Weed Control as Part of Soil Disinfestation with Fumigants and Nonfumigants

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INTRODUCTION

Strawberries and vegetable crops are highly susceptible to weed competition immediately after planting when the plants are small and frequent irrigation provides ideal conditions for weed germination. In coastal California, most weeds that invade strawberries and vegetable crops are annuals. Weeds such as little mallow (cheeseweed), burclover, sweet clover, and filaree invade during stand establishment and are common problems in strawberry fields because their seeds survive fumigation. After strawberry transplanting, weeds with windblown seeds, including sowthistle and common groundsel, may become problems. In conventional strawberry fields, effective weed management requires a combination of cultural practices, preplant soil fumigation, and additional herbicide applications when necessary. Proper field and bed preparation is essential for a good weed control program. Fumigation with a mixture of 1,3-dichloropropene/chloropicrin (Telone C35, Inline, Pic Clor 60) or chloropicrin alone for disease control, followed by an application of metam sodium or metam potassium, are among the best alternative disease & weed control treatments available for California strawberry producers. The use of impermeable films enhances weed control provided by Inline and Pic Clor 60, but the higher cost of these films has limited their adoption. For weeds that escape preplant controls, hand-weeding and/or selective herbicides are used.

Nonfumigant methods of soil disinfestation such as solarization or steam use a lethal dose of heat to kill soil pests including weed seed.

Crop Rotation. Rotational crops can be an important part of a weed control program. Rotations can be vegetable crops such as celery, lettuce or cole crops, or cover/ green manure crops such as barley, cereal rye, oats, or wheat. Where the cropping cycle permits, sudangrass may be included in the rotation cycle as a summer annual green manure crop. Intensive cultivation of a vegetable crop rotation such as lettuce or a cole crop helps control many problem weeds. A densely planted cereal rye cover crop or small grain crop is highly competitive with weeds and provides better weed control than a legume cover crop. In addition, alternative herbicides are available in rotational crops. Difficult to control perennial weeds such as field bindweed must be controlled in fallow ground with timely applications of glyphosate. No strawberry production should be attempted while a field is infested with field bindweed, because no fumigant or herbicide available for strawberry can control this weed. Instead field bindweed should be controlled with herbicides during fallow periods and during other crop cycles.

KILLING WEED SEEDBANKS WITH FUMIGANTS AND NONFUMIGANTS

Fumigation. Fumigation with methyl bromide, Telone C35, Inline, Pic Clor 60, chloropicrin, and metam sodium (Vapam, Sectagon 42) before bed preparation kills the seeds of most weeds

and the reproductive structures of some perennials. Nearly all fumigant applications are either immediately covered with plastic mulch or are injected through the drip irrigation system under plastic mulch. Drip injection of fumigants such as Inline or chloropicrin often improves the weed control compared to shank fumigation of these same fumigants. However, it is important to thoroughly wet the planting bed during drip fumigant injection to ensure weed control on the edges of the bed. Where drip fumigation is used, only the bed is treated, and the row middles are not fumigated. Soil-applied herbicides such as flumioxazin, napropamide or pendimethalin can be used to control weeds in the row middles. Soil fumigants control weeds by killing both germinating seedlings and dormant/quiescent seeds. Methyl bromide, Inline, Telone C35, and metam sodium kill weed seedlings and seeds by respiration inhibition. However, to kill weed seeds, fumigants must be able to penetrate the seed coat and kill the seed embryo. It is more effective to kill moistened seed, because the seed tissues swell with water and allow the fumigant to penetrate more thoroughly. Moist seeds also have higher respiration rates and are more susceptible to fumigants than dry seed with low respiration rates. The need for adequate soil moisture to wet weed seed means that proper irrigation before fumigation is one of the keys to effective weeds control with all fumigants.

Heat. Heat treatment can be used for soil sterilization or pasteurization. Studies have shown that most plant pathogens, insects and weeds will die when moist soils are heated to temperatures of 150°F for 30 min. (Baker and Roistacher, 1957). Most annual weeds can be controlled by solarization (Hartz et al., 1993). Annual sowthistle, barnyardgrass, London rocket, black nightshade, common purslane and tumble pigweed were all susceptible to temperatures above 122°F (Dahlquist et al., 2007). Perennial and bulbous weeds are, however, hard to control via solarization (Linke, 1994). Those in the legume family with hard seed coat are also not controlled well with solarization (Linke, 1994). Weeds such as nutsedge can also sprout under solarization treatments and the resulting shoots are generally trapped under the clear tarp (Chase et al., 1998).

