fumigation, a soil moisture at 60-70% of field capacity is desired for an effective fumigation. Especially in our climate with hot humid summers, soil moisture of the field needs to be monitored before fumigation. It is recommended to plan fumigation a week earlier than necessary to have some buffer time, due to August droughts or heavy rain storms. During dry weather some growers will irrigate the field with overhead sprinklers a day or two before bedding and fumigation.

**Table 1:** Overview of commonly used fumigants in strawberry production

| NAME | ACTIVE SUBSTANCE |
|---|---|
| **PIC-CLOR 60** | Chloropicrin (56,6%)<br>1,3 Dichloropropene (37.1%) |
| **PIC-CLOR 80** | Chloropicrin (79.8%)<br>1,3 Dichloropropene (19.5%) |
| **TRI-PIC 100** | Chloropicrin (99%) |
| **PIC PLUS** | Chloropicrin (85.5%) |
| **STRIKE PRODUCTS** | Chloropicrin (several rates) |
| **IN LINE** | Chloropicrin (33.3 %)<br>1,3- Dichloropropene (60.8%) |
| **TELONE C17** | Chloropicrin (16.5 %)<br>1,3- Dichloropropene (81.5%) |
| **TELONE C35** | Chloropicrin (34.7 %)<br>1,3- Dichloropropene (63.4%) |
| **TELONE II** | 1,3- Dichloropropene (97.5%) |
| **METAM CLR 42** | Sodium methyldithiocarbamate (42 %) |
| **METAM SODIUM** | Sodium methyldithiocarbamate (32.7 %) |
| **VAPAM** | Sodium methyldithiocarbamate (42 %) |
| **SECTAGON-42** | Sodium methyldithiocarbamate (42.2 %) |
| **KPAM HL** | Potassium N- methyldithiocarbamate (54 %) |
| **PALADIN** | Dimethyl disulfide (98.8%) |
| **PALADIN PIC 21** | Dimethyl disulfide (78.1%)<br>Chloropicrin (20.9%) |
| **BASAMID G (GRANULAR)** | Dazomet (99%) |
| **DOMINUS** | Allyl Isothiocyanate (96.3%) |

**2.) Personal Protective Equipment (PPE)**

Nobody likes to wear protective gear in hot and humid weather. Unfortunately, at the peak time for strawberry fumigation - in August - it truly is hot outside. Protective gear morphs into a mini-greenhouse, and constant sweating requires frequent water breaks in the shade. The summer weather in the Southeast makes it tempting to wear shorts and a T-Shirt rather than long sleeve shirt, jeans and Tyvek suit. That unfortunately is bad practice and can be dangerous. Fumigants are extremely dangerous pesticides. Fumigant exposure can lead to short- and long term and sometimes irreversible health effects. Those health implications can range from digestive problems to respiratory disorders. Possible impacts on health due to short-term and long-term exposure of the commonly used fumigants 1-3 Dichloropropene and Chloropicrin are listed in Table 2.

**Table 2:** Possible health problems due to the short-term and long-term exposure to the common fumigants Chloropicrin and 1,3 Dichloroporpene.

| **Fumigant** | **Short-Term Exposure** | **Long-Term Exposure** |
|---|---|---|
| Chloropicrin | Sever irritation of skin, eyes, respiratory tract | Long-lasting Nausea, vomiting, diarrhea |
| | Difficulty breathing, Headache, Nausea | Affects respiratory tract |
| 1,3 Dichloropropene | Chest Pain, breathing difficulties | Nasal tract, respiratory tract, Urinal bladder |
| | | Maybe carcinogen |

Depending on the soil type, water content and plastic mulch, fumigants can dissipate into the air very quickly after injection, exposing field workers immediately. Workers can be exposed to fumigants before any odor is smelled. By the time the fumigant odor is prevalent, personnel have already experienced exposure. Therefore, good agricultural practice requires the use of PPE any time fumigants are handled in the field. That includes operation such as hooking up the gas cylinder, calibration of the fumigation rig, the application itself, cleaning of the fumigation rig and the storage of fumigants.

**What is PPE?**

PPE stands for Personal Protective Equipment. On each pesticide label, including fumigants minimum requirements for PPE are clearly listed. Please always follow at least those recommendation if you handle fumigants. The most common routes of exposure to fumigants are through inhalation, eye or skin contact. PPE is the equipment that prevents or minimizes those routes of exposure.

For handling fumigants, even if it is not explicit on the label, we recommend several pieces of clothing and a full-face air purifying respirator as minimum requirements (Figure 1). Some pieces such as gloves, air filters and Tyvek suits are recurring costs, while a full face respirator and rubber boots are one-time investments (Table 3). All equipment, if previously exposed to fumigants, needs to be stored in a separate plastic bag and needs to be disposed as hazardous waste.

**Table 3:** Estimated costs of costs for recommended fumigation PPE per person.

| **Equipment** | **Cost** | **Frequency of investment** |
|---|---|---|
| Full Face Respirator | $ 150-200 | One-time |
| Cartridges | $ 40 / pair | Frequent |
| Chemical resistant gloves | $ 30-50 / pair | After each application |
| Rubber Boots | $ 40-60 / pair | One-time |
| Tyvek suit | $ 20-30 / piece | After each application |
| **TOTAL One-time** | | **$ 190-260** |
| **TOTAL Frequent** | | **$ 40** |
| **TOTAL Each Application** | | **$50-80** |

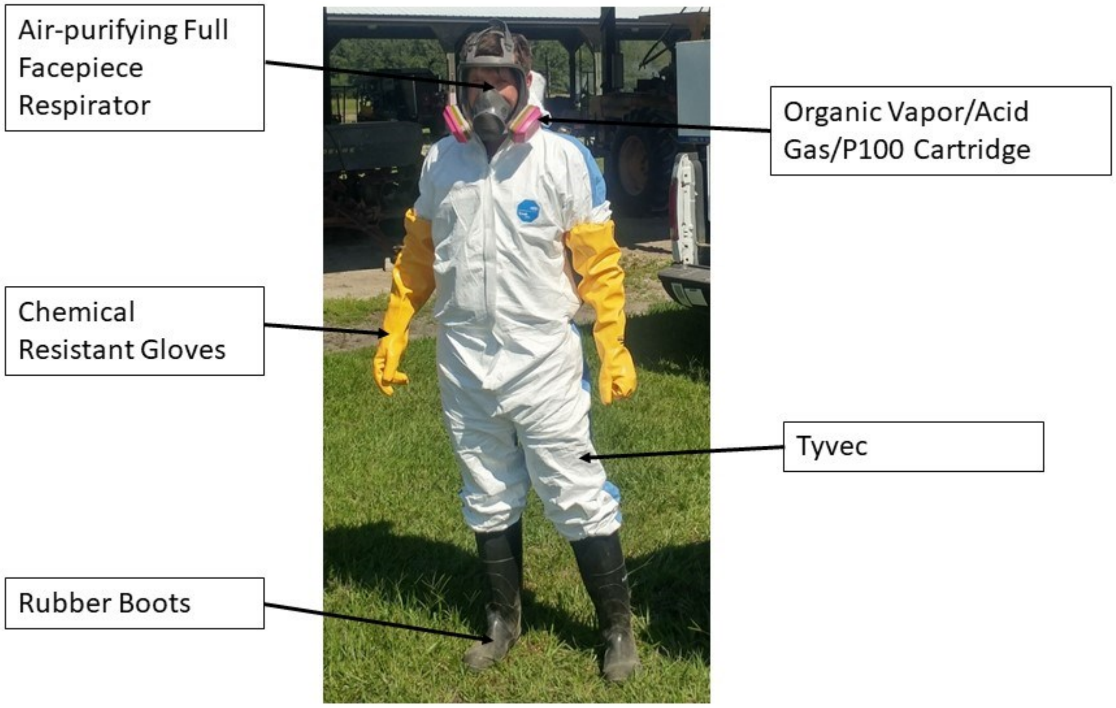


**Figure 1:** Common Personal Protective Equipment (PPE) for handling fumigants. Please consult the label of each fumigant to find out which gloves and boots you will need to wear.