Seedbanks. Weed seeds in the soil are called the weed seedbank. Most weeds in the soil are dormant and only a fraction of the seeds are available to germinate under good conditions. Preemergence herbicides kill germinating seedlings, and therefore act on only a small fraction of the weed seedbank. Similarly, postemergence herbicides, cultivators and hoes only kill emerged weeds. Therefore, most of our weed control tools do not affect the dormant weed seedbank. Soil fumigants such as methyl bromide, and metam sodium are an exception and can kill dormant and nondormant weed seeds. Methyl bromide and other fumigants are respiration inhibitors. Dormant, nondormant, and germinating weed seeds are living organisms that respire, and therefore most can be killed with fumigants such as methyl bromide. However, not all weed species are susceptible to fumigants. Among those species that are tolerant to fumigants are: California burclover, sweet clover, little mallow and filaree. Those weed species are tolerant due to the presence of hard seed coats that prevent penetration of the fumigant through the seed coat (Figure 1). The hard seed coat also means that water cannot penetrate and the embryo is dry.

Wetting of seeds with water is necessary to make them swell and respire. Weed seeds that are dry are highly resistant to fumigants. Plant cells in the embryos of dry seed are tightly compacted and the fumigants can only move slowly through dry seed. In contrast, the wet weed seed has cells that are fully expanded and full of free water that allows the fumigant molecule to move more freely. Many people state that before fumigation you need to irrigate the field to "germinate weed seeds". While it is true that fumigants do a good job of killing weed seedlings, fumigants can also kill ungerminated weed seeds with soft seed coats such as common chickweed. For hard coated seed such as clover, the only seed that will be killed are those that germinate. In summary, if you can get a lethal dose of fumigant through the seed coat and into the embryo of a wet seed, then you can kill soft-coat weed seed whether it is germinating or not, but most hard coated seeds can only be killed if they germinate.

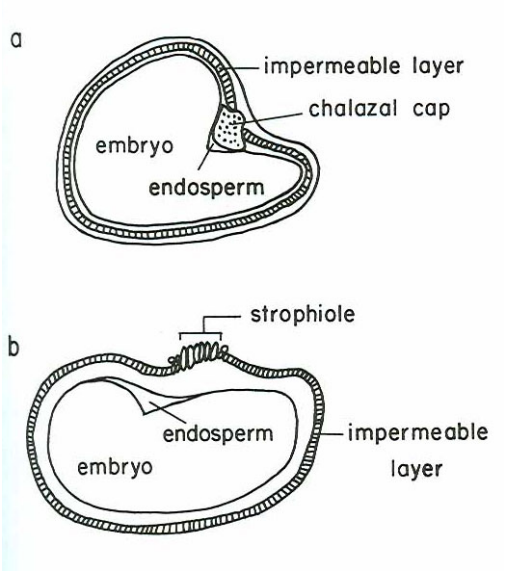

Figure 1. Hard-coated seeds that are difficult to kill with fumigants: a) little mallow, b) clover.

WHERE WEEDS MUST BE CONTROLLED

Weeds must be controlled on the top and shoulders of raised beds and in the furrow bottoms. Weed control on the bed top and shoulders are controlled by 1. fumigants, 2. herbicides, 3. mulches, 4. hand weeding.

Table 1. The optimum and maximum depths of emergence for several weeds (Radosevich and Holt 1984).

Weed	Optimum emergence depth (inches)	Maximum emergence depth (inches)
Annual bluegrass	0.4	0.8
Calif. burclover	0.5	--
Common chickweed	0.4	0.8
Common lambsquarters	0.2	1.9
Little mallow (cheeseweed)	0.5	--
Shepherd's-purse	0.2	0.8

Most weed seeds are small and emerge from shallow layers in the soil (Table 1). Because of this, the most critical zone for controlling weeds is the surface soil layer. To kill weed seeds in the surface layer, the fumigant concentration or temperature in the case of heat must reach the critical dose required to kill the weed seed.

Lethal fumigant doses. The objective of using a fumigant is to temporarily create conditions that are lethal for pests, and by doing so to disinfest the soil of pathogens and weed seed. Lethal conditions are created by maintaining the fumigant concentration above a critical level for a sufficient amount of time to kill the weed seed. The lethal conditions are usually described as the lethal dose required to kill 50 or 90 percent of a pest population ($LD_{50's}$ or $LD_{90's}$). For example, Inline maintained at or above 130 lbs/A for 72 hours will kill 90 out of 100 chickweed seeds (Table 2).

Table 2. Inline dose (lbs/A) required to control 90% (LD_{90}) of weed seeds.

Weed species	LD_{90} lab (24 hour)	LD_{90} field (72 hour)
	---------- Lbs/A ----------	
Knotweed	340	180
Common chickweed	162	130
Common purslane	121	80
Little mallow (cheeseweed)	>4005	>400
Filaree	>4005	>400

Because weed seeds can emerge from shallow layers anywhere on the bedtop and bed shoulders, good lateral distribution of the fumigants within the bed is necessary. Fumigants applied by drip irrigation must be applied in sufficient water to move them to the edge of the bed at a high enough concentration to kill weed seeds. The edge of the bed is a particularly difficult area for the fumigant to penetrate at concentrations necessary to kill weed seeds there because of the longer distance from the drip tape that the fumigant must travel (see arrow in Figure 2). Proper soil moisture conditions are required to get the lateral distribution necessary for effective weed control at the edge of the bed.