Here our recommendations of PPE for a safe fumigant application:

(1) Air-Purifying full-face respirator with Organic Vapor/Acid Gas/P100 combined cartridge. Half-face respirators and a face shield can be used as well, but are not recommended. Cartridges need to be replaced frequently. The life span of a cartridge depends on your rate of breathing and environmental conditions. In our humid and hot weather, the life span is usually shorter.
All users of respirators should have a medical evaluation, go to a fit-test, and have respirator training. All tight fitting masks need to be fit-tested to make sure no fumigant reaches inside the mask. Faces need to be shaved and clean before putting on any tight fitting respirator. For more information, please visit: [http://www.ncagr.gov/SPCAP/pesticides/license.htm](http://www.ncagr.gov/SPCAP/pesticides/license.htm)

(2) Chemical Resistant Gloves, such as barrier laminate (EVAL, Silver Shield) or Viton gloves (more than 14 mils). Although barrier laminate gloves offer the highest level of overall chemical resistance, they have virtually no cut resistance and are more expensive than other PPE gloves. Leather, Cotton, Natural Rubber, Polyethylene Latex, Nitrile or Neoprene gloves are not adequate for working with fumigants. Combination of barrier lamination gloves and PPE gloves might be desirable. Find more information on chemical resistant gloves under: http://extensionpublications.unl.edu/assets/pdf/g1961.pdf

(3) Tyvek suit/Long sleeve shirt and long pants/Overall: We recommend you wear sweat absorbing functional clothing (long sleeve, long pants and socks) under a Tyvek suit. This helps to absorb sweat and keep the body a little bit cooler. The Tyvek need to be replaced every single time after usage.

(4) Chemical resistant rubber boots. Can be re-used.

**Dealing with the heat:**

Using this kind of PPE in our climate is exhausting and it will increase the time of a fumigation operation. Here are some recommendations to make sure you stay safe at any time of a fumigation event.

*Before fumigation:* Make sure that you have a certified heat stress emergency kit available in a truck, tractor or a nearby shed. Make sure you know the emergency contact at the site of fumigation. Charge your cell phone the night before. Bring a car charger for your phone and leave both, phone and charger at a visible spot in the truck/car. Keep also the keys of the truck/car visible inside the truck and keep the doors unlocked at any time. Make sure there is at least one other person, who knows the location of the emergency kit, the emergency contact and also has a charged cell phone.

*During fumigation:* Check the weather forecast one-two days before fumigation. Start early in the morning if possible. This is usually the coolest time of the day, if not when a weather change is predicted. To make sure you are able to work most efficiently through the day, take frequent short water breaks in the shade or in an AC regulated room or car are essential. This requires that you frequently take off your respirator and your gloves. Store the respirator and the gloves inside a bag or container in the shade. Don't leave them exposed directly to the sun! They will heat up and it will be impossible to wear after the break. Store respirator and gloves away from food, drinks and other people. Only take off your PPE if you are not in the field anymore and outside the buffer zone.

As a rule of thumb, a water break should be taken every 30-40 min. Have at least two gallons of water and maybe one gallon of other fluids (tea, lemonade, coke) for each person. Also have all sorts of snacks for the day. Keep part of the fluids and snacks in a cooler and part in the shade. Drink plenty of cool and cold fluids over the day. Please avoid having heavy meals. We recommend more frequent, but smaller portions (such as chocolate and nut bars, small sliders, all sorts of fruit, sugar containing drinks etc.). Please avoid the consumption of diet products, especially diet drinks, unless you have a health condition that requires you to eat or drink them.

Try to have a light lunch. If you stay hydrated and not hungry, it will help your body to deal with the heat and the constant sweating.

*After fumigation:* Bring a change of clothes and a towel. If you are done for the day, take a rest in an AC regulated room or car. Drink plenty of cool or cold fluids even if you don't feel thirsty anymore. It will have been an exhausting day and you should try to get some rest and a good night sleep.

**3.) Field Preparation before Fumigation and Types of Plastic Mulch**

Properly preparing a field for plasticulture strawberry planting is a very important factor in getting good fall root growth and higher spring yields. This is something that can't be corrected later! Machines are used that shape the bed, install drip tape for irrigation, fumigate and cover beds with plastic mulch all at the same time.

Even with fumigation and plasticulture strawberry field sites should be rotated whenever possible. It would be ideal to rotate with a field that had been fallow or in cover crops. Be careful to consider what pesticides had been applied if rotating with another field crop. The first step after identifying the field for strawberry production is to try and remove any large weeds or left over previous crop or cover crop debris. Herbicides can be applied to kill this plant material but large undecomposed debris will obstruct good planting bed formation and fumigation. The next step is to subsoil the field in two directions to break up any present hardpans. Once the hardpans are broken chisel plowing the field will break up large clods. Any large stones or sticks should be removed as well.

Pre-plant fertility rates should be checked with a soil test before planting. The soil test will determine amount of lime and phosphate needed to be broadcast applied to soil. Strawberry plants grow best with a pH around 6.0 – 6.2. Without soil test results to determine soil pH lime should not be added to soils. Nitrogen is not tested for in soil tests but for strawberry production the recommended rate is 60 lbs of N per acre pre-plant. If you use compost or poultry litter for fertility be share to have them tested for nutrient content.

If a soil test was not conducted, the standard pre-plant fertilizer recommendation for strawberry production is the 60lbs/acre Nitrogen, 60lbs/acre phosphate and 120lbs/acre potassium. Broadcast the pre-plant fertilize and incorporate before making beds.

In some soils growers pre-bed the rows to make sure there is enough loose soil available to get good bed formation. It is important that the beds slope from the center, the highest point, down to the edges. If there is a depression in the center from not enough soil, water will collect there and not move through the bed correctly to the plant roots. Good drainage of the field as well as of the bed itself is extremely important for a successful season. Especially in soils with high clay content, a correct bed shape is important. Growers aim for beds to be 6-10 inches high. Field capacity between 50-70% is recommended to successfully form a bed. Field capacity describes the amount of water which stays in soils of uniform texture and structure after all excess water has drained. This usually takes place 1-2 days after a rain or irrigation. It is not recommended to form beds under extremely wet or dry soil conditions. In dry conditions, , slight irrigation may be necessary before bedding.

To get the best results from fumigants field capacity of the soil should be between 50-70% and soil temperature should be between 50 and 95 F.

Proper bed formation is also important to make sure the plastic mulch fits tightly to the soil beds. Air pockets need to be avoided when possible. The edges of the beds need to have the plastic mulch thoroughly covered with soil so that there are not any fumigate leaks and the wind does not get under them. Once plastic mulch starts blowing in the wind it continues to tear. The drip tape in the center of the beds needs to have the orifices facing upward not down into the soil. The drip tape should be buried 1 to 2 inches so the plastic fits tightly over this as well. If you chose to use two dip lines per bed, put the lines 3-4 inches in each side from the center. That will give you enough space to punch holes without piercing the drip tape. A straight bed is more important if you use two drip lines instead of one, especially if you plan to plant plug plants with a waterwheel.

**Types of Plastic Mulch for strawberry production**

Plasticulture strawberry growers use black plastic mulch to help retain bed shapes, keep the soil from cooling, control weeds and pests, and regulate moisture and evaporation. The ability of a fumigant to pass thru a mulch is dependent on the physical characteristics of the mulch, the fumigant used, and environmental conditions. Several types of plastic mulch are available:

- **Polyethylene Plastic (PE):** PE plastic mulch is the most cost effective option, but has a poor capacity to retain fumigants such as 1,3D in soil. Low Density Polyethylene Plastic (LDPE) often have high fumigant permeability. High Density Polyethylene Plastic (HDPE) is often more stiff and harder to lay, while still being permeable to fumigants. Research has shown that certain fumigants can evaporate faster from soil under all PE. Therefore, we recommend to use PE plastic mulch only if you chose not to fumigate.
- **Metallized film** has a thin reflective metal layer on a LDPE plastic. Metalized films have a reduced fumigant permeability, compared to LDPE. Metallized film can be used to control insect pests such as thrips. This works best with varieties with a smaller canopy size.
- **Virtually impermeable films (VIF) mulch** have three layers of plastic: the first and the third layer is LDPE, the middle layer consists of Polyamid. This makes VIF films 200-300 less permeable to certain fumigants than PE. VIF films are less costly than TIF, while providing a certain impermeability to fumigants such as 1,3D.
- **Totally impermeable film (TIF)** have in total five layers. Between two outside LDPE layers, TIF has two adhesive and one resin layer. TIF films are impermeable and designed to be used with fumigation. They are impermeable to certain fumigants (e.g. 1,3D). TIF are costly and should only be used, if fumigants are used.
- **Biodegradable plastic mulch films** can be used for plasticulture strawberries where no fumigation is used. The mulch does not always control all the weeds or last though the whole season.