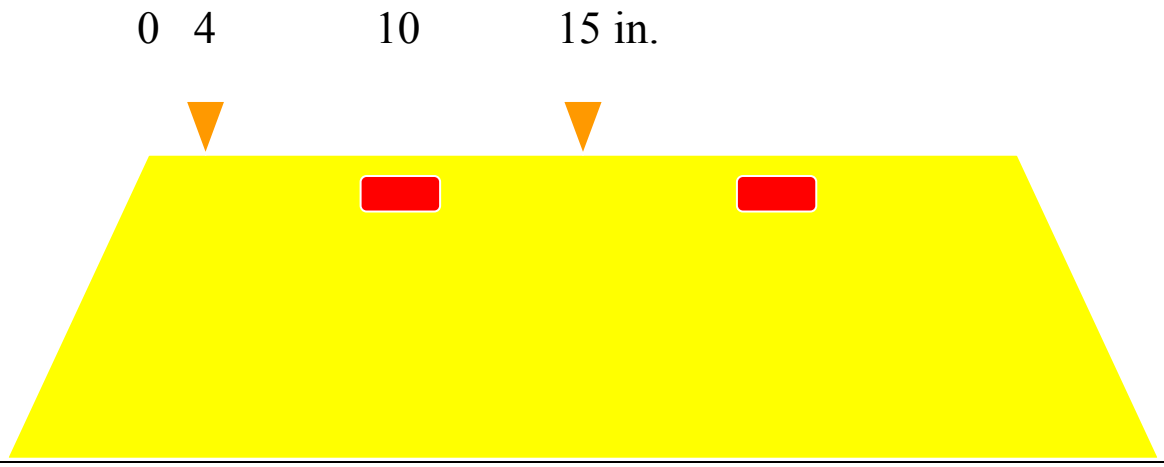

Figure 2. A strawberry bed fumigated by drip irrigation. The arrows show the locations in the center and edge of the bed (distance in inches from the edge) where it is more difficult to get the fumigant at concentrations needed to kill weed seeds.

Sequential applications of metam sodium. With the phase out of methyl bromide, the most effective soil fumigation treatments are a sequential application of chloropicrin or Inline followed 5 to 7 days later by metam sodium or metam potassium. This use of sequential application of complementary fumigants can provide effective control of weeds as well as soilborne pathogens, soil insects and nematodes.

Chloropicrin is effective on soilborne diseases, but less effective on weeds. Inline (1,3-dichloropropene plus chloropicrin) tends to provide better weed control than pure chloropicrin, but generally Inline provides less effective weed control than methyl bromide. One way to improve weed control with chloropicrin and Inline is to use a sequential application of metam sodium or metam potassium.

Metam sodium (Sectagon 42, Vapam HL and others) or metam potassium (Kpam) are used as sequential fumigants following drip applications of chloropicrin or Inline. In this procedure, chloropicrin or Inline can be applied through the drip irrigation system followed 5 to 7 days later by metam sodium/potassium applied through the drip irrigation system. It is necessary to have a 5 to 7 day interval between the chloropicrin or Inline application and the metam application due to chemical incompatibility between the products. Critical aspects to be aware of when using a sequential application of metam sodium/potassium are that: 1) soil must be in seed bed condition with clods no larger than 0.5 inches in diameter, 2) beds must be shaped and ready for planting, and 3) soil moisture must be 50 to 80% of field capacity at time of application. These factors are important to ensure good fumigant distribution throughout the soil profile and to ensure that viable weed seed are moist and easier to kill. It is important to avoid soil disturbance after treatment to avoid movement of viable weed seeds from deeper layers to the soil surface.

USE OF IMPERMEABLE FILMS WITH FUMIGANTS

Impermeable films are designed to reduce fumigant emissions to near zero (Figure 3). Researchers have found that, if impermeable films can be installed intact with minimal stretching or tearing, then fumigant emission is reduced. Reduction of fumigant emissions by impermeable film causes an increase in the fumigant concentration under the tarp. Because fumigant concentrations are higher under impermeable film, more weed seeds are killed and weed control is improved.

Figure 3. Impermeable film consists of at least three layers. In the three layer film shown above, the top and bottom layers consist of normal polyethylene tarp, and the middle layer consists of an impermeable layer.

SUMMARY

The keys to effective weed control with fumigants and heat in strawberry and vegetables are:

1. Careful field selection to avoid difficult to control perennial weeds and severe annual weed populations.
2. Ensure proper soil moisture at time of fumigation so that weed seeds either germinate, or that dormant seed can absorb fumigants.
3. Ensure good lateral distribution of fumigant in the planting bed to control weeds throughout the bed.
4. Sequential applications of metam sodium or metam potassium following chloropicrin or Inline can improve weed control.
5. Increased retention of fumigants with impermeable film can improve weed control.
6. The activity of heat for soil disinfestation with steam or solarization is similar to the activity of fumigants that kill weed seed. Fumigants kill weed seed by reaching lethal concentrations, and heat kills weed seed by reaching lethal temperatures.

References

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