We recommend to check fumigant labels to determine which mulch is recommended for the fumigant used. Especially TIF films can increase the waiting period on the transplanting. Planting holes can be punched a few days before transplanting to help the fumigant to gas off. The fumigant plant back intervals are very important. If not followed, phytotoxic response to strawberry transplants can occur.

## 4.) Calculations and Calibration

A successful fumigation requires the correct calibration of the fumigation rig and the correct calculations on the amount of desired fumigant in the soil. This chapter will walk you through essential calculations for fumigants and information on fumigant rig calibrations.

### Important Calculations:

Row acre:

To calculate the correct amount of fumigant, especially in broadcast fumigation applications, the rate of fumigant per row acre[1] needs to be calculated. This is a three-step procedure:

(1) To calculate the amount of linear feet of row in one acre, divide one acre (= 43,560 sqft) by your row spacing[2].
(2) To calculate the complete amount of linear feet of all beds, multiply the number of beds with the length of each bed.
(3) To calculate the amount of row acre in your field, divide the complete amount of linear feet by the amount of linear feet in one acre (divide (2) by (1)).

*Here is an example:*

Your row spacing is 5 feet, and you plan 100 rows, with a length of 200 feet each.

(1) Amount of linear feet of row per acre:

$$\frac{43{,}560\ sqft}{5\ ft} = \mathbf{8{,}712\ ft}$$

(2) Complete amount of linear feet for all beds:

$$100\ rows * 200\ ft = \mathbf{20{,}000\ ft}$$

(3) Calculation of row acre:

[1] The definition of row acre is the number of linear feet of bed that equals one acre of ground

[2] The row spacing in strawberries is the linear space (in inches or feet) from one row middle to the next row middle.

$$\frac{20{,}000\ ft}{8{,}712\ ft} = \mathbf{2.29\ acre}$$

In this example (5 ft row spacing, 100 rows, 200 feet per row), the total row acreage is 2.29 acres.

<u>Broadcast Equivalent Rate:</u>

Every certified applicator supervising the application of fumigants has to prepare a site-specific fumigant management plan (FMP). We will cover this topic in more detail in the next issue. However, the broadcast equivalent rate[3] has to be correctly reported with each FMP. The calculation procedure of the broadcast equivalent rate is also explained on the fumigant label.

To calculate the broadcast equivalent rate, the total amount of fumigant applied to the rows needs to be divided by the total amount of land which is under production. That does not include ditches, roadways etc. It does include, however, space for sprinkler pipes. Further, the rate of fumigant/row acre needs to be known as well as the bed width and the row spacing. The broadcast equivalent rate is calculated in four steps:

(1) Calculate the actual size of land (beds and furrows) without ditches and roads
(2) Divide bottom bed width by row spacing to get a spacing factor
(3) Calculate the proportion of the application block to be treated
(4) To calculate the broadcast equivalent rate, multiply the fumigant rate with the proportion of the application block and the spacing factor

*<u>Here is an example:</u>*

Let's say the beds are 32 inch at the bottom, row spacing is 60 inches. 350 lbs/row acre of Pic-Clor 60/80 will be applied, the total application block is 5 acres, but there is a 0.25 acres ditch in there.

(1) The actual size of fumigated land in the actual block is:

$$5\ acres - 0.25\ acres = \mathbf{4.75\ acres}$$

(2) To calculate the spacing factor, divide bottom width of bed by row spacing:

$$\frac{32"}{60"} = \mathbf{0.53}$$

(3) Calculate the proportion of the block which will be treated:

$$\frac{4.75\ acres}{5\ acres} = \mathbf{0.95}$$

(4) Calculate the Broadcast Equivalent Rate:

$$350\frac{lbs}{rowacre} * 0.95 * 0.53 = \mathbf{176.22}\frac{\mathbf{lbs}}{\mathbf{acre}}$$

In this example, the broadcast equivalent rate is 176.22 lbs/acre.

[3] Broadcast Equivalent Rate: The amount of fumigant applied on one acre of treated land.

**Calibration of a fumigant shank injection rig:**

All rigs should be checked for spongy or cracked hoses, rusty fittings and other potentially broken parts before hooking up a fumigant or gas cylinder. If hoses need to be replaced, be careful and wear protective gear (see July 2018 issue). Pipes and hoses can still contain small amounts of fumigants. Read the label of the fumigant you used last with this rig and wear PPE according to the label if you need to replace a hose, a pipe or a fitting at the fumigation rig. Older rigs might need an additional replacement of blades and other bed shaping parts. We highly recommend to contact local fumigation experts (e.g. Tri Est) early to assist you in your calibration efforts! Every fumigation rig is a little different and here we can only give a rough outline.

Fumigant flow rate: Flow meters are often calibrated for water and need to be re-calibrated for fumigants. Fumigants are heavier than water and therefore have different flow properties. The calibration of the flow meter is essential to apply fumigant at the correct flow rate.

(1) Take the amount of time it needs to fumigate a row of 100 feet. Practice several times and without a fumigant or gas cylinder attached to the rig. Take the time it needs to lay 100 feet of plastic.
(2) Calculate the area by multiplying row spacing with 100 feet of test run.
(3) Calculate the amount of time it would need to lay 1 acre of linear foot of plastic.
(4) Calculate the flowrate based on the used fumigant[4]
(5) Adjust your flow meter settings to the amount of fumigant you want to apply (in gal/a)[5]

*Here is an example:*

It needs 22 sec. to fumigate a 100 ft row on a 5 ft row spacing. 350 lbs/row acre Pic-Clor 60 is the broadcast equivalent which will be applied. According to the label, 350 lbs/acre of Pic-Clor 60 are equivalent to 29.6 gal/acre. The 100% flow rate of the flow meter is 2 gal/min and the flow meter is calibrated for water.

(1) The hypothetical area covered in the test run: $100\ ft * 5\ ft = \mathbf{500\ sqft}$
(2) The amount of time per sqft: $\frac{22\ sec.}{500\ sqft} = 0.044\frac{sec}{sqft}$
(3) The amount of time per acre: $0.044\frac{sec}{sqft} * 43{,}560\frac{sqft}{acre} = 1{,}917\frac{sec}{acre} = \boldsymbol{approx.\ 32\frac{min}{acre}}$

It will take 32 min of application time to apply fumigant on an acre.

(4) Calculate the 100% flow rate for the specific fumigant. Please contact your fumigant application service for assistance at your farm!

$$2\frac{gal}{min}\ (flow\ rate\ flowmeter) * 0.85^6 = \mathbf{1.7}\boldsymbol{\frac{gal}{min}}$$

(5) Adjust the flow rate for the amount of fumigant application:

[4] Please ask your local fumigant service to help with the flow rate calibration.
[5] Lbs/gal are indicated on the label of the fumigant
[6] Each fumigant has specific numbers. This is just an example. If you are unexperienced, please let your local fumigant service assist you with the calibration.

$$32\frac{min}{acre} * 1.7\frac{gal}{min} = 54.4\ gal\ (100\%)$$

$$\frac{29.6\frac{gal}{acre}}{54.4\ gal} * 100 = \mathbf{54.4}\%$$

In this example, the flow meter has to be set to 54.4 %.

## 5.) Problematic Soil-borne Pests and Diseases

Fumigants control several important soilborne pests and diseases in North Carolina.

### 1. Fungal Pathogens:

The most common fungal soil-borne pathogens in North Carolina are the 'Black Root Rot complex' and 'Phytophthora crown rot'. The soil-borne diseases 'Verticillium wilt' and 'Charcoal rot' cause major wilting symptoms in other regions of the U.S. However, those diseases seem to have a minor or no impact on strawberry production here in the Southeast. 'Southern Stem Blight' is known to be present in the Southeast, but is rarely reported to be a major problem in strawberry production.

a) Black Root Rot (BRR)

Several organisms are involved in developing BRR symptoms. The most common organisms are the fungal pathogens of the genus *Pythium* ssp. (e.g. *Pythium irregulare*), *Rhizoctonia fragariae* root-lesion nematodes (*Pratylenchus* ssp.). Not all organisms have to present in order to cause BRR symptoms, but all involved organisms are common in the Southeast and lead frequently to damages and yield losses. Several other soil-borne disease organisms (e.g. *Fusarium* ssp.) can be associated with the BRR complex as well. Which organisms are dominant seems to depend highly on soil type and region. However, in annual plasticulture systems, the disease usually builds up over time, often causing the most damages at harvest.

Usual symptoms are reduced plant growth, stunting, small fruit, dead leaves, and reduced yield. Roots may start to deteriorate, develop lesions and are less fibrous. Flooding and poor soil drainage can enhance the symptoms of BRR. Besides site selection and drainage, the usage of disease free planting material, **fumigation is the major chemical control** method for Black Root Rot. Especially applications of Pic-Clor 60 or 80 lead usually to good control of pathogens involved in BRR. For more information on BRR, please visit:

https://diagnosis.ces.ncsu.edu/strawberry/disorder/detail/black-root-rot

b) Phytophthora Crown Rot

The causal agent of Phytophthora crown rot is *Phytophthora cactorum.* This pathogen increasingly occurs in poorly drained, flooded or over-irrigated soils under warm weather conditions. Under wet conditions, so called Oospores produce zoospores, which actively can move through the soil water, but also can be passively transported with water. Therefore, especially wet soil conditions increase the potential risk of a Phytophthora crown rot infestation.

*Phytophthora cactorum* has two potential sources in North Carolina: (1) the pathogen can be transported via plug plants (2) the pathogen can already be present in the soil of the field site.

Phytophthora Crown Rot can lead to the collapse and death of a plant, soon after planting until harvest. Plants usually start to wilt. For diagnosis, cut wilting plants open lengthwise and look for brown discoloration of the crown. The usage of disease free planting material and the selection of sites with low disease pressure are the most important control mechanism. Mefenoxam (Ridomil Gold) or formulations of metalaxyl, when applied through drip tape, can control Phytophthora crown rot after planting. However, especially under wet conditions, we highly recommend to fumigate in addition of using drip applied fungicides after planting. Pure cloropicrin, Pic-Clor formulations as well as Metam-Sodium formulations are able to control *Phytophthora cactorum* in the soil. For more information, please visit:

https://diagnosis.ces.ncsu.edu/strawberry/disorder/detail/phytophthora-crown-rot

2. **Nematodes:**

Nematodes can become a major problem affecting North Carolina strawberry production areas. Especially sandy soils can promote nematodes. Some nematode species are able to move vertically through soil pores and may have escaped flooding. It is highly recommend to re-test soil after flooding for the presence/absence of nematodes.

Strawberries are susceptible to multiple soil-borne nematode species, especially sting nematodes and root-lesion nematodes. Common symptoms of a nematode infestation start with areas of stunted growth and decline in a field, which then increase in size over time.

There are no chemical post-transplant control methods, and pre-plant fumigation is pretty much the only chemical control method available. Telone products (Telone EC, Telone 35, In-Line etc.) are highly effective in controlling nematodes and need to be used if nematode levels are high. Paladin and/or Pic-Clor 60 in higher rates can control nematodes as well.

3. **Weeds**

Weed seeds and tubers are very likely to have survived the flood, and it can be assumed that the weed pressure might be higher than normal, especially in the next two months. Nutsedge and clover are two weeds that have the potential to thrive this fall. The application of a pre-plant herbicide is recommended in areas of known high weed pressure. Post-transplant, low dosages of Stinger 3EC are shown to be effective in reducing broad-leaf weeds in planting holes. To control grass weeds in planting holes, selective herbicides (such as Select) could be applied.

However, the main method to control weeds under plastic is pre-plant fumigation. Fumigants which control nutsedges and other weeds are: Paladin, Pic-Clor 60, Metam-Sodium and Dominus to some extent. For more information on weed control in strawberries, please visit:

https://strawberries.ces.ncsu.edu/strawberries-weeds/

**6. Research on soil fumigant alternatives**

In this last chapter, we want to discuss research on soil fumigation alternatives. Many of the following described practices are still under investigation and the subject of research here in the Southeast. However, over the last two decades, a whole tool-box of possible soil disinfestation applications were developed and researched in the US. Besides fumigation with 1,3D, Metam-Sodium or Chloropicrin, methods such as soil solarization, anaerobic soil disinfestation (ASD) or steam have been explored.

It is important to understand that the term 'alternative' can be misleading, especially if used in connection to the loss of Methyl Bromide (MB). MB could be applied under almost all circumstances and still control weeds, pathogens and pests successfully. In other words, MB was a very 'forgiving' soil fumigant with an extremely wide spectrum of target organisms. Most researchers agree that the development of a real 'alternative' in a sense of finding a similar 'silver bullet' solution is not possible. Therefore, today soil conditions, application techniques, plastic choice, pest, weed and disease problems as well as increased consumer awareness play a much more decisive role in the use and efficacy of soil disinfestation.

a) Soil Solarization:

Soil solarization is a method used to disinfest soil by heat. Clear plastic tarp (PE or PC material) is used to cover a bed for 4-6 weeks before planting. Sunlight generates heat under the tarp, which leads to the control of weeds and pathogens. The method is widely used in regions with an excessive amount of sunlight. However, the efficacy of soil solarization depends highly on the weather conditions and can vary with season and region.

Beds are shaped 4 to 6 weeks before planting and covered with clear, UV stabilized plastic, ca. 1.5-3 mm thick. If temperatures of 99 F or higher are achieved for a period of 2-4 weeks, most weeds and some pathogens will be controlled. Punctures and holes in the plastic need to be patched immediately to prevent heat loss.

In North Carolina and Virginia, past research on soil solarization showed variable results on pathogen and weed control efficacy. To improve weed and pathogen control with soil solarization research is now focusing on the combination of soil solarization practices with prior embedded soil amendments or drip applied pesticides. These combinations can hold viable alternatives for soil disinfestation practices in the Southeast in the future.

b) Anaerobic Soil Disinfestation (ASD):

Anaerobic Soil Disinfestation (ASD) is a complicated, but a successful method to replace fumigant applications in several regions in the US and the world. ASD is a non-chemical soil disinfestation method and is used in Florida and in some areas of California successfully to control weeds, soil-borne pathogens and nematodes. The principle of ASD is based on the promotion of growing conditions for specific antagonistic soil microorganisms in a pre-plant application. Those microorganisms grow under anaerobic (no air) conditions and produce substances that are toxic and suppressive for several pests, diseases and weeds.

To promote growth of anaerobic micro-organisms, a carbon source needs to be implemented ca. 5 weeks before transplanting. In many regions, the carbon source differs and often is a locally/regionally available waste product. Rice bran is widely used in California, but research is also be done on coffee ground, brewery waste, molasses, poultry litter, grass mulch, mustard seed meal etc. After incorporation of a carbon source, beds need to be covered with impermeable polyethylene mulch (TIF) to prevent oxygen flow into the soil. To reduce the existing air in the soil, beds need to be irrigated to saturate the soil with ca. 2 inches of water. This process usually takes 3-4 weeks before holes can be punched. Plants can be transplanted a few days after holes were punched and oxygen levels return to normal.

The efficacy of ASD highly depends on the used carbon source, soil properties, the length of the time period under which the soil was saturated and also the weather. It seems to be more consistent under warmer conditions. Although this method is currently not available for North Carolina growers, research is under way in North Carolina at the research station in Castle Hayne and a good amount of research has been done in Florida.

c) Steam:

The use of steam for soil disinfestation is a very old method, and used frequently in greenhouse operations to control weeds, pathogens and nematodes. This process is called soil pasteurization. Early pest control with steam can be traced back to 1893 in the US. In recent years, research on mobile steam applicators for large and small scale field disinfestation has increasingly been in the focus of industry and public research. Several workable mobile steam applicators have been built world-wide and are commercially available in parts of Europe.

Steam will control weeds, pathogens and pests successfully when temperatures of 160 F are reached for a duration of ca. 20-30 min. After steam is applied, plants can be transplanted as soon as the soil has cooled down to normal temperature (usually 1-2 days).

Research has shown that strawberry harvest yields under a steam treatment can be equal to that of strawberries grown in beds treated with the chemical fumigant Pic-Clor-60. However, field applications of steam are logistically complicated and technology available in the USA is slow (1-2 acres/day). Transportation techniques, and fuel and water consumption are critical points which make this method usually more cost-intensive and currently not a viable option for strawberry growers.